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Weight Loss and Nutrient Dynamics during Leaf Litter Decomposition of *Quercus variabilis* and *Pinus densiflora* at Mt. Worak National Park

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ABSTRACT: Weight loss and nutrient dynamics of oak and pine leaf litter during decomposition were investigated from December 2005 through June 2008 at Mt. Worak National Park as a part of National Long-Term Ecological Research Program in Korea. The decay constant (*k*) of oak and pine leaf litter were 0.314 and 0.217, respectively. After 30 months decomposition, remaining weight of oak and pine leaf litter was 45.5% and 58.1%, respectively. Initial C/N ratio of oak and pine leaf litter was 53.4 and 153.0, respectively. Carbon % of initial oak and pine leaf litter was similar with each other; however, nitrogen content of initial oak leaf litter (0.85%) was greater than that of initial pine leaf litter (0.33%). N and P concentration in both decomposing leaf litter increased significantly during decomposition. There was no net N and P mineralization period in decomposing pine leaf litter. K, Ca and Mg concentration in both decomposing leaf litter showed different pattern with those of N and P. After 30 months decomposition, remaining nutrients in oak and pine leaf litter were 97.7 and 216.2% for N, 123.2 and 216.5% for P, 39.3 and 44.8% for K, 47.9 and 40.6% for Ca, 30.7 and 51.2% for Mg, respectively.

Key words: C/N ratio, Decay constant, Immobilization, Litter decomposition, Mineralization

INTRODUCTION

Forest ecosystems are self-maintained through primary production and nutrient cycling. In most forests the major source of nutrient for tree growth is the process of litter decomposition. Decomposition of leaf litter, by which organic matter and nutrients are returned to the forest soils, is a primary mechanism and has received considerable attention for sustainable forest soil fertility (Alhamd et al. 2004). Decomposition of litter is mainly a biological process carried out by insects, worms, bacteria, and fungi both on the soil surface and in the soil (Satchell 1974). In general, climate rules decomposition of litter on a regional scale whereas litter chemical composition dominates the process on a local scale. Meentemeyer (1978) and Berg et al. (1987) showed a large-scale effect which is affected by climate on decomposition rate of fresh plant litter. It appears, however, that the picture may be more complicated than that.

The concentration of plant nutrient in litter material is important because of its influence both on the rate of decomposition of the litter and on the amounts of nutrient liberated during decomposition. Swift et al. (1979) proposed that litter quality is a major regulatory factor in litter decomposition. C/N and lignin/N ratios are frequently identified as the qualities most correlated with litter weight loss (Melillo et al. 1982, Taylor et al. 1989). High litter N contents have generally been considered to increase decomposition rates, and a positive correlation between litter decay rates and N contents has been reported in a great number of studies (Enriquez et al. 1993). However, Berg et al. (1987) and Fog (1988) suggested that the role of N as a rate regulating factor in litter decomposition is not always clear, and seems to be linked to litter type and stage of decomposition.

As a part of National Long-Term Ecological Research Program in Korea, carbon and nutrient cycling in major plant communities, such as *Pinus densiflora, Quercus variabilis* and *Q. mongolica,* at Mt. Worak National Park in Chungbuk Province have begun since April 2005. As a part of nutrient cycling, we are conducting the study of litter production and decomposition in major plant communities. The objective of the present study was to quantify the weight loss, the changes of C/N ratio of substrate and nutrient dynamics during leaf litter decomposition of *Q. variabilis* and *Pinus densiflora* at Mt. Worak National Park.

MATERIALS AND METHODS

Study Area

The Mt. Worak National Park is located between Mt. Soback and Mt. Sogri (N 36° 47'～36° 55', E 128° 4'～128° 12'), and stretches over both Gyeongsangbuk-do and Chungcheongbuk-do. The highest peak of the Mt. Worak National Park, Munsubong, is 1,162

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m above sea level.

Q. variabilis forest is located at 330 m above sea level, a steep incline of about 50 degrees, south-west direction of Yongha valley (N 36° 53' 19" E 128° 68' 55"). Tree density was 2,550 trees/ha and average DBH was 12.3 ± 4.71 cm. In shrub layer, *Lindera obtusiloba* and *Clerodendron trichotomum* were distributed with very low density. Herb layer was very sparse. *P. densiflora* forest is located at 380 m above sea level, south-west direction of Songgye valley (N 36° 51' 7" E 128° 64' 1"). Tree density was 1,300 trees/ha and average DBH was 14.6 ± 5.98 cm. In shrub layer, shrubby *Q. variabilis*, *Fraxinus sieboldiana, Indigofera kirilowii* were distributed with low density. Herb layer was dominated by *Pteridium aquilinum* and *Miscanthus sinensis*. According to the Jechon meteorological station, about 30 km distance from the study area, annual average temperature and precipitation for thirty years from 1976 through 2005 was 10.1℃ and 1,349.8 mm, respectively.

Litterbag Preparation, Installing and Retrieval

Freshly fallen oak and pine leaves were collected in *Q. variabilis* and *P. densiflora* forest on September 2005. They were dried at 80℃ oven for 72 hrs. The litterbag technique was used, using litterbags ca. 20 × 25 cm, made with 2mm mesh size nylon net. Approximately 5 g of leaf litter was packed into each litterbag with an aluminum tag which gives the exact weight of litter enclosed. Litterbags were scattered in each of the forest floor on December 2005. They were fastened to the ground with string and nails.

Five litterbags were retrieved every three months in each site from March 2006 through June 2008. Litterbags were cleaned free of soil, and oven dried at 80°C. Weight loss and nutrient dynamics during litter decomposition were determined by measuring remaining weight and nutrient concentration of litter in the litterbags. Weight loss of litter was expressed as % of initial sample weight. The decay constant (k) was calculated by Olson's $X_t = X_0e^{-kt}$, where X_0 is the initial weight of litter, X_t is the remaining weight of litter after time t, t is the time (in years), respectively (Olson 1963). Samples were ground with mixer for chemical analysis. The *t*-test was used for detecting a significant difference in the decay rate between the two species of leaf litter.

Chemical Analysis

Chemical analyses of litter were carried out with 3 replicates. C/N ratios of initial and decomposing litter were analyzed with Elemental Analyzer (EA1112, Thermo Fisher Scientific Inc.). T-N and T-P were analyzed with Flow Injection Analyzer (Lachat: QuickChem 8000) after litter samples were digested on block digestor. K, Ca and Mg were determined with Atomic Absorption Spectrophotometer (Perkin-Elmer 3110) after wet digestion on block digestor. Remaining nutrient after a given month decomposition were calculated by the following formula:

$$\text{Remaining (\%)} = (L_tC_t \ / \ L_0C_0) \times 100$$

where L_t is the dry weight of litter after time t, L_0 is the initial dry weight of litter, C_t is the concentration of nutrient in litter after time t, and C_0 is the initial concentration of nutrient in litter (Alhamd et al. 2004).

RESULTS AND DISCUSSION

Weight Loss

Weight loss of oak and pine leaf litter during decomposition continued steadily over 30 months (Fig. 1). From the early stage of decomposition, weight loss of oak litter was greater than that of the pine litter. After 12 months, oak and pine leaf litter lost 32.9% and 20.2% of initial litter weight, respectively. After 30 months decomposition, remaining weight of oak and pine leaf litter was 45.5% and 58.1%, respectively. The *t*-test revealed significant differences in decomposition rates between the two species ($p < 0.001$).

Weight loss in summer season (from 6 through 9 months and from 18 through 21 months in Fig. 1) was greater in both litter than that in winter season. This may be due to the greater activities of decomposer in summer season and water soluble fractions in litter leached out more in wet summer season (Jensen 1974, Millar 1974, Swift et al. 1979). Mun and Kim (1992) reported that needle litter (*P. densiflora*) in the limestone area lost 30% of the initial weight after 12 months decomposition. The decay constant (k) of oak and pine leaf litter were 0.314 and 0.217, respectively. The decay constant

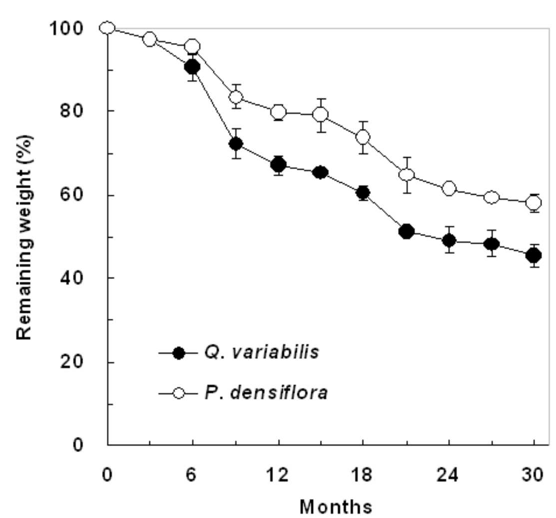

Fig. 1. Remaining weight (%) in decomposing leaf litter of *Q. variabilis* and *P. densiflora* at Mt. Worak National Park.

(k) of oak was significantly higher than that of pine ($p < 0.001$). Yang and Shim (2003) reported that weight loss rate of *P. densiflora* at Mt. Cheonma was 0.33, which was higher than our result.

C/N Ratio of Decomposing Leaf Litter

The C and N contents are important as decomposer organisms utilize carbon as a source of energy and nitrogen to grow and reproduce. Without sufficient nitrogen, there will be few microorganisms, and decomposition will be slow (Seereeram and Lavender 2003). Resource quality, such as C/N ratio and lignin/N ratio, is recognized as one of the major regulatory factors in litter decomposition (Swift et al. 1979, Melillo et al. 1982, Taylor et al. 1989). High litter N contents have generally been considered to increase decomposition rates, and a positive correlation between litter decay rates and N contents has been reported in a great number of studies (Enriquez et al. 1993).

C/N ratio of decomposing oak and pine leaf litter were depicted in Fig. 2A. Initial C/N ratio of oak and pine leaf litter were 53.4 and 153.0, respectively. Carbon % of initial oak and pine leaf litter were 45.3% and 50.5%, respectively. However, N content of initial oak leaf litter (0.85%) was greater than that of initial pine leaf litter (0.33%). C/N ratio of decomposing pine leaf litter decreased rapidly during the early stage of decomposition. This is because C content of decomposing pine leaf litter showed almost constant but N content increased during decomposition (Fig. 2B, C). Nitrogen content of decomposing oak leaf litter also increased during decomposition. Contrary to pine leaf litter, however, C content of the decomposing oak leaf litter decreased from 45.3% to 32.8%. Therefore, C/N ratio of decomposing oak leaf litter decreased slowly during the experimental period.

C/N ratios are often used as a measure to ensure that nitrogen is present in sufficient quantities for a proper nitrogen balance. Janssen (1996) suggested that mineralization of organic nitrogen requires microbial conversion of the organic material. Initial C/N ratio of litter is higher than that of the microbes. The fraction of organic N that is mineralized is less than the fraction of organic C that is dissimilated. So, C/N ratio of the remaining litter is decreasing during decomposition until it has the same value as that of the microbes. Janssen (1996) reported that more easily decomposable leaf species with low C/N ratios harbored higher numbers of bacteria than did more resistant leaf species, especially in freshly fallen litter. With progressive decay the influence of the tree species decreased, and environmental influences increased (Janssen 1996).

Nutrient Dynamics in the Decomposing Leaf Litter

N concentration in both decomposing leaf litter increased significantly until 27 months elapsed (Fig. 3A). Initial N concentration of *Q. variabilis* leaf litter was 7.44 mg/g. It increased to 16.95 mg/g at 27 months, and then decreased to 15.99 mg/g at 30 months elapsed. Initial N concentration of *P. densiflora* leaf litter was 3.02 mg/g. It increased to 12.50 mg/g at 27 months, and then decreased to 11.24 mg/g at 30 months elapsed. The increase in N concentration in decomposing leaf litter is a common observation (Berg and Staaf 1981, Melillo et al. 1982, Xu et al. 2004). Such an increase could be attributed to the addition of N from exogenous sources into microbial biomass (Melillo et al. 1982, Xu et al. 2004). Percentage of remaining N in decomposing pine leaf litter increased to 109.9% at 27 months elapsed, and then decreased thereafter (Fig. 3B). There was no net N mineralization period in decomposing pine leaf litter. On the other hand, remaining N in decomposing oak leaf litter did not change significantly during the experimental period (Fig. 3B).

Initial P concentration of oak and pine leaf litter was 0.16 and 0.09 mg/g, respectively (Fig. 3C). P concentration in both decomposing leaf litter also showed a increasing pattern during the experimental period. After 30 months elapsed, P concentration of oak and

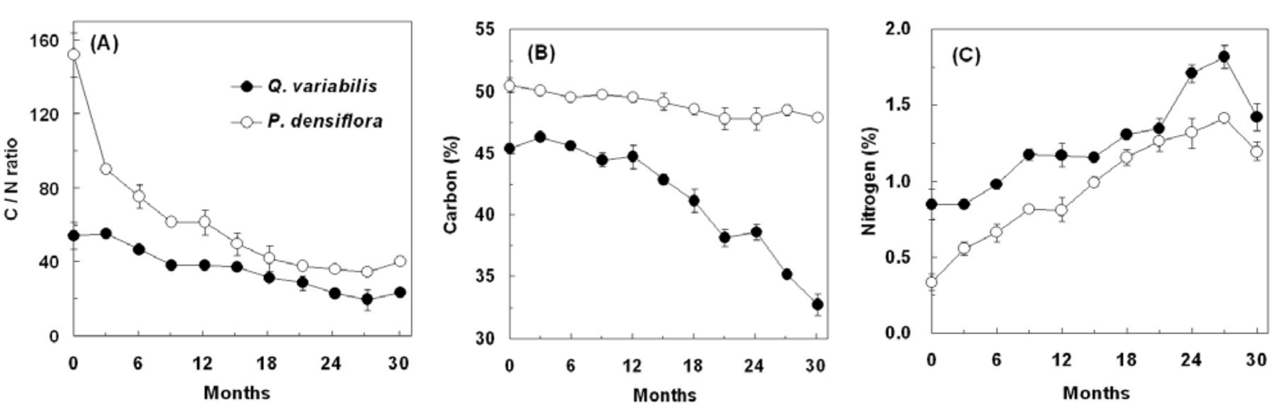

Fig. 2. Changes of C/N ratio (A), % carbon (B) and % nitrogen (C) in decomposing leaf litter of *Q. variabilis* and *P. densiflora* at Mt. Worak National Park.

pine leaf litter was 0.44 and 0.35 mg/g, respectively. The behavior of P during the decomposition process varies among species (Gosz et al. 1973, Schlesinger 1985, Baker et al. 2001). In present study, there was no net P mineralization period in both decomposing leaf litter (Fig. 3D). The possible mechanisms for this immobilization may be retention in microbial biomass or translocation from fungal mycelium (Xu et al. 2004).

Initial K concentration of oak and pine leaf litter were 2.39 and 0.99 mg/g, respectively (Fig. 4A). It decreased to 1.11 and 0.48 mg/g, respectively, during 15 months decomposition, and then showed increasing trend onward. Remaining K in both decomposing leaf litter decreased rapidly during early stage of 15 months decomposition (Fig. 4B). There was no K immobilization period in both decomposing oak and pine leaf litter. This pattern is due to the fact that K is not structural components of plant litter and is subject to physical removal by leaching (Gosz et al. 1973, Lousier and Parkinson 1978, Xu et al. 2004). After 30 months elapsed, about 60.7% and 55.2% of initial K in oak and pine leaf litter was released, respectively.

Initial Ca concentration of oak and pine leaf litter was 2.95 and 3.84 mg/g, respectively (Fig. 4C). Unlike the other nutrients, initial Ca concentration of pine leaf litter was greater than that of oak leaf litter. Ca concentration of decomposing oak leaf litter increased during early stage of decomposition, and then decreased thereafter. However, Ca concentration of decomposing pine leaf litter showed decreasing trend during the experimental period. There was net Ca immobilization during early stage of decomposition in oak leaf litter (Fig. 4D). From 9 months through 30 months, however, net Ca mineralization occurred in decomposing oak leaf litter. Remaining Ca in decomposing pine leaf litter decreased steadily during the experimental period. There was no net Ca immobilization period in decomposing pine leaf litter. After 30 months decomposition, about 52.1% and 59.4% of initial Ca in oak and pine leaf litter was released, respectively. Gosz et al. (1973) and Edmonds and Thomas (1995) reported that Ca release pattern was somewhat similar to the weight loss pattern because it is a structural component and thus protected from physical leaching. However, Klemmedson et al. (1985) found an accumulation of Ca and a slow release in the later stage of decomposition.

Initial Mg concentration of oak and pine leaf litter was 2.36 and 0.62 mg/g, respectively (Fig. 4E). In decomposing oak leaf litter, Mg concentration decreased rapidly during first 15 months decomposition, and then showed more or less increasing pattern onward. In case of decomposing pine leaf litter, Mg showed no significant pattern during the experimental period. Net Mg mineralization was occurred in decomposing oak leaf litter during the experimental period (Fig. 4F). After 30 months elapsed, 69.3% of initial Mg was released. In case of pine leaf litter, there was a short immobilization period in the early stage of decomposition, and then net mineralization occurred onward. After 30 months elapsed, about 48.8% of initial Mg was released from pine leaf litter. Gosz et al. (1973) and Xu et al. (2004) reported that dynamics of Mg are similar to the pattern of K. In plants, Mg is readily extracted with water (Mar

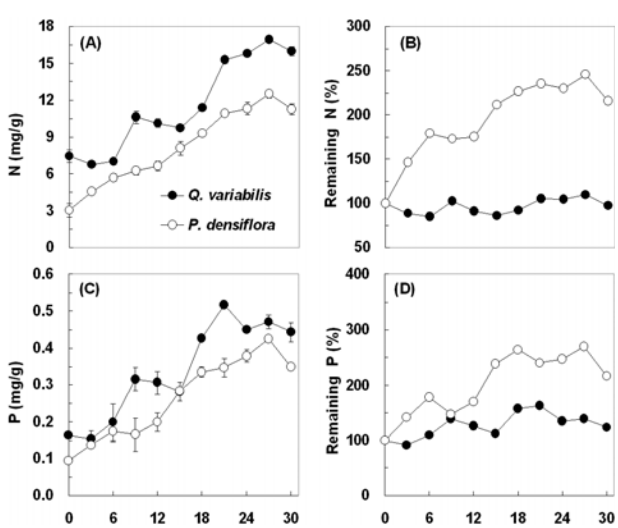

Fig. 3. Changes of N(A) and P(C) concentration, and % remaining N(B) and P(D) in decomposing leaf litter of *Q. variabilis* and *P. densiflora* at Mt. Worak National Park.

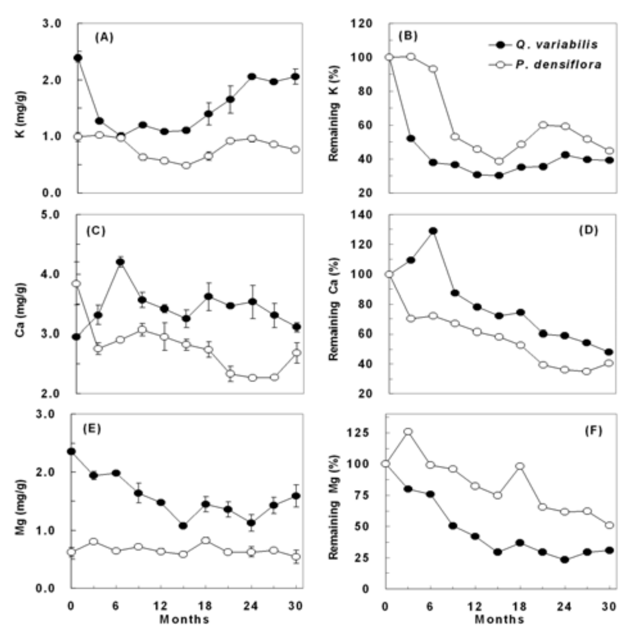

Fig. 4. Changes of K(A), Ca(C), Mg(E) concentration, and % remaining K(B), Ca(D), Mg(F) in decomposing leaf litter of *Q. variabilis* and *P. densiflora* at Mt. Worak National Park.

shner 1995). This means that Mg could be leached out by rainwater in the decomposition process (Xu et al. 2004).

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