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Litterfall and Nutrient Dynamics in Pine (*Pinus rigida*) and Larch (*Larix leptolepis*) Plantations

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Abstract : Litterfall and nutrient inputs were measured in even-aged coniferous plantations (a 31-year-old *Pinus rigida* and a 31-year-old *Larix leptolepis*) on a similar site condition in the Forest Practice Research Center, Gyeonggi Province. Litterfall was collected monthly from circular littertraps (collecting area : 0.50 m^2) for three years between April 1997 and February 2000. Average total annual litterfall was significantly higher for pine (5,802 kg/ha/yr) than for larch (4,562 kg/ha/yr) plantations. Needle litter in both plantations accounted for about 63% of total litterfall. Litterfall in the larch was distributed as follows: needle > other leaf > branch > miscellaneous > bark, while it was needle > miscellaneous > other leaf > branch > bark in the pine plantation. There was no temporal variation in needle litter, other leaf and bark during the 3 year study period. The concentrations of all nutrients (N, P, K, Ca, Mg) in needle litter were significantly higher in the larch than in the pine plantations. The annual nutrient concentration of needle litter in the larch varied among the years, whereas no year variation of needle litter was in the pine except for phosphorus (P). Nitrogen (N) and P inputs by needle litter were significantly higher for larch than for pine plantations established on a similar soil. The differences in N and P inputs were attributed to lower nutrient concentration in pine needle litter compared with larch needle litter, not to total needle litter mass. Annual inputs of nutrient in both plantations were not significantly different among years except for K of the larch although there was yearly different in needlefall mass and nutrient concentration during the 3-year observed period. The results indicate that the mechanisms of litterfall and nutrient inputs vary considerably between pine and larch plantations established on a similar site condition.

Key words : Larix leptolepis, *litterfall, nutrient cycling, nutrient inputs,* Pinus rigida

Introduction

Litterfall inputs represent a large and dynamic portion of the carbon and nutrient cycling in forest ecosystem because the turnover of litter is a major pathway of the nutrient and carbon inputs to forest soils (Bray and Gorham, 1964; Gower and Son, 1992; Kavvadias *et al.*, 2001; Kim, 2004). Litterfall and nutrient inputs depend on several ecological factors such as tree species, site quality, stand age, and stand density (Binkley, 1986; Sharma and Pande, 1989; Perdersen and Bille-Hansen, 1999; Kim, 2004). Although several studies have reported litterfall and nutrient inputs in pine and larch plantations of Korea (Kim and Chang, 1989; Mun and Joo, 1994; Kim *et al.*, 1996; Hwang, 2004), a comparative study related to seasonal and yearly patterns of litterfall inputs is lacking.

The pine (*Pinus rigida*) originated from USA was introduced from Japan in the early 1900's and planted to rehabilitate eroded and erosion areas. This tree was planted about 700 thousand hectares between 1960 and 1994 (Forestry Administration, 1994). The larch (*Larix leptolepis*) was planted about 600 thousand hectares between 1957 to 1990 (Forestry Administration, 1994). In addition, both tree species were the most major planting species for reforestation throughout the country during last thirty years. It is needed to understand information to evaluate the direction and rates of change associated with seasonal and yearly patterns of litterfall and nutrient inputs because tree nutrition and stand nutrient cycling can be decidedly affected by litterfall inputs (Sharma and Pande, 1989; Gower and Son, 1992; Hwang, 2004). The objectives of this study were 1) to determine seasonal and annual litterfall input patterns and 2) to measure the concentration and quantity of nutrients in needlefall in mature pine and larch plantations on an identical site condition as well as the same stand age.

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Material and Methods

The study was conducted in the Forest Practice Research Center in Gwangnung, Gyeonggi Province, Korea. The study sites were classified as slightly dry brown forest soils (B_2). Annual precipitation in the sites averages 1,365 mm and slightly higher than the average of the country (1,274 mm). Dominant understory species in the study site were *Carpinus laxiflora*, *Quercus serrata*, *Styrax japonica*, *Q. acutissima*, *Sorbus alnifolia*, and *Cornus kousa* etc. in the pine plantation. *Carpinus laxiflora*, *Quercus serrata*, *Styrax japonica*, *Stephanandra incisa*, and *Prunus sargentii* were dominated in the larch plantation. Stand tree densities were from 1,800 trees/ha to 2,200 trees/ha in the pine and from 400 trees/ha to 500 trees/ha in the larch plantations. Mean diameter at breast height was 15.3 cm in the pine and 22.1 cm in the larch plantations. Stand basal area was 41.1 m^2/ha in the pine and 16.6 m^2/ha in the larch plantations. More specific information of the study site was reported on other study (Kim, 1999)

Three sampling plots of 20×10 m from the pine and the larch plantations were chosen and litterfall was collected in circular traps devised by Hughes *et al.* (1987) using 1.5 mm nylon net. The collecting area was 0.50 m^2. The six traps in three plots were installed 50cm aboveground. Litter was collected at approximately monthly intervals for three years from April 1997 to February 2000. Litter collected from each trap was transported to the laboratory and oven-dried at 60°C for 48 hours All dried samples were separated into needle, other leaf, branch, bark, and miscellaneous components and each portion was weighed. Needle litter collected in heavy litterfall season (November of each year) was ground in a Wiley mill to pass a 40-mesh stainless steel sieve. Nutrients (N, P, K, Ca, Mg) in needle litter were analyzed by the standard method of National Institute of Agriculture Science and Technology (1988). Analyses of variance for the data were executed with the ANOVA procedure in SAS (SAS Institute Inc., 1989).

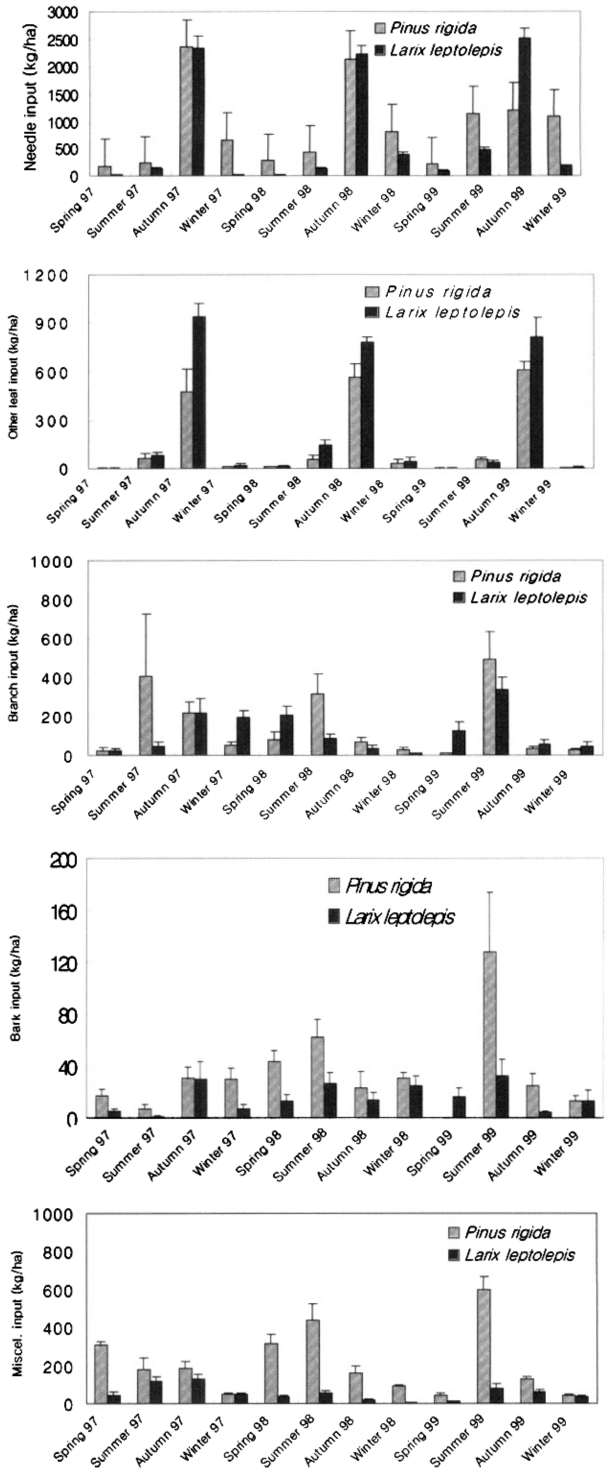

Figure 1. Seasonal litterfall inputs of *P. rigida* and *L. leptolepis* plantations. Vertical bars indicate one standard error (n=6).

Results and Discussion

The seasonal litterfall inputs as needle, other leaf litter, branch, bark, and miscellaneous components are shown in Figure 1. Litterfall inputs in both plantations followed a similar seasonal pattern although the pattern in litterfall inputs was affected by insect infestation (Pedersen and Bille-Hansen, 1999), site, stand age (Bray and Gorham, 1964), climate, and weather patterns (Gresham, 1982). Needle litter in both plantations showed unimodal patterns reached to maximum values in autumn except for 1999. Many studies reported a similar pattern for coniferous tree species because autumn is a natural senescence season of the needles in temperate forest (Bray and Gorham, 1964; Finer, 1996; Kim *et al.*, 1997). However, an unexpected peak in summer 1999 was due to a heavy storm by Typhoon Olga (July 31-August 5 1999).

The storm provoked abnormally increased needlefall compared to other summer seasons. Woody litter consisted of twigs, branch, and bark that fell on the forest floor. Woody litter tended to increase in summer, the windy and heavy rain season, in the country. Other study reported that the amount of woody litter was determined by seasonal strong winds (Christensen, 1975). Other leaf litter showed a peak in autumn when it is a heavy litterfall season in deciduous tree species in temperate forest (Kim *et al.*, 1997). The component of other leaf litter consisted of foliage from understory deciduous tree species such as *Carpinus laxiflora*, *Cornus kousa*, *Quercus serrata*, *Styrax japonica*, *Q. acutissima*, *Prunus sargentii*, *Sorbus alnifolia*, and *Stephanandra incisa* etc. Miscellaneous litter consisted of leaf, reproductive organ, bark and branch fragments. Miscellaneous litter was without a clear seasonal pattern although the litter was generally higher in summer than in other seasons.

The annual litterfall during the 3 year study period is summarized in Table 1. Average total litterfall was significantly different (P<0.05) for both plantations except for the measurements in 1997. Amount of litterfall varied with tree species. The litterfall was significantly higher for pine than for larch plantations during the study periods. Total litterfall during the 3 year sampling period averaged 5,802 kg/ha/yr for the pine and 4,562 kg/ha/yr for the larch plantations, respectively. The total amount of litterfall in this study was comparable to those reported in other pine and larch plantations in Korea (Table 2). In this study, high litterfall inputs in the pine plantation could be attributed to high stand density compared with the larch plantation. The amount of litterfall was significantly different by stand density (Kim, 2004).

Needle litter was the major component of total litterfall in both plantations (Table 1). Mean needle litter accounted for 62.8% and 62.5% of the total annual litterfall for the pine and for the larch plantations, respectively. Litterfall in the larch plantation was distributed as follows: needle > other leaf > branch > miscellaneous > bark, while needle > miscellaneous > other leaf > branch > bark in the pine plantation. The litterfall in larch was 62.5% in needle, 21.1% in other leaf, 10.2% in branch, 1.4% in bark and 4.8% in miscellaneous part. In contrast, the litterfall distribution in pine was 62.8% in needle, 14.6% in miscellaneous, 10.9% in other leaf, 10.1% in branch and 2.3% in bark. Both tree species showed a similar branch and bark distribution, while other leaf litter was higher in the larch than in the pine plantations. Much greater proportion of other leaf litter in the larch plantation could be attributed to more understory deciduous vegetation under more open canopy with low stand density. A high proportion of the miscellaneous litter in pine compared with larch was due to inputs of needle, bark, and reproduction organ fragments which were difficult to sort.

The temporal variation of needle, other leaf, bark and total litterfall was not significantly different (P>0.05) in

Table 1. Litterfall inputs (kg/ha) of *P. rigida* and *L. leptolepis* plantations.

Year	Stand	Needle	Other leaf	Branch	Bark	Miscellaneous	Total
1997	*L. leptolepis*	2,519 (230)bA	1,045 (79)aA	481 (78)aAB	42 (15)bA	340 (65)bA	4,427 (284)aA
	P. rigida	3,436 (163)aA	556 (140)bA	704 (308)aA	84 (6)aA	718 (86)aA	5,498 (474)aA
1998	*L. leptolepis*	2,781 (206)bA	985 (56)aA	337 (46)aB	78 (18)bA	121 (13)bB	4,302 (233)bA
	P. rigida	3,673 (360)aA	669 (109)bA	496 (140)aA	159 (16)aA	1,008 (112)aA	6,005 (546)aA
1999	*L. leptolepis*	3,264 (204)aA	863 (120)aA	573 (32)aA	66 (15)aA	193 (26)bAB	4,958 (207)bA
	P. rigida	3,686 (192)aA	671 (140)aA	559 (153)aA	107 (54)aA	819 (71)aA	5,903 (314)aA
Mean	*L. leptolepis*	2,855 (138)b	964 (51)a	464 (38)a	62 (9)b	218 (31)b	4,562 (149)b
	P. rigida	3,598 (141)a	632 (60)b	586 (118)a	136 (20)a	848 (57)a	5,802 (252)a

*Treatment means with the the same lower-case letter between stand types and treatment means with the same upper-case letter among years are not significantly different at P=0.05. Values in the parentheses are standard errors of the means (n=6).

Table 2. Total annual litterfall inputs (kg/ha) of *P. rigida* and *L. leptolepis* plantations in Korea.

Stand	Stand age	Litterfall input	Location	Reference
P. rigida	nd	6,040	Seoul	Kim and Chang (1989)
P. rigida	25-30	6,532	Chungnam	Mun and Joo (1994)
P. rigida	37	5,020	Gyeonggi	Kim *et al.* (1996)
P. rigida	40	6,289	Gyeonggi	Hwang (2004)
L. leptolepis	37	4,191	Gyeonggi	Kim *et al.* (1996)
L. leptolepis	40	4,447	Gyeonggi	Hwang (2004)
L. leptolepis	36	3,479	Gyeongnam	Kim (2004)

both plantations during the 3 year study period (Table 1). No variation in amount of needle litter could be attributed to canopy closure of these mature plantations. It is known that annual needle litter remains relatively constant after canopy closure (Bray and Gorham, 1964; Gessel and Turner, 1976). In addition, Bray and Gorham (1964) concluded that amount of annual litterfall varies only slightly during the period lasting several decades after canopy closure. Woody litterfall fractions such as branch and/or miscellaneous litter showed greater yearly variation than needle or other leaf litter. Woody litter is known to have a different deposition pattern between years because it is affected by weather conditions (Finer, 1996).

The concentrations of all nutrients (N, P, K, Ca, Mg) in needle litter were significantly higher ($P<0.05$) in the larch than in the pine plantations (Table 3). The average concentration of needle litter was 0.82% for N, 0.03% for P, 0.37% for K, 0.67% for Ca, 0.22% for Mg in the larch, and 0.37% for N, 0.01% for P, 0.22% for K, 0.47% for Ca, 0.17% for Mg in the pine, respectively. High nutrient concentrations in needle litter of larch may be due to high nutrient uptake characteristics compared with pine tree species (Son and Gower, 1992; Lee *et al.*, 2004). The nitrogen value in the pine needle litter was comparable to other pine needle litter such as 0.47% for *P. pinaster* and 0.51% for *P. nigra* in Greece (Kavvadias *et al.*, 2001). However, the nitrogen and phosphorus concentration of needle litter in this study were much lower than 0.82% of 40-year *P. rigida* and 1.98% of *L. leptolepis* plantations in Gyeonggi Province (Hwang, 2004).

The annual nutrient concentrations of needle litter in the larch varied among the years, whereas no year variation of needle litter was in the pine except for phosphorus (Table 3). The yearly variation in the nutrient concentrations of needle litter could be affected by climatic variable, nutrient supply from site, canopy leaching characteristics and retranslocation rates before senescence (Ostman and Weaver, 1981). More nutrient variations between years in needle litter of larch may be attributed to deciduous tree characteristics compared with evergreen tree species (Sharma and Pande, 1989).

The annual average quantities of nutrients (kg/ha) returned to forest floor by litterfall were 23.1 of N, 1.0 of P, 10.3 of K, 18.7 of Ca, 6.4 of Mg for the larch and 13.2 of N, 0.5 of P, 7.9 of K, 16.9 of Ca, 5.9 of Mg for the pine plantations, respectively (Table 4). Nitrogen and phosphorus inputs by needle litterfall were significantly different between the larch and the pine plantations established on a similar soil. However, the differences in nutrient inputs of each plantation type did not corre-

Table 3. Nutrient concentration (% of dry weight) in needle litter of *P. rigida* and *L. leptolepis* plantations.

Year	Stand	N	P	K	Ca	Mg
1997	*L. leptolepis*	0.81 (0.071)aA	0.04 (0.020)aA	0.33 (0.067)aAB	0.69 (0.067)aAB	0.19 (0.009)aB
	P. rigida	0.33 (0.041)bA	0.01 (0.001)aAB	0.27 (0.067)aA	0.62 (0.064)aA	0.19 (0.039)aA
1998	*L. leptolepis*	0.99 (0.037)aA	0.03 (0.003)aA	0.57 (0.064)aA	0.75 (0.007)aA	0.29 (0.019)aA
	P. rigida	0.42 (0.058)bA	0.01 (0.001)bB	0.27 (0.024)bA	0.44 (0.022)bA	0.13 (0.006)bA
1999	*L. leptolepis*	0.65 (0.047)aA	0.03 (0.001)aA	0.21 (0.032)aB	0.56 (0.032)aB	0.20 (0.015)aB
	P. rigida	0.35 (0.013)bA	0.02 (0.001)bA	0.12 (0.012)aA	0.36 (0.013)bA	0.17 (0.012)bA
Mean	*L. leptolepis*	0.82 (0.055)a	0.03 (0.006)a	0.37 (0.060)a	0.67 (0.035)a	0.22 (0.017)a
	P. rigida	0.37 (0.025)b	0.01 (0.002)b	0.22 (0.032)b	0.47 (0.043)b	0.17 (0.015)b

*Treatment means with the the same lower-case letter between stand types and treatment means with the same upper-case letter among years are not significantly different at P=0.05. Values in the parentheses are standard errors of the means (n=3).

Table 4. Nutrient inputs (kg/ha) in needle litter of *P. rigida* and *L. leptolepis* plantations.

Year	Stand	N	P	K	Ca	Mg
1997	*L. leptolepis*	20.7 (3.90)aA	1.03 (0.55)aA	8.06 (1.46)aB	17.4 (2.98)aA	4.62 (0.54)aA
	P. rigida	11.4 (1.03)bA	0.45 (0.05)aA	9.12 (2.29)aA	20.99 (1.98)aA	6.48 (0.98)aA
1998	*L. leptolepis*	27.56 (3.23)aA	0.97 (0.07)aA	15.84 (0.11)aA	20.61 (1.49)aA	8.06 (1.06)aA
	P. rigida	15.40 (3.21)bA	0.45 (0.08)bA	9.96 (0.99)bA	16.29 (2.47)aA	4.78 (0.69)aA
1999	*L. leptolepis*	21.09 (1.98)aA	1.07 (0.14)aA	7.01 (1.56)aB	18.05 (1.20)aA	6.51 (0.94)aA
	P. rigida	13.49 (1.26)bA	0.74 (0.10)aA	4.48 (1.24)aA	13.49 (2.18)aA	6.43 (0.82)aA
Mean	*L. leptolepis*	23.13 (1.92)a	1.02 (0.17)a	10.30 (1.59)a	18.70 (1.13)a	6.39 (0.66)a
	P. rigida	13.20 (1.21)b	0.55 (0.06)b	7.85 (1.13)a	16.92 (1.47)a	5.89 (0.51)a

Treatment means with the the same lower-case letter between stand types and treatment means with the same upper-case letter among years are not significantly different at P=0.05. Values in the parentheses are standard errors of the means (n=6).

sponded to differences in needle litter mass. The distinct differences in the amount of litter N and P inputs between both tree plantations can be attributed to the lower concentrations in pine needle litter compared with larch needle litter, not to total needle litter mass. The nitrogen amount of needle litter in this study was much lower than 52.9 kg/ha of 40-year *P. rigida* and 77.5 kg/ha of *L. leptolepis* plantations in Gyeonggi Province (Hwang, 2004). The nitrogen inputs in this study may be underestimated because nitrogen concentration of needle litter was measured from heavy litterfall season only (November). In addition, the nitrogen and phosphorus concentration of needle litter in *P. rigida* and *L. leptolepis* showed a clear seasonal variation which is highest in summer and lowest in autumn (Hwang, 2004). Other nutrients such as K, Ca and Mg inputs were not significantly different between both tree plantations.

Annual inputs of nutrient in both plantations were not significantly different ($P>0.05$) among years except for K of the larch although there was yearly different in needlefall mass and nutrient concentration during the 3-year observed period (Table 3). The result suggests that tree species in these mature plantations retain constant nutrient return strategies regardless of yearly variation of needlefall mass or nutrient concentration.

Literature Cited

1. Binkley, D. 1986. Forest Nutrition Management. John Wiley & Sons, New York.
2. Bray, J.R. and Gorham, E. 1964. Litter production in forests of the world. Advances in Ecological Research 2: 101-157.
3. Christensen, O. 1975. Wood litter fall in relation to abscissions, environmental factors, and the decomposition cycle in a Danish oak forest. Oikos 26: 187-195.
4. Forestry Administration. 1994. Statistical Yearbook of Forestry. (in Korean)
5. Gessel, S.P. and Turner, J. 1976. Litter production in western Washington Douglas-fir stands. Forestry 49: 63-72.
6. Gower, S.T. and Son, Y. 1992. Differences in soil and leaf litterfall nitrogen dynamics for five forest plantations. Soil Science Society of America Journal 56: 1959-1966.
7. Gresham, C.A. 1982. Litterfall patterns in mature loblolly and longleaf pine stands in costal South Carolina. Forest Science 28: 223-231.
8. Finer, L. 1996. Variation in the amount and quality of litterfall in a *Pinus sylvestris* L. stand growing on bog. Forest Ecology and Management 80: 1-11.
9. Hwang, J. 2004. Belowground carbon dynamics after thinning, liming and litter layer treatments in *Pinus rigida* and *Larix leptolepis* plantations. Ph.D. Dissertation, Korea University.
10. Hughes, J.W., Fahey, T.J. and Browne, B. 1987. A better seed and litter trap. Canadian Journal of Forest Research 17: 1623-1624.
11. Kavvadias, V.A., Alifragis, D., Tsiontsis, A., Brofas, G. and Stamatelos, G. 2001. Litterfall, litter accumulation and litter decomposition rates in four forest ecosystems in northern Greece. Forest Ecology and Management 144: 113-127.
12. Kim, C., Koo, K.S., Kim, Y.K., Lee, W.K., Jeong, J.H. and Seo, H.S. 1997. Dynamics of litterfall and nutrient inputs in *Quercus acutissima* and *Pinus koraiensis* stands. FRI Journal of Forest Science 55: 13-18 (in Korean with English abstract)
13. Kim, C. 1999. Abroveground nutrient distribution in pitch pine (*Pinus rigida*) and Japanese larch (*Larix leptolepis*) plantations. Journal of Korean Forestry Society 88: 266-272.
14. Kim, C. 2004. Effects of stand density on carbon dynamics in a Larch (*Larix leptolepis*) plantation. Journal of Korean Forestry Society 93: 355-362.
15. Kim, J.G. and Chang, N.K. 1989. Litter production and decomposition in the *P. rigida* plantation in Mt. Kwanak. Korean Journal of Ecology 12: 9-20.
16. Kim, J.S., Son, Y., Lim, J.H. and Kim, Z.S. 1996. Aboveground biomass, N and P distribution, and litterfall in *Pinus rigida* and *Larix leptolepis* plantations. Journal of Korean Forestry Society 85: 416-425. (in Korean with English abstract)
17. Lee, I.K., Son, Y. and Oh, J.S. Effect of nitrogen and phosphorus fertilization on aboveground biomass and distribution of nutrient content of *Pinus rigida* and *Larix kaempferi* plantations in Yangpyeong area, Gyeonggi province. Journal of Korea Forestry Energy 23: 1-18.
18. Mun, H.T. and Joo, H.T. 1994. Litter production and decomposition in the *Quercus acutissima* and *Pinus rigida* forest. Korean Journal of Ecology 17: 345-353. (in Korean with English abstract)
19. National Institute of Agricultural Science and Technology. 1988. Methods of Soil Chemical Analysis. Sammi Press, Suwon. (in Korean)
20. Pedersen, L.B. and Bille-Hansen, J. 1999. A comparison in litterfall and element fluxes in even aged Norway spruce, sitka spruce and beech stands in Denmark. Forest Ecology and Management 114: 55-70.
21. SAS Institute Inc. 1989. SAS/STAT User's Guide. Version 6 4th ed. Vol. 2 Cary, N.C.
22. Sharma, S.C. and Pande, P.K. 1989. Patterns of litter nutrient concentration in some plantation ecosystems. Forest Ecology and Management 29: 151-163.
23. Son, Y. and Gower, S.T. 1992. Nitrogen and phosphorus distribution for five plantation species in southwestern Wisconsin. Forest Ecology and Management 53: 175-193.

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