Korean J. Ecol. 15(1) : 35 ~ 46, 1992

Nutrient Cyclings in Mongolian Oak (*Quercus mongolica*) Forest

Kwak, Young-Se and Joon-Ho Kim

Dept. of Biology, Natural Science College, Seoul Nat'l University

신갈나무 숲의 營養鹽類 循環

郭永世 · 金俊鎬

서울大學校 自然科學大學 生物學科

ABSTRACT

To elucidate nutrient cyclings such as nitrogen, phosphorus and potassium in mongolian oak (*Quercus mongolica*) forest, nutrient elements of precipitation, throughfall, outflow, soil, various plant organs and litter were determined at Mt. Nambyeongsan, Pyeongchang-gun, Gangwon province in central part of Korean peninsula. Annual precipitation input, throughfall and outflow of nutrients were 10.3, 8.6 and 4.2 kg/ha for the N, 0.11, 0.24 and 0.02 kg/ha for the P and 1.3, 10.9 and 1.2 kg/ha for the K, respectively. In seasonal changes of nutrient concentrations, N, P and K concentrations which were rich in young leaves decreased steadily until autumn and decreased abruptly during autumnal yellowing.

The standing N, P and K content were 565, 37 and 257 kg/ha for standing phytomass of overstory, 33, 3 and 18 kg/ha for understory, 132, 3.6 and 14 kg/ha for litter on ground including deadwood and 20,752, 14 and 420 kg/ha for the soil, respectively. The amounts of annual uptake, return and retain were 174.2, 57.2, 117.2 kg/ha for the N, 9.9, 3.5, 6.4 kg/ha for the P and 73.2, 30.3, 42.9 kg/ha for the K, respectively. Reabsorption efficiency, ratio of the nutrient amount reabsorbed into woody organs to that in the mature leaves before shedding, was 71%(or 99.8 kg/ha in the amount), 69%(or 5.1 kg/ha) and 57%(or 33.1 kg/ha) and recycling coefficient, ratio of return to uptake, was 0.33, 0.35 and 0.41 for N, P and K, respectively.

These results suggest that in the *Q. mongolica* forest the nutrient cyclings be efficiently made with which the large amount of nutrients is absorbed through roots during growing season(UPTAKE) and reabsorbed from the leaves before shedding(RETAIN) but the small amount of nutrients is returned through litterfall(RETURN).

INTRODUCTION

The nutrient cycling is one of the principal processes supporting the production of organic matter(Duvigneaud and Denaeyer-DeSmet, 1970). Since a synthetic assay on nutrient cycling in temperate deciduous forests was attempted by Duvigneaud and Denaeyer-DeSmet in 1964, many studies have been made in different type of forests (Ovington, 1968; Johnson and Risser, 1974; Kim and Mun, 1982; Papp, 1985; Schlesinger *et al.*, 1989; Cho and Kim, 1989). Mun *et al.*(1977) estimated that the cycling rate of Korean alder stand was higher than that of oak stand. The deciduous plants, however, retain much nutrients from their own body, efficiently reabsorbed to woody organs from leaves before shedding(Aerts and Berendse, 1989).

Successional ecosystems tied unexpectedly up much more amount of nutrients from which lose to outflow than mature ecosystems did(Vitousek and Reiners, 1975). In young *Pinus koraiensis* plantations nutrient retention increased as the plantation aged(Cho and Kim, 1989). The precipitation supplies a significant amount of inorganic nutrients to ecosystems from atmosphere(Borman and Likens, 1967; Ovington, 1968; Alcock and Morton, 1985; Cho and Kim, 1989). When the surface of plant was got with rainwater the amount of nutrients leaching from it was less in coniferous forests than in deciduous ones (Luxmoore *et al.*, 1981). High nutrient concentration in leaves and high rate of reabsorption from shedding leaves were more conspicuous in the fertile habitats than in infertile ones, which was important significance for nutrient cyclings(Chapin and Kedrowski, 1983). The understory greatly contributed to nutrient cyclings of forests even though its standing phytomass is a little compared with overstory(Yarie, 1980)

The purpose of this study was to elucidate quantitatively the amounts of nutrient return by the litterfall, uptake and retain by the plants as well as input and output nutrients through precipitation and outflow in a *Quercus mongolica* forest.

METHODS

Study site and sampling

This study was conducted in *Q. mongolica* forest at Pyeongchang-gun, Gangwon province, Korea, where was described in the previous paper(Kwak and Kim, 1992). Material samplings for plants and soil were made from April 1985 to September 1985 by the same methods described in previous paper(Kwak and Kim, 1992). Collections for the bulk precipitation and throughfall were made respectively with four polyethylene collectors, 3 L bottle with 22 cm in diameter, which were set both in open area and in the neighborhood of the tree canopy on June 20, 1985.

Prior to setting the collector, the bottle was rinsed with 3N hydrochloric acid, washed and then 5 ml of ethylene chloride was put into bottle to inhibit microbial activity. During periods of high rainfall, collections were made more frequently to prevent the collection bottles from overflowing. In addition, sampling of the surface outflow water at the stand was conducted at the lower catchment basin. Subsamples were frozen until analyses of inorganic nutrients. The amount of the outflow was estimated from the difference between the amounts of precipitation and evapotranspiration according to Thornthwaite and Mather(1957). Data of climate from the Daegwalryoung meteological observatory, at about 35 km NE apart from the study area, were 1,497 mm in the annual mean precipitation and 6.3 annual mean temperature.

Chemical analyses of nutrients

The total nitrogen content in plant and soil were determined by a modified micro-Kjeldahl method(Jackson, 1967). Phosphorus was determined by ascorbic acid method(APHA, 1981). For determination of potassium, the extracting with 0.2N hydrochloric acid for plant materials and with 2N ammonium acetate for soil samples was measured by flamephotometer(Coleman 51). The concentrations of nitrogen and phosphorus of water samples were determined by Strickland and Parsons method(1972) and potassium of water was measured by flamephotometer(APHA, 1981).

Estimation for nutrient cyclings

Data on phytomass and net primary production of each organ and litterfall for nutrient cyclings were made use of materials in the previous paper(Kwak and Kim, 1992). For calculation of annual nutrient cyclings, annual decompositions of roots and litter were regarded the same as annual production.

The amount of nutrients leached through throughfall from the canopy was calculated by subtracting that in the bulk precipitation. Annual nutrient inputs were computed by multipling the amount of annual precipitation by the mean nutrient concentration per unit volume of the bulk precipitation. Annual uptake, return and retain of nutrients were calculated according to Cho and Kim(1989).

RESULTS AND DISCUSSION

Nutrient concentrations in precipitation, throughfall and outflow

Concentrations of NH_4^+-N, NO_3^--N and total dissolved$-$ N per unit volume were 0.35, 0.34 and 0.69 mg/l in the bulk precipitation, 0.32, 0.26 and 0.58 mg/l in the throughfall, and 0.23, 0.22 and 0.45 mg/l in the outflow, respectively(Table 1). Nitrogen concentrations in both precipitation and throughfall were similar to but those in the outflow were rather less than the results from a *Pinus koraiensis* plantation(Cho and Kim, 1989).

The N concentrations in the throughfall were less 9%, 24% and 16% for NH_4^+-N, NO_3^--N and total dissolved N than those in the bulk precipitation. Then, the N concentrations in the outflow were less 34%, 35% and 35% for NH_4^+-N, NO_3^--N and total$-$N than those in the precipitation. The concentration of P in the throughfall increased to about twofold of the bulk precipitation but that in the outflow decreased to about a third of the precipitation. The concentrations of K in both throughfall and outflow increased to 8-fold and 1.4-fold of the precipitation(Table 1). These results suggest that the canopy absorbs significant amount of N from the rainwater in the mongolian oak forest(Voigt, 1960; Alcock and Morton, 1985) but discharges P and K through leaf surface into it, and the soil absorbs much more N and P than the canopy do but discharges considerable amount of K into the outflow.

Table 1. Concentrations of nutrients (mg /1*l*) of water samples

	NH_4^+-N (Range)	NO_3^--N (Range)	$PO_4^{3-}-P$ ($\times10^{-2}$) (Range)	K^+ (Range)
Precipitation	0.35(0.17~0.63)	0.34(0.15~0.45)	0.70(0.30~0.80)	0.09(0.08~0.10)
Throughfall	0.32(0.10~0.55)	0.26(0.18~0.35)	1.60(0.40~2.30)	0.73(0.14~1.49)
Outflow	0.23(0.17~0.30)	0.22(0.10~0.30)	0.20(10.0~0.30)	0.13(0.12~0.14)

Seasonal changes of nutrient concentrations in organ and soil

Seasonal changes of total nitrogen concentration(N) in mg N per g dry weight for soil and the different plant organs are shown in Fig. 1.

The N of the soil increased in both spring and fall, which are not the growing season, but decreased during summer. The N of the leaves with a high concentration decreased gradually from spring(48 mg N /g d.wt. in May) to fall(15 mg N /g d.wt. in November). This is due to increasing accumulation of photosynthetic products and to leaf thickening during development(Waring and Schlesinger, 1985). The N of the small branches was much more dense than that of large branches and the seasonal N pattern of the former was similar to that of the roots, and N of the trunk with the lowest concentration changed hardly with season.

Available phosphorus concentration(P) in mg P per g d.wt. for soil, with a dilute concentration was dense during the growing season in contrast with the seasonal N pattern (Fig.1).The P of the leaves with a high concentration was similar to the seasonal N pattern, that of the small branches with a moderate concentraion was as dense as 0.7 mg P/g d.wt. in October occurring leaffall, and that of roots with a low concentration decreased during the active growing season. Potassium concentration(K) in mg per g d.wt. for soil was low in fall(Fig. 1). The K of the leaves with 16 mg K /g d.wt. in May decrease suddenly to 3 mg K /g d.wt. in November.

The K of the roots and, small and large branches with a moderate concentration were dense during the active growing season in June and August. The N, P and K in the leaves and small branches with high concentration during the growing season actively reabsorbed into woody parts in November(see Fig. 1). Such active withdrawal of nutrients would be explained as reuse for the next year(Waring and Schlesinger, 1985; Tolsma *et al.*, 1987).

Annual mean nutrients concentrations in mg per g d. wt. for the leaves, branches, trunk

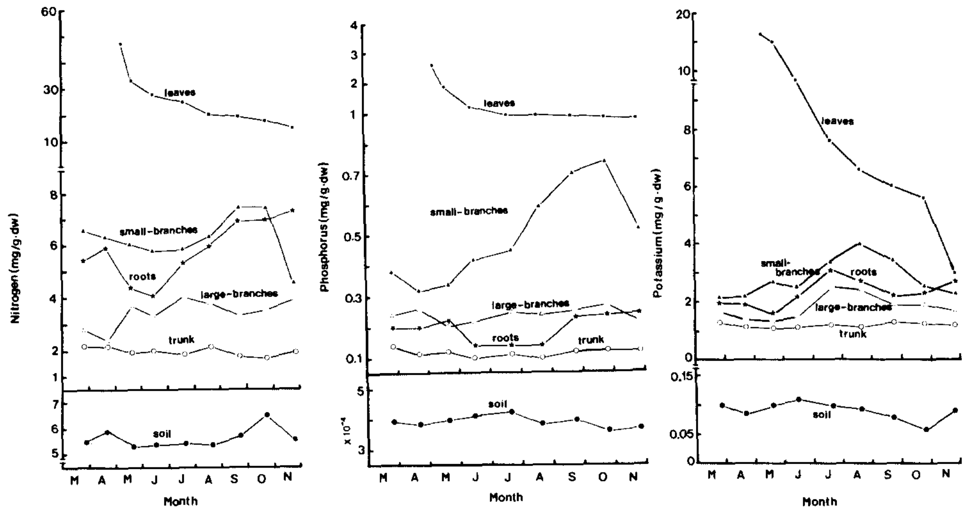

Fig. 1. Seasonal variations of nitrogen, phosphorus and potassium content(mg/g d. wt.) of soil and plant organs of *Quercus mongolica* forest.

Table 2. Annual mean nutrient concentrations of different components in *Q mongolica* froest

Components	N (mg/g)	P (mg/g)	K (mg/g)	Components	N (mg/g)	P (mg/g)	K (mg/g)
Tree				Herb			
Leaves	30.0	1.4	8.8	Leaves	30.4	2.4	16.5
Branches	4.5	0.3	2.0	Roots	15.2	1.3	10.3
Trunk	2.0	0.2	1.2	Litter on ground	14.8	0.4	1.7
Roots	5.7	0.2	2.3	Soil	5.6	0.4×10^{-3}	0.1
Shrup							
Leaves	25.4	1.9	12.4				
Stems & Branches	2.8	0.1	1.1				
Roots	3.1	0.1	1.6				

and roots were 30.0, 4.5, 2.0, 5.7 mg/g d.wt.(100:15:6:19) for the N, 1.4, 0.3, 0.2, 0.2 mg/g d.wt.(100:21:14:14) for the P and 8.8, 2.0, 1.2, 2.3 mg/g d.wt.(100:23:14:26) for the K, respectively(Table 2).

Annual mean N concentration in the leaves of shrub was less than that of tree but those of P and K are vice versa(Table 2). Annual mean concentrations of nutrients in the leaves and roots of herb were much more than that of tree(Table 2). Annual mean nutrient concentrations in the litter lying on ground were as small as about 50% for the N, as 29% for the P and as 19% for the K in the fresh leaves.

A comparison of nutrient concentrations for various organs sampled in October is made among stands of *Q. mongolica*, *Q. acutissima*, *Q. petraea* and *Q. cerris* grown in temperate zone(Table 3).

Table 3. Comparison of nutrient concentrations in various organs among several oak trees in October

Species	Leaves	Branches	Trung	Roots	Habitat	Authous
			Nitrogen (mg / g d.wt.)			
Q. mongolica	18.22	5.45	3.69	6.92	Korea	
Q. acutissima	9.20	3.40	2.10	4.10	Korea	(Mun *et al*, 1977)
Q. petraea	12.82	5.66	4.60	7.91	Hungary	(Papp, 1985)
Q. cerris	14.31	4.16	5.53	6.84	Hungary	(Papp, 1985)
			Phosphorus (mg / g d.wt.)			
Q. mongolica	1.10	0.50	0.20	0.53	Korea	
Q. aculissima	1.20	0.35	0.20	0.41	Korea	(Mun *et al*, 1977)
Q. petraea	1.46	0.39	0.21	0.60	Hungary	(Papp, 1985)
Q. cerris	1.77	0.41	0.21	0.45	Hungary	(Papp, 1985)
			Potassium(mg / g d.wt.)			
Q. mongolica	6.00	2.21	1.35	2.22	Korea	
Q. acutissima	7.40	0.90	1.10	5.20	Korea	(Mun *et al*, 1977)
Q. petraea	7.80	2.15	1.23	3.10	Hungary	(Papp. 1985)
Q. cerris	7.92	2.51	2.36	2.52	Hungary	(Papp, 1985)

In *Q. mongolica* forest compare with other forests, the N is the most dense in the leaves, the P is the most dense in the branches but the most dilute in the leaves, and the K is the most dilute both in the leaves and roots. Consequently the leaves of *Q. mongolica* have more the dense N concentration than the P and K.

In the litter falling into a litter trap, nutrient concentrations in leaves, branches, bud scales, flowers and acorns were 11.0, 4.9, 10.9, 25.7, and 8.8 mg / g d.wt.(43:19:42:100:34) for the N, 0.7, 0.2, 0.6, 3.0 and 0.5 mg / g d.wt.(23:6:20:100:17) for the P and 3.0, 0.8, 1.9, 15.8 and 1.3 mg / g d.wt.(19:5:12:100:80) for the K, respectively(Table 4). Attention is taken, here, to the flowers with dense nutrient concentration.

Standing nutrient content

The standing N, P and K content in kg per ha in the forest were 564, 37 and 257 kg / ha for standing phytomass of overstory, 33, 3 and 18 kg / ha for understory, 132, 4 and 14 kg / ha for litter on ground including deadwood and 20, 752, 14 and 420 kg / ha for the soil, respectively(Table 2, Fig. 2).

The standing N, P and K content in overstory of *Q. mongolica* are larger than those in *Quercus acutissima* stand and 11 years-old *Pinus koraiensis* plantation, which are grown in central parts of Korea(Mun *et al.*, 1977; Cho and Kim, 1989). Comparisons of the ranges of the standing nutrients contents among temperate deciduous forests, 530~1,200 kg / ha for the N, 40~100 kg / ha for the P and 340~1,400 kg / ha for the K, were made by

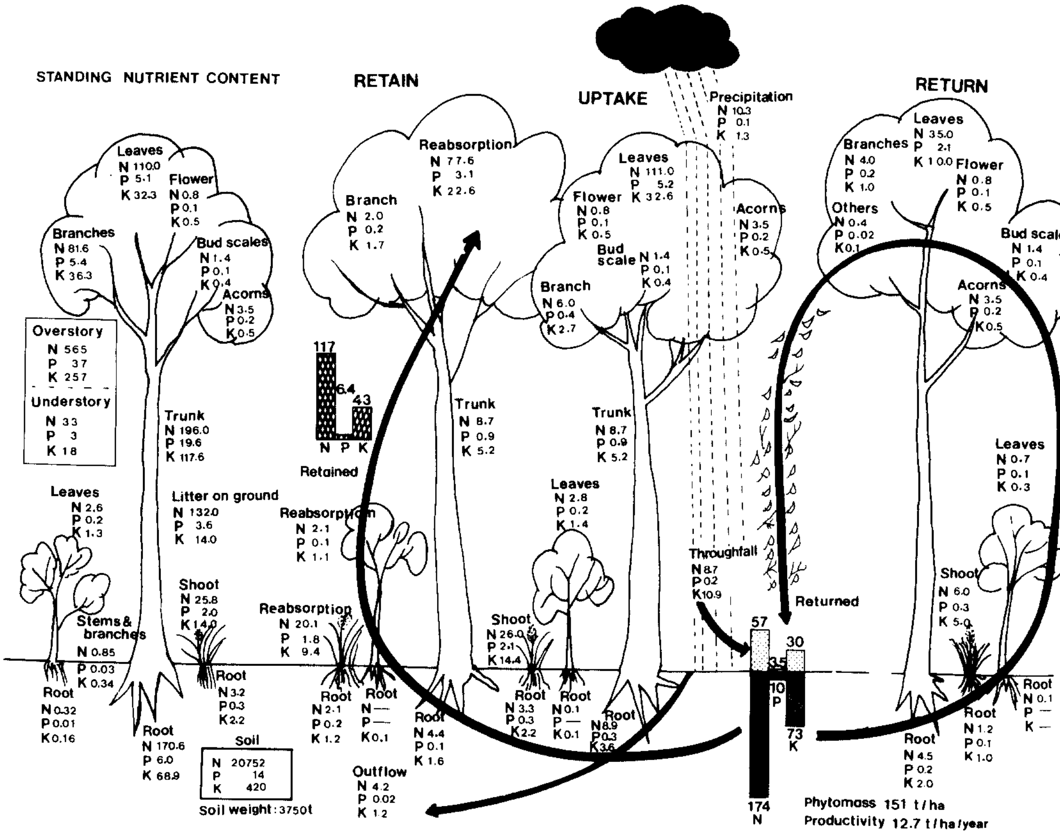

Fig. 2. Standing nutrient content and annual nutrient cyclings(kg/ha) of the nitrogen, phosphorus and potassium in *Quercus mongolica* forest.

Duvingneaud and Denaeyer-DeSmet(1970). The standing N, P and K content in this *Q. mongolica* stand roughly approximate to the lower margin of their ranges.

The standing N, P and K content of the understory correspond to approximately 95% of nutrients existing in the phytomass produced during the current growing season, which is more than that in the understory of mountain hemlock zone with 80% of nutrients absorbing annually(Yarie, 1980).

Nutrient cyclings in the mongolian oak forest

By combining data from nutrient concentrations of the precipitation, throughfall, outflow(Table 1), litterfall(Table 4) and various components of plants(Table 3), as well as the amounts of litterfall and the standing phytomass and annual productivity of *Q. mongolica* stand in Fig. 7 of the previous paper(Kwak and Kim, 1992), annual nutrient cyclings of the N, P and K are depicted as Fig. 2.

The annual precipitation inputs of the N, P and K to ecosystem were 10.3, 0.1 and 1.3 kg/ha, respectively(Fig. 2). According to Ovington(1968), inputs of the N, P and K in

Table 4. Nutrient concentrations of the different components of litter falling into a litter trap

Plant parts	N (mg /g)	P (mg /g)	K (mg /g)	Plant parts	N (mg /g)	P (mg /g)	K (mg /g)
Tree				Shrub			
Leaves	10.97	0.71	3.04	Leaffall	8.70	0.60	3.10
Branches	4.90	0.21	0.80	Dead roots	1.90	0.05	0.13
Bud scales	10.90	0.58	1.92	Herb			
Flowers	25.71	2.99	15.80	Leaffall	9.16	0.50	7.70
Acorns & cups	8.83	0.47	1.30	Dead roots	5.40	0.35	4.70
Others	3.41	0.14	0.78				
Dead root	2.90	0.10	1.30				

temperate region range 0.8~4.9, 0.2~0.6 and 1~10 kg /ha, respectively. Our results were much more about twofold for the N, but less for the P and K than those of his ranges. Addition of the N, P and K to the soil through throughfall were 8.7, 0.2 and 10.9 kg /ha, respectively. Consequently, inputs of nutrient by throughfall were less as small as 10% for the N, but more as much as 140% for the P and 740% for the K, than those by the precipitation. These trends are similar to 11 years-old *Pinus koraiensis* plantation(Cho, 1987). Annual outputs by outflow were 4.2, 0.02 and 1.2 kg /ha for the N, P and K, respectively. These values are less than those *Pinus koraiensis* plantation(Cho, 1987). This is because the *Q. mongolica* forest studied is relatively stable and tie up large quantity of nutrient from in outflow, as stated by Borman and Likens(1979).

Annual uptake from soil by the overstory, understory and whole vegetation in the *Q. mongolica* forest were 142, 32 and 174 kg/ha(82:18:100) for the N, 7.3, 2.6 and 9.9 kg /ha (74:26:100) for the P and 55, 18 and 73kg /ha(75:25:100) for the K, respectively(Fig. 2). These results are higher quantity than those of the *Q. acutissima* stand with 79, 52 and 131 kg /ha for the N, 9.5, 3.0 and 12.5 kg /ha for the P and 58, 54 and 112 kg /ha for the K (Mun *et al.*, 1977), and those of the whole vegetation of the Virelles mixed-oak forest with 92, 6.9 and 69 kg /ha of the N, P and K, respectively(Duvigneaud and Denaeyer-DeSmet, 1970).

Annual return to the stand floor from leaffall, reproductive organs, bud scales, branches, roots and whole overstory litter were 35.0, 4.3, 1.4, 4.0, 4.5 and 49.2 kg /ha (71:9:3:8:9:100) for the N, 2.1, 0.3, 0.2, 0.1, 0.2 and 2.9 kg /ha(73:10:7:3:7:100) for the P and 10.0, 1.0, 0.4, 1.0, 2.0 and 14.4 kg /ha(69:7:3:7:14:100) for the K, respectively(Fig. 2). Return in the understory were 8.0, 0.5 and 6.3 kg /ha for the N, P and K, respectively(Fig. 2). Additions of the P and K to soil through throughfall, moreover, took place as much as of 0.14 and 9.6 kg /ha. Total return of the N, P and K to soil, therefore, were estimated as 57.2, 3.5 and 30.3 kg /ha · yr^{-1}(Table 5). These values were less than those of 80 years-old the post oak-blackjack oak forest with 86, 9.5 and 62 kg /ha of the N, P and K(Johnson and Risser, 1974) and those of the Virelles mixed-oak forest with 62, 4.7 and 53

Table 5. Productivity, uptake, return, and retain of the N, P and K in *Quercus mongolica* forest, 1985

	Productivity (kg/ha·yr⁻¹)	Uptake (kg/ha·yr⁻¹)			Return (kg/ha·yr⁻¹)			Retain (kg/ha·yr⁻¹)		
		N	P	K	N	P	K	N	P	K
Overstory										
Reproductive organs	429	4.3	0.3	1.0	4.3	0.3	1.0	–	–	–
Leaves	3,701	111.0	5.3	42.2	35.0	2.1	10.0	–	–	–
Branches	1,324	6.0	0.4	2.7	4.0	0.2	1.0	2.0	0.2	1.7
Bud scales	129	1.4	0.1	0.4	1.4	0.1	0.4	–	–	–
Trunks	4,331	8.7	0.9	5.2				8.7	0.1	1.6
Roots	1,556	8.9	0.3	3.6	4.5	0.2	2.0	4.4	0.1	1.6
Reabsorption		–	–	–				77.6	3.1	22.6
Subtotal	11,470	140.3	7.3	55.1	49.2	2.9	14.4	92.7	4.3	31.1
Understory										
Shruds aboveground	122	2.8	0.2	1.4	0.7	0.1	0.3	–	–	–
belowground	30	0.1	–	0.1	0.1	–	0.0	–	–	0.1
Herbs aboveground	870	26.1	2.1	14.4	6.0	0.3	5.0	–	–	–
belowground	218	3.3	0.3	2.2	1.2	0.1	1.0	2.1	0.2	1.2
Reabsorption		–	–	–	–	–	–	22.2	1.9	10.5
Subtotal	1,240	32.3	2.6	18.1	8.0	0.5	6.3	24.3	2.1	11.8
Precipitation		1.6	–	–	–	0.1	9.6	–	–	–
Total	12,710	174.2	9.9	73.2	57.2	3.5	30.3	117.0	6.4	42.9

kg/ha of the N, P and K, respectively(Duvigneaud and Denaeyer-DeSmet, 1970).

Recycling coefficient, ratio of return to uptake(Larcher, 1980), was 0.33, 0.35 and 0.41 for N, P and K in the *Q. mongolica* forest, which were lesser than that in a mature spruce forest in west Germany with 0.93 of the K, 0.70 of the N and P(Larcher, 1980) and that of the Virelles mixed-oak forest with 0.67, 0.68 and 0.77 of the N, P and K, respectively (Duvigneaud and Denaeyer-DeSmet, 1970). Adding nutrients to soil from decompositions of litter lying on the ground will estimate as much as 45, 1.2 and 5.2 kg/ha · yr^{-1} for the N, P and K, if annual decomposition of root litter postulates to be equal to annual production.

Annual retain (△B+△RA), the amount of nutrients incorporated in phytomass increment (△B) plus reabsorption (△RA) to woody organs from leaves before shedding, were 92.7, 4.3 and 31.1kg/ha for the N, P and K in the overstory, 24.3, 2.1 and 11.8kg/ha in the understory and 117.0, 6.4 and 42.9kg/ha in the whole vegetation, respectively. These results were higer than those in an 80 year-old deciduous forest in Great Britain with 72.7, 3.3 and 54.1kg/ha of the N, P and K(Cole and Rapp, 1980) and those in the post oak-blackjack oak forest with 17.0, 1.5 and 19.2kg/ha of the N, P and K, respectively(Johnson and Risser, 1974).

Comparing the concentrations of nutrients in the mature leaves of *Q. mongolica* with those of other *Quercus* species, the *Q. mongolica* had the highest in the N but medium in the P and K (Table 6). Reabsorption efficiency, ratio of the amount of nutrient reabsorbed into woody organs to that in the mature leaves before shedding, was 71% (or 99.8kg/ha in the amount), 69% (or 5.1kg/ha) and 57% (33.1kg/ha) for the N, P and K, respectively (Table 6). Such high values in the nutrient concentration in the mature leaves and reabsorption efficiency imply to be made much nutrient retain within the plant itself but less return through litterfall (Ryan and Borman, 1982).

Table 6. Comparisons of the nutrient concentrations in mature leaves and reabsortion efficiency among *Quercus* species

Species	Nutrient in mature leaves (% of phytomass)			Reabsorption* efficiency(%)			Site	Reference
	N	P	K	N	P	K		
Q. mongolica	2.1	0.09	0.66	71	69	57	Korea	
Q. alba	1.0	0.09	0.69	49	72	53	New York	Woodwell (1974)
Q. coccinea	1.1	0.06	0.62	57	76	62	"	"
Q. rubra	1.8	1.08	1.00	39	23	24	Tennessee	Grizzard *et al*(1976)
Q. prinus	1.9	0.08	1.03	58	68	30	"	"

* Reabsorption/nutrient in mature leaves

From these results a conclusion is conducted that in the *Q. mongolica* forest the nutrient cyclings be efficiently made with which the large amount of nutrients is absorbed through roots during growing season(UPTAKE) and reabsorbed from the leaves before shedding(RETAIN) but small amount of nutrients is returned through litterfall(RETURN).

적 요

신갈나무 숲의 영양원소 순환을 밝히기 위하여 강원도 평창군 남병산에서 강수량, 수관 통과수, 유출수, 토양, 식물체 각 기관 및 낙엽량의 질소, 인 및 칼륨 함량을 측정하였다. 연강수량에 의한 유입, 수관 통과수 및 유출수 중의 질소는 각각 10.3, 8.6 및 4.2, 인은 0.11, 0.24 및 0.02 그리고 칼륨은 1.3, 10.9 및 1.2 kg/ha이었다. 잎의 질소, 인 및 칼륨의 농도는 생육초기에 많았지만 시간의 지남에 따라 감소하여 낙엽기에 급격히 감소하였다.

단위 면적당 교목층의 질소, 인 및 칼륨함량은 각각 565, 37 및 257, 임상식물의 그것은 각각 33, 3 및 18kg/ha이었다. 고사목을 포함 누적 낙엽량의 그것은 각각 132, 3.6 및 14kg/ha, 토

양의 그것은 각각 20,752, 14 및 420kg/ha이었다. 연흡수량, 연회수량 및 연축적량은 질소가 각각 174.2, 57.2 및 117.2kg/ha, 인이 9.9, 3.5 및 6.4kg/ha 그리고 칼륨이 각각 73.2, 30.3 및 9kg/ha 이었다. 낙엽시기를 통하여 잎으로부터 목재부로의 재흡수비는 질소, 인 및 칼륨에서 각각 71%, 69% 및 57%이었다. 재순환계수, 즉 회수량/흡수량의 비는 질소, 인 및 칼륨에서 각각 0.33, 0.35 및 0.41이었다.

본 신갈나무 숲은 영양원소의 많은 흡수와 재흡수에 의한 축적량으로 효율적인 영양원소 순환이 일어났지만 낙엽에 의한 회수는 적었다.

REFERENCE

Aerts, R. and F. Berendse. 1989. Aboveground nutrient turnover and net primary production of an evergreen and a deciduous species in a heathland ecosystem. J. of Ecology 77:343-356.

Alcock, M. R. and A. J. Morton. 1985. Nutrient content of throughfall and stem-flow in woodland recently established on heathland. J. of Ecol. 73:625-632.

APHA, 1981. Standard methods for examination of water and wastewater. New York. 1134 pp.

Bormann, F. H. and G. E. Likens. 1967. Nutrient cycling. Science 155: 422-429.

Bormann, F. H. and G. E. Likens. 1979. Pattern and process in a forested ecosystem. Springer-Verlag, New York, 253 pp.

Chapin, F. S., III and R. A. Kedrowski. 1983. Seasonal changes in nitrogen and phosphorus fractions and autumn retranslocation in evergreen and deciduous Taiga trees. Ecology 64(2):376-391.

Cho, K. H. 1987. Dynamics of nutrients in young Korean white pine(*Pinus koraiensis*) plantations along different age. Seoul Nat'l. Univ. MS thesis. 60 pp.

Cho, K. H and J. H. Kim. 1989. A comparison of nitrogen cycling in young *Pinus koraiensis* plantations of different ages. Korean J. Ecology 12: 245-256.

Cole, D. W. and M. Rapp. 1980. Elemental cycling in forest ecosystems. In Dynamic principles of forest ecosystems, D. E. Reichle(ed.) Cambridge Univ. Press, London. pp. 341-409.

Duvigneaud, P. and S. Denaeyer-DeSmet. 1970. Biological cycling of minerals in temperate deciduous forests. In Analysis of temperate forest ecosystem, D. Reichle(ed.). pp. 199-255. Springer-Verlag, New York.

Grizzard, T., G. S. Henderson, E. E. L. Clebsch and D. E. Reichle. 1976. Seasonal nutrient dynamics of foliage and litterfall on Walker Branch watershed, a deciduous forest ecosystem. Publication 814, Oak Ridge National Laboratory, Environmental Sciences Division, Oak Ridge, Tennessee, USA.

Jackson, M. L. 1967. Soil chemical analysis. Pretice-Hall. 497 pp.

Johnson, F. L. and P. G. Risser. 1974. Biomass, annual net primary production and dynamics of six mineral elements in a post oak-blackjack oak forest. Ecology 55:1246-1258.

Larcher, W. 1980. Physiological plant ecology. Springer-Verlag, New York. 303 pp.

Luxmore, R. J., T. Gizzard and R. H. Strand. 1981. Nutrient translocation in the outer canopy and understory of an eastern deciduous forest. For. Sci. 27:505-518.

Kim, J. H. and H. T. Mun. 1982. Ecological studies on the montane grassland of Mt. Soback in Korea. II. Production and nutrient cyclings. Korean J. Ecol. 5:204-210.

Kwak, Y. S. and J. H. Kim. 1992. Secular changes of density, litterfall, phytomass and primary productivity in mongolian oak(*Quercus mongolica*) forest. Korean J. Ecol. 15(1) 19~33.

Mun, H. T., C. M. Kim and J. H. Kim. 1977. Distributions and cyclings of nitrogen, phosphorus and potassium in Korean alder and oak stands. Korean J. Botany 20:109-118.

Ovington, J. D. 1968. Some factors affecting nutrient distribution within ecosystems. UNESCO, Natural Resources Research 5:95-105.

Papp, B. L. 1985. Nutrient content of woody plants. In Ecology of an oak forest in Hungary. Jakucs(ed.). pp. 321-348. Akademiai Kiado, Budapest.

Ryan, D. F. and F. H. Borman. 1982. Nutrient reabsortion in northern hardwood forest. BioScience 32:29-32.

Schlesinger, W. H., E. H. Delucia and W. D. Billings. 1989. Nutrient-use efficiency of woody plants on contrasting soils in the western great basin, Nevada. Ecology 70(1): 105-113.

Strickland, J. D. H. and T. R. Parsons. 1972. A practical handbook of seawater analysis. Bull. Fish. Res. Bd. Canada, 310 pp.

Thornthwaite, C. W. and J. R. Mather. 1957. Instructions and tables for computing potential evapotranspiration and water balance. Drexel institute of technology laboratory of climatology publication in climatology. Vol. X(3) centerton, New Jersey. pp. 185-243.

Tolsma, D. J., W. H. O. Ernst, R. A. Verweij and R. Vooljs. 1987. Seasonal variation of nutrient concentrations in a semi-arid savanna ecosystem in Botswana. J. of Ecology 75:775-770.

Vitousek, P. M. and W. A. Reiners. 1975. Ecosystem succession and nutrient retention: a hypothesis. BioScience 25:376-380.

Voigt, G. K. 1960. Alteration of the composition of rain water by trees. American Midland Naturalist 63:321-326.

Waring, R. H. and W. A. Schlesinger. 1985. Forest ecosystem. Academic Press, London. 340 pp.

Woodwell, G. M. 1974. Variation in the nutrient content of leaves of *Q. alba, Q. coccinea* and *Pinus rigida* in the Brookhaven forest from bud-break to abscission. American J. of Botany 61: 749-753.

Yarie, J. 1980. The role of understory vegetation in the nutrient cycling of forested ecosystems in the mountain hemlock biogeoclimatic zone. Ecology 61(6):1498-1514.

(*Receved* 2 *September*. 1991)