Korean J. Ecol. 12 (4) : 245~256, 1989

A Comparison of Nitrogen Cycling among Young *Pinus koraiensis* Plantations of Different Ages

Cho, Kang-Hyun and Joon-Ho Kim
Dept. of Botany, Seoul Nat'l Univ.

잣나무 幼林의 樹齡에 따른 窒素循環의 比較

趙 康 鉉·金 俊 鎬
서울大學校 自然科學大學 植物學科

ABSTRACT

Nitrogen cycling was investigated in *Pinus koraiensis* plantations with different ages, 1,2,3,6,9 and 11 years, which were reforested after clear-cutting. Annual N input by bulk precipitation was 10 $kg \cdot ha^{-1} \cdot yr^{-1}$, and output by runoff decreased as the plantation aged, especially in NO_3^--N. The standing N content of the whole vegetation increased approximately 5 times through 11 years. Understory surpassed *P. koraiensis* plants in the distribution of standing N content for the initial 9 years, but reversed thereafter. Annual N uptake of *P. koraiensis* plants increased greatly through 11 years, but that of understory increased somewhat until 9 years and decreased thereafter. The maximum N uptake of the whole vegetation was made in the 9-yr-old plantation. In the 1-yr-old one, 59% of the maximum was already absorbed by understory which mainly consisted of herbs. The recycling coefficient, ratio of annual return to uptake, of the whole vegetation decreased as the plantation aged and the value of understory was greater than that of *P. koraiensis* plants. On the contrary, the N use efficiency, ratio of the net primary production to N uptake, of the whole vegetation increased as the plantation aged and the value of understory was less than that of *P. koraiensis* plants. Consequently, it is emphasized that understory played an important role in such plantation reforested after clear-cutting for the initial 9 years.

INTRODUCTION

The cycling and availability of mineral nutrients, especially of nitrogen, function as a principal process in ecosystem and as a limiting factor for productivity (Duvigneaud and Denaeyer-DeSmet, 1973; Odum, 1971).

There has been an argument on nutrient dynamics with the successional sere: one pointed out that nutrient retaining ability increases more and more as ecosystems develop (Odum, 1969), while

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This work was supported by the 1986 research grant for the basic science from Ministry of Education.

others emphasized that less quantities of nutrient are lost in the mid-stage of succession, when net productivity reaches the highest (Vitousek and Reiners, 1975; Gorham *et al.*, 1979).

Disturbance of a forest, such as clear-cutting, changes the ecosystem processes to reduce the uptake of nutrients greatly and to accelerate evapotranspiration, decomposition and nitrification. Removing the canopy brings about runoff increase due to the reduced transpiration (Kochenderfer and Wendel, 1983), and nitrifying bacteria in soil produce large amounts of nitrate from decaying litter. Nitrate is leached through the soil profile and discharged in streamwater (Bormann and Likens, 1979). On the other hand, as forests regenerate after clear-cutting, large amounts of nutrients are absorbed by the regenerated vegetation, minimizing nutrient losses (Marks and Bormann, 1972; Vitousek, 1977; Boring *et al.*, 1981).

Forests of *Pinus koraiensis*, producing good timber and edible pine-nuts, are widespread in the central and northern part of the Korean Peninsula. Its plantations are generally reforested after the clear-cutting of the deciduous forests in Korea. In the plantation, the rapid growth and environmental changes take place during the early growth stage (Switzer and Nelson, 1972). However, there is only little information on nutrient cycling in the young plantation reforested after clear-cutting (Gholz *et al.*, 1985).

The purpose of this study is to compare distribution and cycling of nitrogen among six different aged plantations of *P. koraiensis* reforested after clear-cutting.

STUDY AREA

This study was carried out in young *Pinus koraiensis* plantations which were reforested 1,2,3,6,9 and 11 years ago, located at Susan-ri, Sudong-myon, Namyangju-gun, Kyonggi-do in the central part of the Korean Peninsula. A detailed documentation of their past record, floristic composition, density, coverage, primary production and phytomass in these plantations has been presented elsewhere(Kim *et al.*, 1988). The 1-, 2-, 6-, 9- and 11-yr-old plantations were reforested after the clear-cutting of the secondary forests of *Quercus mongolica,* while the 3-yr-old one was planted after *Pinus densiflora* forest. Prior to reforestation, only timber was removed out and litter was left on site after clear-cutting. Saplings 2 to 3 years old were planted at a density of 2,990 trees per ha.

Climatic data of the Seoul Central Meteorological Station located 35 km SW from this study area were shown in Fig. 1. Annual precipitation was 1538 mm and annual mean temperature was 11.2°C during the study period (August 1985-July 1986).

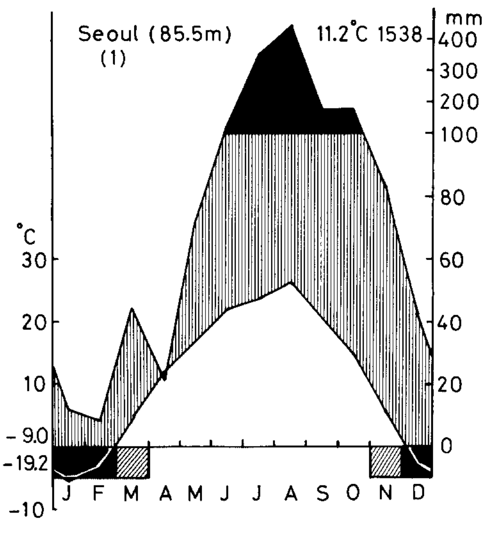


Fig. 1. Climate diagram of Seoul, 35 km SW from the study area (from Aug. 1985 to Jul. 1986).

METHODS

Sampling

Samples of soil, litter and understory were collected at an interval of 4 weeks during the growing season through August 1985-July 1986. Soil was taken from 0-10 cm depth with 5 replicates in each plantation and passed through 2 mm sieve after air-drying. Litter was sampled using five 0.5 x 0.5 m quadrats and washed with tap water. Aboveground organs of understory growing among the trunks of *Pinus koraiensis* plants were clipped within five 1 x 1 m quadrats and separated into woody, non-woody and dead parts. Underground organs were dug out, washed and screened in September 1985. Sampling for *P. koraiensis* plants was carried out in April 1986. Samples were separated into each organ. These plant materials were dried to a constant mass at 80°C and pulverized for chemical analyses.

Input of Nitrogen (N) from rainwater was monitored at the 11-yr-old plantation. Throughfall was collected in a funnel with 22 cm diameter connected to polyethylene bottle under the canopy of *P. koraiensis* plants. Sampling for bulk precipitation was made outside of the tree canopy. Runoff was collected by burying a plastic bucket with 25 cm diameter and 30 cm depth at both 1-yr-old plantation with 35° in slope and 6-yr-old one with 25° in slope. Such water was sampled 5 times, in 3 replicates, from June to August in 1986 and was immediately frozen at $-40°C$ for later chemical analyses.

Chemical analyses

Total nitrogen (T-N) of materials was determined using the micro-kjeldahl procedure (Jackson, 1967). Ammonium-nitrogen (NH_4^+-N) in water was measured colorimetrically using the phenate method (Strickland and Parsons, 1972) and nitrate-nitrogen (NO_3^--N) using the cadmium reduction method (APHA, 1981).

Estimation for nitrogen cycling

Basic data necessary to estimate N cycling, such as phytomass and net primary production in each organ and litterfall, were obtained from previous data collected in the same plantations (Kim *et al.,* 1988). The underground biomass was estimated by multiplying the highest aboveground biomass by 0.25 (Johnson and Risser, 1974).

Annual N uptake (U) by vegetation from the soil would be equal to the sum of the N retained in the biomass increment (ΔNB) and the N returned (R) from vegetation to the soil (Cole and Rapp, 1980; Gholz *et al.,* 1985; Johnson and Risser, 1974).

$$U = \Delta NB + R$$

Here R is assumed to be the sum of N in annual litterfall (L) and canopy leaching (T) by the throughfall through the canopy of *P. koraiensis* plants.

$$R = L + T$$

Canopy leaching (T) is defined as the net difference between the N amount in the throughfall and bulk precipitation. In this study, the N concentration of the throughfall from *P. koraiensis* plants was less than that of the bulk precipitation (Table 1). Therefore, T should be negligible.
So, annual N uptake is estimated as follow:

$$U = \Delta NB + L$$

Annual N input by bulk precipitation can be obtained by multiplying the amount of annual precipitation by the mean concentration of NH_4^+-N and NO_3^--N in a unit volume of bulk precipitation. Amount of N leached by throughfall from *P. koraiensis* plants is calculated as a function of the coverage of *P. koraiensis* plants in these plantations. The amount of annual runoff in the 6-, 9-, and 11-yr-old plantations was assumed to balance the difference between annual bulk precipitation and annual evapotranspiration calculated according to Thornthwaite method (1948). The amount of annual runoff in the 1-, 2- and 3-yr-old plantations was estimated to be 1.3, 1.2 and 1.1 times that amount in the older plantations (Lee *et al.,* 1967).

RESULTS

Nitrogen concentration

N concentrations per unit volume in the bulk precipitation were 0.34 $mg \cdot l^{-1}$ as NH_4^+-N, 0.33 $mg \cdot l^{-1}$ as NO_3^--N, and 0.67 $mg \cdot l^{-1}$ as total dissolved-N (Table 1), which were similar amounts in an oak stand in the central part of Korea (Kwak, 1986). NO_3^--N concentration was lower than other countries (Likens *et al.,* 1977; Gholz *et al.,* 1985). The N of throughfall was 12% lower for NH_4^+-N, 25% for NO_3^--N and 18% for total dissolved-N than that of the bulk precipitation (Table 1). These results showed that the canopy absorbed significant amounts of N from the rainwater (Kwak, 1986; Carlisle *et al.,* 1966). The N of the runoff water was 174-191% higher for NH_4^+-N, 64-124 % for NO_3^--N and 128-149 % for total dissolved-N than that of the bulk precipitation. The N of the runoff tended to decreased as the plantation aged, especially in case of NO_3^--N.

Seasonal changes of total nitrogen (T-N) concentration in mg per g dry wt. for soil, litter and non-woody and woody parts of understory are shown in Fig. 2. In the soil, T-N concentrations changed hardly with season but changed largely with plantation ages as will be described later. In the litter, T-N concentrations in all plantations were lowest in May and highest in October. Those for the non-woody parts of understory were highest in May, decreased sharply until July and remained constant through August to November. Those for the woody parts, however, showed a tendency to be lowest in July and to be highest in November.

Table 1. Nitrogen concentrations of bulk precipitation, throughfall through the canopy of *Pinus koraiensis* plants and runoff

Water sample	Nitrogen concentration ($mg \cdot l^{-1}$)		
	NH_4^+-N	NO_3^--N	Dissolved-N
Bulk Precipitation	0.34 (0.29-0.44)	0.33 (0.23-0.50)	0.67
Throughfall	0.30 (0.13-0.62)	0.25 (0.14-0.40)	0.55
Runoff			
1-yr-old plantation	0.59 (0.43-0.84)	0.41 (0.25-0.57)	1.00
6-yr-old plantation	0.65 (0.49-0.89)	0.21 (0.16-0.29)	0.86

*Values in parenthesis indicate the range of measures.

Annual mean values of T-N of the soil were 2.5, 4.5, 1.7, 3.6, 3.7, and 3.5 $mg \cdot g^{-1}$ (1.0: 1.8: 0.7: 1.4: 1.5: 1.4) in the 1-, 2-, 3-, 6-, 9- and 11-yr-old plantations, respectively (Fig. 3). These results indicated that the T-N of soil in 1-to 3-yr-old plantation varied greatly, but in 6-to 11-yr-old ones kept constant as shown in a significance at 0.05 level in terms of Tukey's studentized range test (Helwig and Council, 1979). Such differences of T-N in the soil among the younger plantations might be due to the original attributes of soil before reforesting and due to the differences of the topography. In the understory, T-N of non-woody parts was a large as 18-20 $mg \cdot g^{-1}$ in all plantations. The T-N of woody parts, however, was about one third that of non-woody parts.

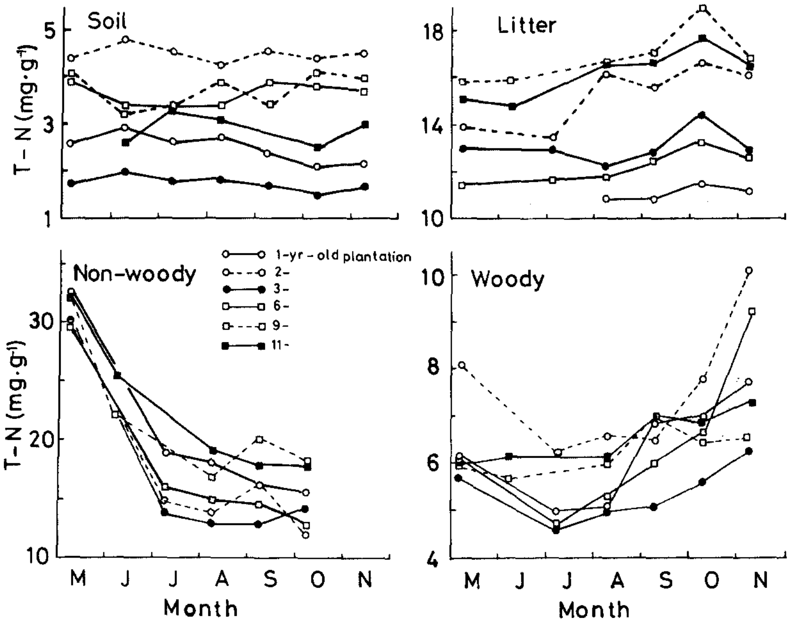


Fig. 2. Seasonal changes of total nitrogen concentrations in mg per g dry weight of soil, litter and non-woody and woody parts of understory in *Pinus koraiensis* plantations with different ages.

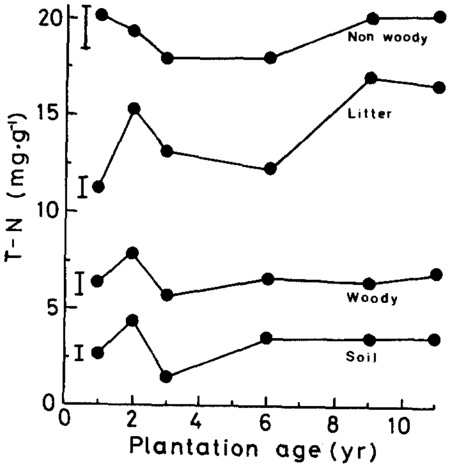


Fig. 3. Annual means of total nitrogen concentrations mg per g dry weight of soil, litter and non-woody and woody parts of understory in *Pinus koraiensis* plantations with different ages. Vertical bars indicate minimum significant difference (significant level = 0.05).

Moreover, T-N of the older plantations was lower than that of the younger ones.

In *Pinus koraiensis* plants, T-N concentrations decreased within the range of 4.9 to 1.4 mg·g^{-1} for stems and 8.5 to 3.7 mg·g^{-1} for branches as the plantation aged (Table 2). This trend was also observed for roots. Such decreasing tendency with ages might be due to the lower ratio of living to dead tissue. The T-N of leaves remained fairly constant in all plantations.

Standing nitrogen content

Standing N content in kg per ha in the soil, litter, both herbs and shrubs of understory and *P. koraiensis* plants is presented in Fig. 4. The standing N content of the soil within 0-10 cm depth in the 1-, 2-, 3-, 6-, 9-, and 11-yr-old plantations was 6480, 6450, 4030, 7770, 7260 and

Table 2. Total nitrogen concentrations in the organs of *Pinus koraiensis* plants with different plantation ages (mean ± S.E.)

Plantation age (yr)	Total nitrogen concentration (mg·g^{-1})			
	Stems	Branches	Leaves	Roots
1	4.8±0.91	8.5±1.18	12.1±1.69	—
2	4.9±0.46	7.5±0.53	15.6±2.19	—
3	3.1±0.27	4.4±0.31	15.3±2.76	7.8
6	2.7±0.41	4.4±0.27	12.7±1.25	—
9	1.9±0.51	4.0±1.10	11.7±0.17	—
11	1.4±0.15	3.7±0.07	12.8±0.50	3.5

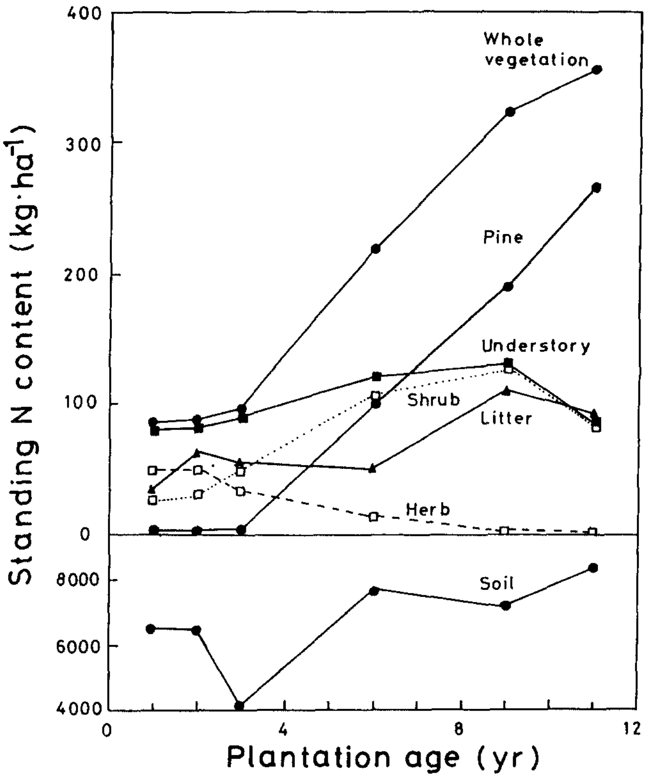
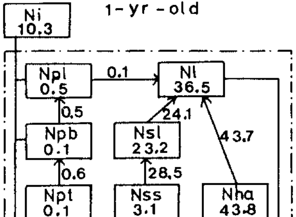
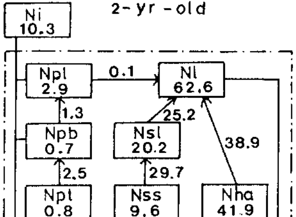


Fig. 4. Standing content of nitrogen in soil, litter and plants per unit area in *Pinus koraiensis* plantations with different ages. Understory includes shrubs and herbs.

8540 kg·ha^{-1}(1.0:1.0:0.6:1.2:1.1:1.3), respectively. These results showed an increasing tendency after reforesting, except for the 3-yr-old plantation. The standing N content of the litter also increased from 37 kg·ha^{-1} in 1-yr-old to 110 kg·ha^{-1} in 11-yr-old plantations. The standing N content of understory continuously increased from 79 kg·ha^{-1} in 1-yr-old to 133 kg·ha^{-1} in 9-yr-old plantation, thereafter decreased to 89 kg·ha^{-1} in the 11-yr-old plantation. Besides, ratios of the standing N content of herbs to that of understory were 0.61, 0.56, 0.41, 0.11, 0.02 and 0.02 in


1-yr-old


2-yr-old

the 1-, 2-, 3-, 6-, 9- and 11-yr-old plantations, respectively. The standing N content of *P. koraiensis* plants increased abruptly 6 years later and amounted to 270 kg·ha^{-1} 11 years later. The standing N content in the whole vegetation increased 4.5 times from 79 kg·ha^{-1} in 1-yr-old to 356 kg·ha^{-1} in 11-yr-old plantation. Although the standing N content of the 11-yr-old plantation was similar to the 10-yr-old *P. caribaea* (Kadeba and Aduayi, 1986) and the 25-yr-old *P. koraiensis* stand (Shin, 1985), this was more than the 14-yr-old slash pine (Gholz *et al.*, 1985) and the 10-yr-old loblolly pine plantation (Switzer and Nelson, 1972). The proportion of the standing N content in the whole vegetation allocated to understory was 0.99, 0.94, 0.95, 0.53, 0.41 and 0.25 in the 1-, 2- 3-, 6-, 9- and 11-yr-old plantations, respectively. Such decreasing trend was due to the reduced productin of understory under the interfering canopy of *P. koraiensis* plants as the age increased.

Nitrogen cycling

Annual N input into the *P. koraiensis* plantation by bulk precipitation was 10 kg·ha^{-1} ·yr^{-1} in the study area (Fig. 5). Annual addition of N to the soil by throughfall was 8.4 kg·ha^{-1} ·yr^{-1} in the case of the 11-yr-old plantation, and this corresponded to 82% of the bulk precipitation. N addition to the soil by throughfall tended to decrease gradually as the plantation aged because of the expanding coverage of *P. koraiensis* plants which absorbed significant amounts of N from the rainwater. Annual N output from soil by runoff was 10 and 7 kg·ha^{-1} ·yr^{-1} in the 1- and 6-yr-old plantations, respectively.

Annual N uptake (*U*) of the whole vegetation from the soil increased slightly for the initial 3 years, increased rapidly, thereafter reached the maximum of 159 kg·ha^{-1} ·yr^{-1} in 9-yr-old plan-

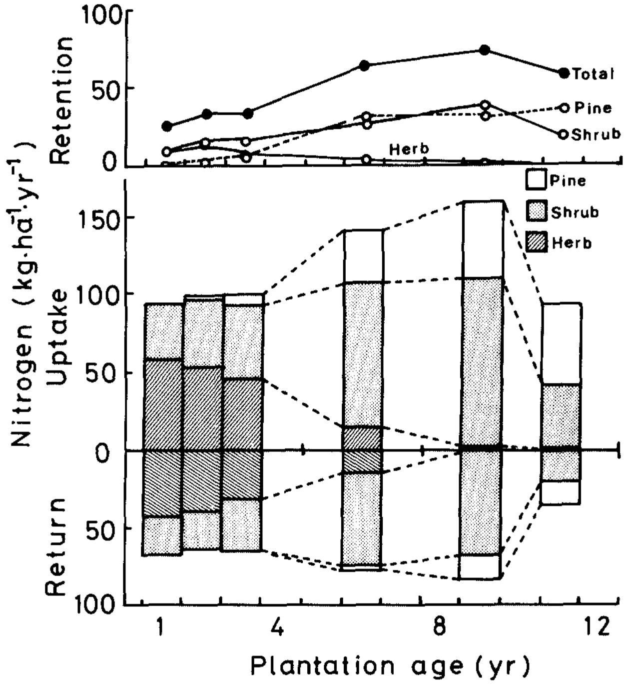


Fig. 6. Annual retention, uptake and retun of nitrogen in *Pinus koraiensis* plantations with different ages.

Table 3. Recycling coefficient of nitrogen of *Pinus koraiensis* plants, understory and the whole vegetation with different plantation ages

Plantation age (yr)	Recycling coefficient		
	P. koraiensis	Understory	Whole vegetation
1	0.13	0.73	0.72
2	0.03	0.67	0.65
3	0.04	0.71	0.66
6	0.05	0.70	0.54
9	0.32	0.62	0.53
11	0.28	0.48	0.37

Table 4. Nitrogen use efficiency of *Pinus koraiensis* plants, understory and the whole vegetation with different plantation ages

Plantation age (yr)	Nitrogen use efficiency		
	P. koraiensis	Understory	Whole vegetation
1	111	64	64
2	169	68	69
3	144	74	63
6	160	66	89
9	184	60	98
11	214	85	157

tation and then decreased to 94 kg·ha^{-1}·yr^{-1} in the 11-yr-old one (Fig. 6). The annual N uptake by *P. koraiensis* plants increased dramatically as the age increased from the 1-yr-old plantation with 1 kg·ha^{-1}·yr^{-1} to the 11-yr-old one with 52 kg·ha^{-1}·yr^{-1}. Those of understory, however, increased scarcely to 110 kg·ha^{-1}·yr^{-1} in the 1-to 9-yr-old plantation, decreased abruptly into 42 kg·ha^{-1}·yr^{-1} thereafter. The ratio of N uptake of understory to that of the whole vegetation, and the ratio of N uptake of herbs to that of understory, both decreased as the plantation aged; *i.e.* the former was 0.99, 0.97, 0.93, 0.76, 0.69 and 0.45 and the latter 0.62, 0.56, 0.48, 0.13, 0.02 and 0.04 in the 1-, 2-, 3-, 6-, 9- and 11-yr-old plantations, resectively.

Annual N return (*R*) to the plantation floor by litterfall showed no significant change with 64-68 kg·ha^{-1}·yr^{-1} for the initial 3 years, but increased to the maximum 84 kg·ha^{-1}·yr^{-1} in the 9-yr-old plantation, and then decreased markedly (Fig. 6). Annual return by *P. koraiensis* plants tended to increase conspicuously, but those of understory didn't. The ratio of the annual return of understory to the whole vegetation was the same for the initial 3 years, but decreased fairly 6 years later.

Recycling coefficients, ratio of annual return (*R*) to annual uptake (*U*) (Larcher, 1980), of understory ranged from 0.5 to 0.7 and these values were greater than those of *P. koraiensis* plants (Table 3). It means that most of the annual N uptake by understory was returned to the plantation floor as litterfall (Fig. 6). The recycling coefficient of the whole vegetation decreased gradually as the plantation aged, though that of *P. koraiensis* plants increased.

The annual retention (ΔNB) of N in the biomass increment of the whole vegetation increased to 95 kg·ha^{-1}·yr^{-1} from the 1- to 9-yr-old plantations and decreased thereafter. Retention in *P. koraiensis* plants and shrubs showed a similar trend, but retention in herbs decreased abruptly as the plantation aged.

Nitrogen use efficiency

N use efficiency, ratio of net primary production to annual N uptake (*U*) (Chapin, 1980; Gholz *et al.*, 1985; Waring and Schlesinger, 1985), of *P. koraiensis* plants was higher than that of understory in all plantations (Table 4). N use efficiency of the whole vegetation tended to increase as the plantation aged, *i.e.* the 11-yr-old planatation was 2.5 times higher than the 1-yr-old one.

DISCUSSION

Foregoing data confirmed that annual N input by bulk precipitation was 10 $kg \cdot ha^{-1} \cdot yr^{-1}$ in the *Pinus koraiensis* plantations as well as in an oak forest in Kangweon-do, Korea (Kwak, 1986). Annual N output from soil by runoff was 10 and 7 $kg \cdot ha^{-1} \cdot yr^{-1}$, and N accumulation was estimated to be 0.5 and 3.4 $kg \cdot ha^{-1} \cdot yr^{-1}$ in the 1- and 6-yr-old plantations, respectively (Fig. 5), in spite of excluding the amounts of N fixation and denitrification. Annual N output by runnoff tended to decrease as the plantation aged: the 6-yr-old plantation was 14% less than the 1-yr-old one, especially 50% less for NO_3^--N (Fig. 5). In the young plantations, where large amounts of organic residues remained and the floor vegetation thrived, loss of NO_3^--N was considerably smaller, because the large amount of N was absorbed by plants regrowing luxuriantly and immobilization of N was increased by bacterial activity (Vitousek and Matson, 1985).

Standing N content of the whole vegetation in the *P. koraiensis* plantations, 79-356 $kg \cdot ha^{-1}$ (Fig. 4) was less than the average amount of various older coniferous forests (Waring and Schlesinger, 1985). The ratio of the standing N content of understory to the whole vegetation suggested that for the initial 9 years understory surpassed *P. koraiensis* plants but thereafter stunted. Furthermore, for the initial 6 years after clear-cutting, the herbs of understory played an important role in the distribution of standing N content.

Maximum uptake of N was made in the 9-yr-old plantation (Fig. 6). About sixty percent of the maximum uptake was already absorbed, especially 99 % by the understory, until the first year after clear-cutting. The uptake by understory rapidly declined by 9 years though the uptake by *P. koraiensis* plants continuously increased until 11 year. Here, we have to emphasize an importance of understory in the young stage of plantation. The rapid recovery of N uptake after clear-cutting in the our plantations was attributable to abundance of herbs and shrubs in young plantation (Marks and Bormann, 1972; Likens *et al.*, 1978; Boring *et al.*, 1981). In the 1- and 2-yr-old plantations, vegetation was rapidly recovered by herbs such as *Lysimachia clethroides, Spodiopogon sibiricus* and *Smilax nipponica,* which were replaced by shrubs such as *Weigela subsessilis, Stephanandra incisa* and *Rubus parvifolius* in the older plantations. Since such understory had particularly rapid growth and N-rich tissues of non-woody parts (Fig. 3), they conserved the substantial N pool in their biomass and initiated a rapid recovery of N cycling processes (Boring *et al.*, 1981). After all, the decrease of N loss by runoff as the plantation aged might be due to rapid N uptake by understory.

Annual return of N by understory approximated to total return of the whole vegetation from the 1- to 6-yr-old plantations and corresponded to about 60 % even in the 11-yr-old plantation (Fig. 6), because understory had a relatively high recycling coefficient (Table 3). Since understory had a large amount of return as well as uptake, they could affluently provide the retained N to *P. koraiensis* plants. In the case of the 11-yr-old plantation, the standing N content of understory was no more than 25 % of the whole vegetation, but uptake and return by understory were as large as 45 % and 59 % of those of the whole vegetation. These results suggest that understory contributes greatly in N cycling in spite of small amounts of its biomass (Tappeiner and Alm, 1975; Yarie, 1980).

The low N use efficiency of the younger plantations (Table 4) might be due to the large of N return to soil by understory (Fig. 6). N use efficiency, however, increased in the older plantations as *P. koraiensis* plants grew rapidly (Table 4). N use efficiency could be increased substantially by adaptation to minimize N loss and to increase the internal reuse of N (Waring and

Schlesinger, 1985). From these results, it can be concluded that our plantations became more efficient in N use as they aged.

摘要

既存의 森林을 伐木한 후 造林한 1, 2, 3, 6, 9 및 11년생 잣나무 造林地에서 窒素循環을 밝히기 위하여 빗물, 樹冠通過水 및 地表流出水, 토양, 식물체 및 낙엽 중의 窒素量을 측정하여 강수에 의한 流入量, 지표수에 의한 流出量 및 토양과 식물체 사이의 循環量을 추정하였다. 빗물에 의한 窒素의 流入量은 10 kg・ha^{-1}・$년^{-1}$이고, 지표수에 의한 流出量은 造林年齡이 낮을수록 많았는데, 특히 NO_3^--N 의 流出이 많았다. 단위면적당 全植生의 질소량은 조림 후 11년간 5배로 증가하였다. 林床植物의 질소량은 조림 후 9년까지 잣나무보다 많았으나 그 이후 적었는데, 특히 조림 직후 草本의 질소량이 많았다. 잣나무의 年窒素吸收量은 11년간 계속 증가하였지만, 林床植物의 것은 9년까지 큰 변동이 없고 그 이후에 급격히 감소하였다. 즉 全植生의 年窒素吸收量은 9년에 최대량에 달하였는데 그 중의 50% 만큼을 이미 1년 造林地에서 흡수하고 그 대부분을 林床植物, 특히 草本이 흡수하였다. 1-3년 造林地에서 落葉에 의한 年窒素回收量은 林床植物이 100%를 차지하였다. 全植生의 窒素循環常數, 즉 年回收量/年吸收量의 比는 造林年齡이 높아짐에 따라 감소하였으며, 林床植物이 잣나무보다 컸다. 이와 대조적으로 全植生의 窒素利用效率, 즉 年純生產量/年窒素吸收量의 比는 造林年齡이 높아짐에 따라 증가하였으며, 林床植物이 잣나무보다 작았다. 이상의 결과는 伐木 후의 잣나무 造林地가 9년 까지 林床植物 특히 草本이 繁茂하여 많은 窒素를 흡수하고 보유하므로 窒素利用效率이 높아져서 正常循環으로의 회복이 촉진됨을 나타내었다.

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(Received 28 September 1989)