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Total Nitrogen Distribution and Seasonal Changes in Inorganic Nitrogen at a *Pinus koraiensis* Stand in Kwangju-gun, Kyŏnggi-do, Korea[1]

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京畿道 廣州地方의 잣나무林分에 있어서 全窒素의 分布와 無機態 窒素의 季節的 變化[1]

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ABSTRACT

This study was conducted (1) to measure the nitrogen content of various parts of trees in a 24-year-old *Pinus koraiensis* plantation, providing a harvest method with the least impact on the self-serving mechanisms in the nitrogen status of the ecosystem and (2) to examine the seasonal changes in inorganic nitrogen (ammonium salt and nitrate, separately) at various soil depths and to study the self-serving mechanisms for nitrogen at the ecosystem, providing an appropriate method and season for the application of nitrogen fertilizers. The results obtained in this study were as follows; 1) Of the total nitrogen content of the total tree biomass (except for roots), nearly 61.5% was distributed in the needles, 20% in the branches, 5.5% in the stem bark, and 13% in the stem wood. Therefore, the harvest method of removing only wood parts for pulpwood production has little impact on the self-serving mechanisms of the site's nitrogen status. 2) Inorganic nitrogen concentrations decreased with increasing soil depths. The seasonal average concentration of inorganic nitrogen was highest in early spring and decreased in the following descending order; autumn, followed by mid-summer, and early summer. This pattern resulted from the fact that the loss of nitrate was greatly influenced by environmental factors. Thus, it was suggested that an application of active nitrogen fertilizer would be appropriate in spring.

Key words: Pinus koraiensis; *total nitrogen distribution; self-serving mechanisms; inorganic nitrogen; ammonium salt; nitrate nitrogen.*

要　　約

本 硏究는 京畿道 廣州郡 都尺面에 位置한 서울大學校 中部演習林의 24年生 잣나무 人工造林地를 對象으로 하여 (1) 林分內 全窒素의 分布를 調査하여 更新法에 따른 잣나무林 生態系의 自己施肥系가 받는 衝擊의 程度를 알아보며, (2) 그 林分의 土壤에서 여러 깊이에 따른 無機態 窒素의 季節別 變化樣相을 암모니아態 窒素와 窒酸態 窒素로 나누어 分析硏究 하고, 또한 잣나무林에 있어서 窒素質養料에 對한 自己施肥機構를

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研究하여 適切한 施肥時期와 方法에 대한 情報를 얻으려고 試圖하였는데 다음과 같은 結論을 얻을 수 있었다. 1) 뿌리를 除外한 現存量에 包含된 全窒素中 61.5%는 針葉中에, 20%는 가지에, 5.5%는 樹皮에, 13%는 樹幹의 木質部에 分布한다. 따라서 樹幹의 木質部만 收穫하는 것이 生態系의 自己施肥系에 衝擊을 가장 적게 준다고 볼 수 있다. 2) 土壤中의 無機態窒素의 含量은 土壤이 깊게 들어갈수록 變化가 약해졌으며 그 含量을 季節別로 보면 봄, 가을, 한여름, 초여름 順으로 減少하였다. 이러한 樣相은 窒酸態窒素의 損失이 環境因子에 크게 左右되기 때문에 일어나며, 이러한 結果에 따라 速效性 窒素肥料를 봄에 施肥하는 것이 가장 適合하다고 結論을 내릴 수 있었다.

INTRODUCTION

Nitrogen is one of the most important limiting nutrients in ecosystem production.[10,21] Forest ecosystems are emphasized because their mineral cycles are usually more closed than those found outside the forest.[22,47] Therefore, in natural forest ecosystems nitrogen is being accumulated with the development of the ecosystem and a steady state is maintained.[11] However, because forest products are required more and more, complete-tree utilization is becoming prevalent. This necessitates more removal of biomass products from the forest stands and thus disturbs the "self-serving mechanisms" in the nutrient cycling of the ecosystem. Total biomass, and nitrogen content of and distribution in various parts of ecosystem (pine trees, understory vegetations, forest floor, and soil) need to be investigated to examine self-serving mechanisms of nitrogen in a *Pinus koraiensis* stand. *P. koraiensis* has been planted widely because it is native species and produces good timber as well as edible pine nuts.

Nitrogen content in a stand is abundant unless exogenous factors disturb the system. However, the turnover rate of organic nitrogen is the key to nitrogen balance in a stand. Conditions of nitrogen content in coniferous forests are especially important, since the soil under coniferous forests is usually poorer in nitrogen than that under broadleaf deciduous forests.[33] Trees utilize nitrogen in the form of nitrates, nitrites, ammonium salts, or organic nitrogen compounds such as urea. Regardless of initial form, most of the nitrogens are usually absorbed in the form of nitrates or ammonium salts.[3,22,33] Great importance is therefore attributed to the processes of ammonification and nitrification of organic nitrogen compounds in soil and plant litter.

According to today's systems ecology, soil is neither the beginning nor the end product of vegetation but is a compartment in a network of interactions among soil, flora, fauna and man with his manipulation and industry.[47] Nitrates and ammonium salts in the soil compartment become susceptibly changeable due to physical, chemical or biological conditions. Thus the objectives of this study were (1) to determine the distribution of nitrogen in various parts of a 24-year-old *P. koraiensis* plantation, (2) to examine the variation in inorganic nitrogen (nitrate and ammonium salt seperately) seasonally and by soil depths, and the relations with environmental factors in a *P. koraiensis* plantation; consequently to investigate the self-serving mechanisms for nitrogen at the ecosystem.

LITERATURE REVIEW

Distribution of Nitrogen

The distribution of nitrogen in the ecosystem has been much studied since 1930.[13]. Dengler (1930) reported annual uptake, retention and return of nitrogen by *Pinus sylvestris* and *Fagus sylvatica* forest. Thereafter many researchers have studied the distribution of nitrogen in connection with the nutrient cycling[11,15,23,27] and IBP (International Biological Program) have conducted intensive studies on the distribution of nitrogen and nutrient cycling recently.[11,14,41,45] Firsova *et al.* (1971) reported that the content of mobile forms of nitrogen decreased in the following direction of the system; ground vegetation ——→ litter and humus ——→ mineral horizon. Maclean *et al.* (1981) found that nitrogen concentrations were higher in new tissues of *Picea rubens* than in old tissues. The removing of debarked pulpwood from *Pinus taeda* plantations had little effect on the site nutritional status (Jorgensen *et al.* 1975). Kramer (1979) summarized the distribution of nitrogen in various parts of various trees.

Seasonal Changes in Inorganic Nitrogen

Since Hwang (1938) studied nitrogenous decomposition and Remezov (1941) conducted research on ammonification and nitrification in forest soils, many researchers have studied seasonal changes in inorganic nitrogen. Remezov (1941) found that in coniferous forests, a weak degree of nitrification existed, although the ammonium salt form predominated. He also reported that seasonal fluctuations of nitrification were related to changes in soil temperature and aeration. Brinson *et al.* (1981) reported that temperature was probably the single most important variable affecting rates of mineralization of organic matter where moisture and oxygen availabilities did not limit decomposition rates.

Selim et al. (1981) reported nitrate was more susceptible to leaching than ammonium salt. Stefanson (1976) reported denitrification was increased by the addition of an energy source in the form of root exudates. Westerman (1978) reported that denitrification was markedly affected by temperature and increased rapidly with increased temperature. Flowers *et al.* (1983) reported nitrification rate constants increased with increasing temperature. Nitrate in the soil to be stored at 5°C was accumulated steadily, though its rate was slow (Stout 1984). However Campbell *et al.* (1983) reported nitrate content did not increase with increasing temperature unlike ammonium and consequently nitrate was formed in a higher proportion at 10°C than at 30°C. Stone (1973) and others suggested that nitrification was suppressed in coniferous forest soils, whereas Vitousek *et al.* (1982) observed rapid and substantial increases in nitrate concentrations below the rooting zone in several coniferous forests. These contrary trends probably occurred on the ground that nitrate content was more susceptible to changes of environmental conditions than ammonium salt as mentioned by Donov *et al.* (1976).

MATERIALS AND METHODS

Study Area

The experimental plots made at the Seoul National University Forests (127° 18′ E, 37° 18′ N) were located at low elevation (150-250 m) of Mt. Taehwa in Sanglim-lee, Docheok-myeon, Kwangju-gun, Kyŏnggi-do, Korea. The area faces northeast with a slope averaging between 5 and 15 degrees. Soils were loamy in depth from 0 to 40 cm, clay loamy in depth from 50 to 80 cm and acidic (ph $<$ 5.3). Temperature averaged yearly about 10°C and mean annual precipitation showed about 130 cm in Icheon which is 12 Km away from experimental plots. The forest stand used in the study was a 24-year-old *Pinus koraiensis* plantation in which the density was 30 trees per 200 m^2.

Methods

Two sampling plots (20 m x 10 m) were set up to predict the total biomass and distribution of total nitrogen. Six trees (three trees from each plot) were harvested for biomass measurement on August 6, 1984. Then, stems were cut into segments to determine wood and bark weights, growth rates and nitrogen content. Some branches were taken to measure nitrogen content and branch weight. Needles of different ages were weighed separately. Understory vegetation, litter, humus and roots (roots greater than or less than 5 mm in diameter) were also collected for nitrogen analysis. Stem dry weight, bark dry weight, branch dry weight, and needle dry weight were regressed separately on diameter at breast height (DBH).[25] All of the other biomass products in different times were predicted with the regression equation.[25] Total nitrogen contents were analyzed with the micro-Kjeldahl method.

Four pits (80 cm x 120 cm x 80 cm: width/length/depth) were made to collect soil samples from 0 to 80 cm in depth at 20 cm intervals. Soil temperature was measured at 10 cm depth from the forest floor. Soil sampling was conducted bimonthly from April 1 to October 6. Then, nitrates, ammonium salts, and total nitrogen contents were determined with the micro-Kjeldahl method. Split plot design was used for analysis of their variance. Total nitrogen in the soil was analyzed only on August 6. Soil pH (1:1, H_2O) and soil moisture content were also measured seasonally. Soil moisture content was determined gravimetrically after drying for 72 hours at 105°C.

RESULTS AND DISCUSSION

Nitrogen Distribution

The distribution of nitrogen in various parts of a 24-year-old *Pinus koraiensis* tree harvested on August 6 in Figure 1 was similar to that of other species. In *Pseudotsuga menziesii* ranging in age from 350 to 550 years, the concentration of nitrogen was 10.7 g/kg in the current year's foliage, 10.3 in the past year's foliage, 0.56 in boles, branches and twigs, 0.90 in the roots greater than 5 mm in diameter, and 6.2 in the roots less than or equal to 5 mm in diameter (Sollins *et al.* 1980). In 30-year-old *Pinus taeda*, it was 12.2 g/kg in current foliage, 2.2 in older branches, 1.9 in stem bark, and 0.4 in stem wood (Kramer 1979).

The nitrogen concentration in the needles of *P. koraiensis* was higher than in any other parts of the tree and decreased from young to old needles. This may indicate that the distribution of the nutrients is determined by the relative activity of the plant tissues and the nutrients taken up by the roots are mostly distributed within the actively growing parts by translocation. The close association between cell proliferation and nutrient concentration was shown by the much higher content of nutrients found in the bark (including the cambium), compared with the adjacent sapwood. This supports that most productive tissues absorb the greater amounts of nutrients for accumulation. Thus photosynthetic tissues always had the highest concentration of nitrogen followed by the young roots (Figure 1). Perennial tissues showed the **lowest nitrogen**. The nitrogen content of the humus was higher than that of the litter. This result was supported by Hwang (1938) who studied on nitrogenous decomposition and acidity changes in decaying forest litter. Total nitrogen in tree except for roots distributed as follows; about 61.5% in the needles, about 20% in the branches, 5.5% in the stem bark, and 13% in the stem wood. In 16-year-old *Pinus taeda*, 32% in the needles, 23% in the branches, 31% in the stem wood, 14% in the stem bark.[21] Since the ratio of needle biomass to total above ground biomass in 18-year-old *P. koraiensis* plantation was 13.8%, while the ratio of that in 16-year-old *P. taeda* plantation abovementioned was 5.1%, the difference of nitrogen content between *P. koraiensis* and *P. taeda* was probably due to differences of biomass in various parts of the two species.

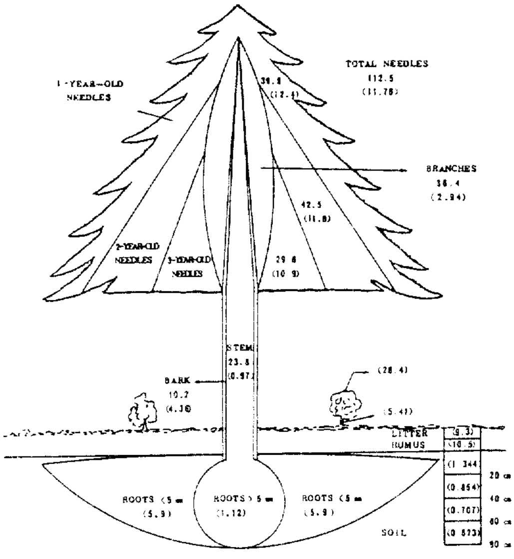

Fig. 1. Distribution of nitrogen(g) in an average tree(DBH: 13cm)
(The numbers in parenthesis indicate the concentration of nitrogen(g/kg)).

Allometric regression equations for estimating biomass of *P. koraiensis* tree are shown in Table 1. The amount of biomass and nitrogen content are shown in Table 2. Needles, stem bark, branches, and stem wood yielded 92.167 tons/ha. This portion would contain about 80% of total nitrogen in the tree biomass.[21,23] A less destructive harvest alternative which removes only the stem wood and bark, produces 53.095 tons/ha. This form of harvest takes away only about 20% as much nitrogen as total-tree harvest, but yields 58% as much biomass. Removing only debarked pulpwood from a stand takes about 30 percent less N from the site than harvesting in normal way, and it will reduce the weight yield by only 9 percent.

The effects not only of the harvest options but of rotation length on the nutrient cycling should be considered along with biomass removal. In general, the longer the rotation, the more nutrients will be removed at any one harvest options from a stand because the larger size of trees harvested. However, because maximum nutrient accumulation occurs during the early stages of stand development, the shorter the rotation the greater will be the nutrient removal on an annual basis. If only pulpwood were removed, even short rotations would have little effect on the nutritional status of sites. In this alternative the natural inputs from precipitation and biological fixation would be able to nearly balance nutrient removal from the site.

Table 1. Allometric relations between growth variables and DBH of the 24-year-old *Pinus koraiensis* trees

Growth variables	Equations	R^2
Stem D.W.	y = 2.0962x - 2.1799	0.8870
Bark D.W.	y = 2.8243x - 6.3927	0.6903
Branch D.W.	y = 1.9026x - 2.3628	0.9320
Needle D.W.	y = 1.8618x - 2.5169	0.9352
1-year-old needles	y = 1.3322x - 2.2477	0.6000
2-year-old needles	y = 2.2600x - 4.5164	0.9576
3-year-old needles	y = 1.9752x - 4.0682	0.8117

* Allometric regression formula was used as log Y = a x log X + b (Y and X indicate growth variables and DBH, respectively)

Table 2. Biomass and nitrogen content per ha in the 24-year-old *Pinus koraiensis* stand

Tree component	Dry weight(Kg)	Nitrogen(Kg)
Stem wood	48514.0	47.0586
Stem bark	4581.3	19.9745
Branch	22080.5	64.9167
Needle	16991.5	199.8200
Total	92167.3	331.7698
Understory vegetation		
Leaf	77.625	2.2046
Branch	57.575	0.3115
Gross total	92302.5	334.2859

Chemical and Physical Condition

Chemical and physical conditions were measured to examine the relations of seasonal variations in inorganic nitrogen with environmental factors in the *P. koraiensis* stand. Seasonal variation in pH by soil depths are shown in Figure 2. Acidification in the surface was greater and extended deeper during the summer season when the decomposition rate of litter was higher than during other seasons. When decomposition rate was high more CO_2 was evolved from respiration of soil organisms decomposing organic matters. Being dissolved in soil water, carbonic acid (H_2CO_3) was probably formed and then it disassociated the hydrogen (H^+) and bicarbonate (HCO_3) ions. Thus, the interaction of bicarbonate ions and leaching of bases probably

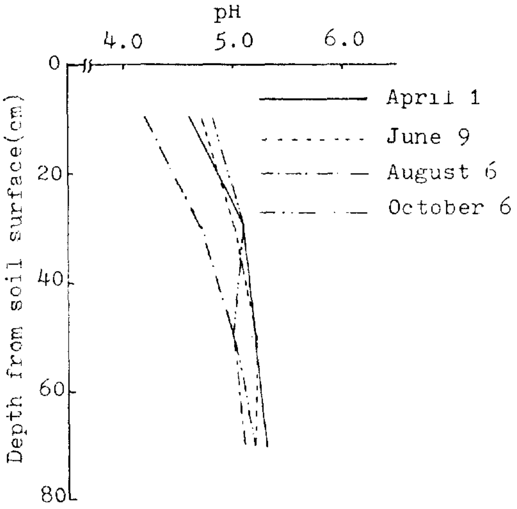

Fig. 2. Seasonal changes in pH by soil depth.

increased the surface acidification.

There was little diurnal change but much seasonal change in soil temperature, ranging from 2°C in early spring to 22°C in mid-summer(Figure 3).

Soil moisture content was the highest in early spring (April 1), among all the seasons. The lowest soil moisture content was exhibited in early summer (June 9th). The highest in early spring probably occurred due to thawing. The lowest in early summer is consistent with the fact that early summer is dry season in Korea. The rate of soil moisture content decreased with increasing soil depths (Figure 4). Soils were loamy in depth from 0 to 40cm, clay loamy in depth from 40 to 80cm.

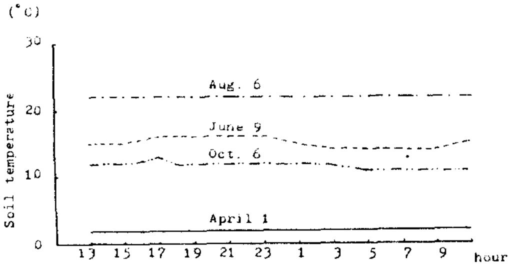

Fig. 3. Diurnal and seasonal variations in soil temperature

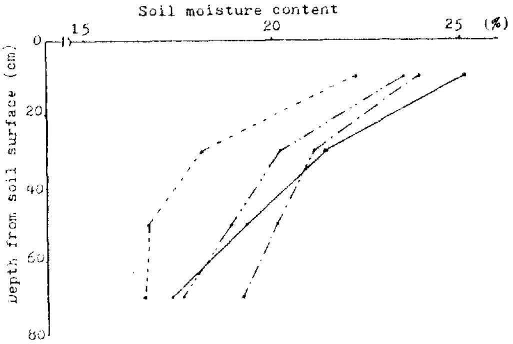

Fig. 4. Soil moisture distribution by soil depth

———— April 1　　—.— —.. Aug. 6
- - - - - - June 9　　—.. —.. — Oct. 6

Seasonal Change in Inorganic Nitrogen

OVERALL DESCRIPTION: Inorganic nitrogen, ammonium salt and nitrate contents were significantly different at various soil depths (Tables 3,4 and 5). This trend was similar to Isakandar's results.

Table 3. Analysis of variance for soil inorganic nitrogen at various depths during the growing season.

S.V.	D.F.	SS	MS	F
Blocks	3	16.686	5.562	
Depth, factor A	3	243.451	81.150	22.943**
Error (a)	9	31.834	3.537	
Month, factor B	3	42.209	10.552	2.671^{ns}
Interaction, AB	9	164.064	18.229	4.613*
Error (b)	36	142.248	3.951	
Total	63	640.492		

Total 4. Analysis of variance for soil ammonium nitrogen at various depths during the growing season.

S.V.	D.F.	SS	MS	F
Blocks	3	0.761	0.254	
Depth, factor A	3	68.786	22.929	25.718**
Error (a)	9	8.024	0.892	
Month, factor B	3	88.311	22.078	23.518**
Interaction, AB	9	27.690	3.077	3.277^{ns}
Error (b)	36	33.795	0.939	
Total	63	227.367		

Table 5. Analysis of variance for soil nitrate nitrogen at various depth during the growing season.

S.V.	D.F.	SS	MS	F
Blocks	3	3.022	1.007	
Depth, factor A	3	101.354	33.785	26.516**
Error (a)	9	11.467	1.274	
Month, factor B	3	193.270	48.317	29.432**
Interaction, AB	9	117.376	13.042	7.944*
Error (b)	36	59.099	1.642	
Total	63			

The differences in seasonal changes of ammonium salt and nitrate content were highly significant. It coincides with Blintsov's results (Blintsov *et al*, 1974 and 1976). However that of inorganic nitrogen was not significant. This explained that NO_3-N correlated with NH_4-N negatively. Significant effects of interaction between soil depth and season indicate different patterns of seasonal changes in inorganic nitrogen and nitrate contents at different depths. The similar result was presented by Clarholm *et al.* (1981) and Cole *et al.* (1981) This trend probably occurred due to different changes in inorganic nitrogen and nitrate content during early spring and autumn from other seasons (Figures 5 and 7). This indicates that nitrate concentration at the soil surface was more influenced by seasonal change of environmental factors than ammonium salts concentration, whose interaction effect between soil depth and season was not significant. Furthermore, since the overall changing pattern of inorganic nitrogen was similar to that of nitrate nitrogen(Figures 5 and 7), the fact that the effects of interaction in inorganic and nitrate nitrogen were significant (Tables 3 and 5) and the effects of interaction in NH_4-N were not significant indicates that variation of NO_3-N contributed to the changing pattern of inorganic nitrogen much more than NH_4-N.

The overall changing pattern of inorganic nitrogen content at various depths in early spring was similar to that in autumn. Likewise, its pattern in early summer was also similar to that in mid-summer (Figure 5). Great differences in inorganic nitrogen contents were found between the soil depths of 10cm and 70cm in early spring and autumn. However, little difference was shown between the two layers in early summer and mid-summer. This was probably due to similar environmental and biological factors between early summer and mid-summer, and also between early spring and autumn. Inorganic nitrogen contents decreased rapidly as the soil depth increased, which was similar to the result reported by Iskandar *et al.* (1981) who studied nitrogen transport. This was probably caused by the fact that the surface layer of soil was influenced more greatly by environment than the deep layer. Inorganic nitrogen supply largely depending on the biological decomposition of plants or animals would be highly affected by environmental condition.

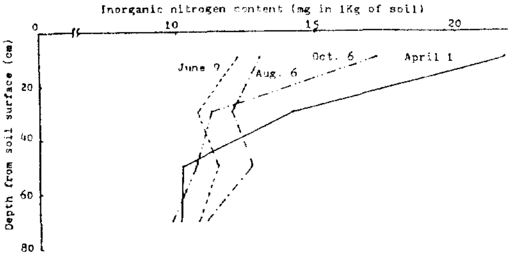

Fig. 5. Seasonal variations in inorganic nitrogen content by soil depth

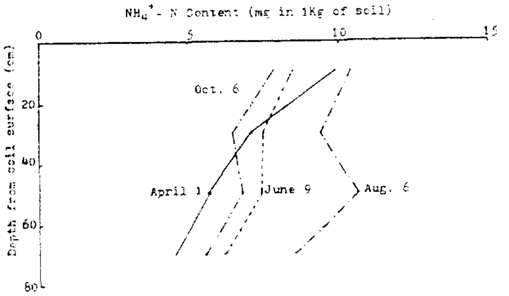

Fig. 6. Seasonal variations in NH_4-N content by soil depth

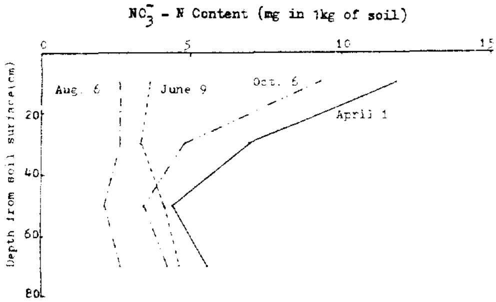

Fig. 7. Seasonal variations in NO_3-N content by soil depth

Stone(1973) and Williams(1983) have suggested that nitrification was suppressed in coniferous forest soils due to high acidity and low levels of ammonium nitrogen, while Vitousek *et al.* (1982) observed rapid and substantial increases in nitrate concentrations below the rooting zone in several coniferous forests. The results obtained from this study showed considerable amounts of NO_3-N content in early spring and autumn. In early summer and mid-summer, however, the amount of NO_3-N content was very low as compared with NH_4-N (Figure 7). This probably occurred on the ground that nitrate nitrogen content was more susceptible to changes of environmental conditions than ammonium salt as mentioned by Donov *et al* (1976).

The seasonal variation in NH_4-N content was relatively low except for the mid-summer when high soil temperature stimulates the turnover rate of organic nitrogen(Figure 6). This probably because NH_4-N was less susceptible to leaching due to the adsorption-desorption reaction on the exchange sites of the soil matrix and because volatilization of ammonia contributed much less than denitrification to the gaseous loss of nitrogen from natural forests (West *et al.* 1978).

MID-SUMMER: The amount of inorganic nitrogen in surface soil was equivalent to 21.8, 12.2, 13.0 and 17.2 mg/kg soil in early spring, early summer, mid-summer and autumn respectively (Figure 5). The mineralization-immobilization process is known to be associated closely with the activity of the decomposers. Rapid decomposition rates should occur when aerobic conditions is under some optimum regime of wetting and drying, but temperature is probably the single most important variable affecting rates of organic matter loss where moisture and oxygen availabilities do not limit decomposition rates.6) In most temperate forests where moisture and oxygen conditions are mostly adequate for microbial activity as shown in Figure 4, variations in mineral turnover rates are primarily governed by temperature.6,17,47) Therefore, higher temperature resulted in increased amounts of inorganic nitrogen.10,40) However, the amount of inorganic nitrogen in midsummer at highest soil temperature among the seasons was third in rank. In early spring, on the contrary, it was the highest. During the summer, the turnover rate of organic matter increased, while nitrification, denitrification, leaching of nitrogen, nitrogen uptake by plants, microbial absorption were accelerated too. Thus, this result can be explained by two processes by which the loss of inorganic nitrogen occurred; (1) nitrification, denitrification, and leaching of nitrates, (2) uptake by plants and microbial absorption.

(1) Nitrification and loss of nitrates: The fact that nitrification increased during the summer period was similar to that indicated by Flowers *et al.* (1983) and Williams (1983). They found that nitrification rate constants increased with increasing temperature and the level of nitrate increased at the expense of ammonium. Consequently, subsequent nitrate ions in the soil solution may be readily available to plants, easily leached, or much denitrified. Since much precipitation and leaching occur during the summer, they are much more susceptible to loss due to leaching.3) Denitrification increased markedly with increasing temperature,45) and increased after heavy rain in summer.7) NH_4-N contents were most and NO_3-N contents were least in summer (Figures 7 and 8) compared to any other season. This provides additional evidence that the turnover rate of organic nitrogen was highest in summer, the greatest content of NO_3-N was lost due to leaching, and the denitrification process was greatest. This is supported by recent findings that nitrate content was higher when incubated at 10°C than 30°C (Nakos, 1984).

(2) Loss from uptake by plants and microbial absorption: Pinus koraiensis roots distributed mostly in the soil surface might absorb more inorganic nitrogen in summer (June-September) than early spring (April 1) or autumn (Oct. 6). This was also shown by Kramer (1979) who mentioned that root growth was highest in summer. More roots in summer will uptake more inorganic nitrogen than other seasons. Furthermore, Stefanson(1976) argued that denitrification was increased by the addition of an energy source in the form of root exudates because it increased microbial population. More roots in summer23) will result in more root exudates, and denitrification will increase. Consequently, inorganic nitrogen in the soil surface was less in summer than in early spring or autumn (Figure 5). This hypothesis was compatible with the fact that the highest inorganic nitrogen concentration was observed in the deep soil, in which fine roots were scarce.

It is also expected that immobilization of inorganic nitrogen by microbes in summer was more than other seasons because summer conditions were more favorable than other season's conditions. Microbial consumption of inorganic nitrogen amounts to remarkable quantity. Between the major source (soil organic matter) and sinks (uptake by plants and microbial immobilization), both the rates and pathways of nitrogen transformation could be altered by the concentrations of nitrogen species and the size of the microbial population. Even without the major sink of uptake by plants, the very low increment in mineral nitrogen concentrations indicated how rapidly mineral nitrogen could be immobilized by the microbial population.39) Ladd *et al.* (1981) found that most of the ^{15}N went into soil organic nitrogen. However, of the total nitrogen mobilized during fifteen months, 49% was taken up by wheat, nearly 20% was immobilized by microbes or remained on residues, and another 9% remained in the soil profile in inorganic form.

AUTUMN: Although the amount of NH_4-N is accumulated, total inorganic nitrogen may not be compensated until microbial activity and mineral uptake by plants decrease due to low temperature, and the leaching rate lessens due to the decrease of rainfall. Any depressing effect of fluctuating temperature on nitrogen mineralization is probably compensated by lower microbial activity leading to less assimilation and immobilization of nitrogen.7) Campbell *et al.* (1983) reported that, in laboratory incubation, nitrate content unlike ammonium production did not increase with increasing temperature. Consequently, nitrate formed a higher proportion of the mineral nitrogen content at 10°C than at 30°C.7) More NO_3-N in autumn than in summer was consistent with that report (Figure 7).

EARLY SPRING: Stout *et al.* (1984) reported that nitrate in the soil to be stored at 5°C was accumulated steadily, though its rate was slow. The optimum temperature for nitrification is generally quoted between 25°C and 35°C.18,41,43) With respect to the optimum temperature for soil nitrification, however, Mahendrappa *et al.* (1966) reported that nitrifying microorganisms in soils of the western United States are affected by their climatic region. Similar results have also been reported by Anderson *et al.*(1971) for soils from different climatic regions of Georgia, suggestive of variation in microbial adaptation. This hypothesis is supported by recent findings of possible adaptation of the nitrifying microorganisms to low temperature 10°C (Nakos 1984). According to his data, however, the case was different with ammonification. Ammonium concentration was still low at low temperature, although there was Aref'eva's(1970) report that NH_4-N content increased during winter. As shown in Figure 6, NH_4-N content increased a little from autumn to early spring and NO_3-N content in Figure 7 increased more than NH_4-N indicated in Figure 6. Thus inorganic contents in early spring were higher than those in autumn.

EARLY SUMMER: The question is why the inorganic nitrogen content in early summer was the least among the seasons. It is considered that the amount of mineralized nitrogen could be very low because of low cumulative soil temperature, the large quantity of inorganic nitrogen taken up by plants during the blooming period, and the dry spring which stimulated nitrogen uptake by plants owing to a high rate of evapotranspiration. However, Chapin (1980) reported that the rapid growth of plants was supported more by stored nutrients than by concurrent absorption. The spring increase in leaf nutrient capital coincided with decreasing pool sizes of nitrogen in stems and large roots of wild plants.9) In contrast to deciduous perennials, however, Mooney *et al.* (1979) found that evergreen species retained leaf nutrients *in situ* during winter rather than translocating them to stem or roots. In subsequent years, evergreen leaves might retain stable concentrations and pool sizes of nutrients.8,32) Leaf and shoot growth of evergreens began later and occurred more gradually than in deciduous perennials, and thus could be supported by direct absorption from the soil.29,30,32)

FERTILIZATION: The maximum growth rate of field-grown corn was obtained when the concentration of nitrate in the soil solution was 10±5me/l (Kafkafi *et al.* 1978). An excess of solution nitrate above that level caused reduction in yields by reducing phosphate concentration in the plants, probably by anionic competition. Evaporation and transpiration may reduce the water content in a

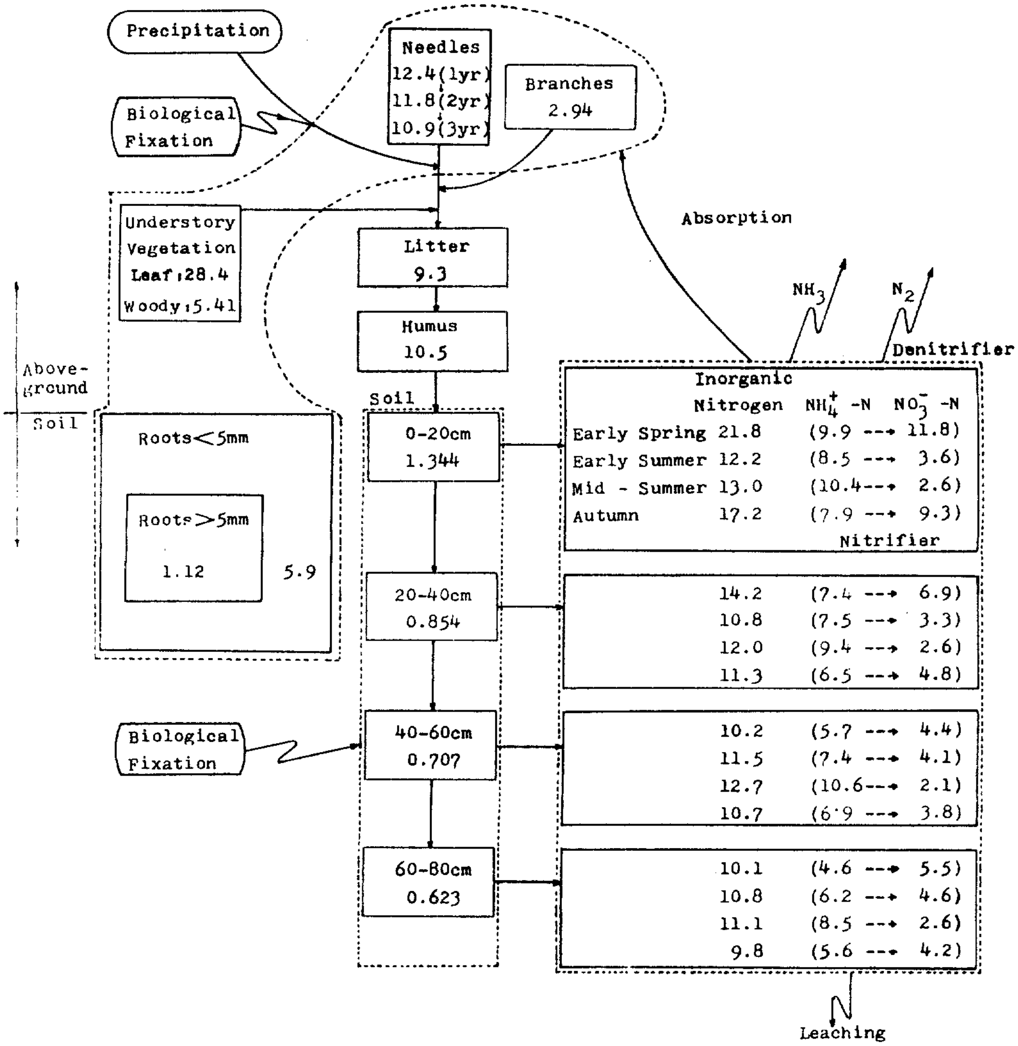

Fig. 8. Schematic diagram of self-serving mechanisms of nitrogen in concentration (total nitrogen concentration was expressed in g/Kg and inorganic nitrogen concentration in mg/Kg).

particular root zone to about 50 percent of field capacity before the next rainfall occurs. In such case, the nitrate concentration may be doubled. For this reason, the value of 100 ppm of NO_3-N in the soil solution was chosen as the optimum concentration that should be maintained during the main uptake period of most plants. Frequent additions of nitrate nitrogen are required in soil because of its high mobility in soil and its uptake by plants. An experience indicated that the lowest concentration of NO_3-N would be 50 ppm and the highest 250 ppm. Below or above these values, plant growth may slow.[22] The concentrations of inorganic nitrogen in the surface layer of soil obtained in this study were 21.8, 12.2, 13.0 and 17.2 ppm (0-20 cm) in early spring, early summer, mid-summer and autumn, respectively (Figure 8). Thus this stand needs an application of nitrogen fertilizer. In particular, rapid active fertilizer would be desirable because of abundant total nitrogen (1344 ppm) and of great seasonal fluctuation of inorganic nitrogen content. It would be also desirable to apply fertilizers in spring since inorganic nitrogen content is the least in early summer. According to Kruh's (1978) report, measurement of nitrate concentrations by soil profiles after applying 180 kg N/ha, showed that the early spring (March) application gave relatively high nitrate concentrations in a zone where presumably most of the actively growing roots are concentrated. The winter (November) application produced a deeper peak of nitrate concentration in the soil profile, and the April application gave a very shallow nitrate peak.

CONCLUSION

1. The concentration of nitrogen in various parts of trees in a 24-year-old *Pinus koraiensis* stand amounted to 12.4 g/kg in 1-year-old needles, 11.8 in 2-year-old needles, 10.9 in 3-year-old needles, 2.94 in branches, 0.97 in the stem, and 4.36 in the bark. For understory vegetation, its concentration amounted to 28.37 g/kg in the leaves, 5.41 in the stem and branches. It showed 9.28 g/kg in litter, 10.5 in humus, 5.88 in the roots less than 5 mm in diameter, and 1.12 in the roots greater than 5 mm in diameter. At various soil depths, 1.344 g/kg of nitrogen were distributed in the layer 0 to 20 cm, 0.854 in the layer 20 to 40 cm, 0.707 in the layer 40 to 60 cm, and 0.623 in the layer 60 to 80 cm.

2. Of the total nitrogen content of the total tree biomass (except for roots), nearly 61.5% was distributed in the needles, 20% in the branches, 5.5% in the stem bark, and 13% in the stem wood. Accordingly, harvest by removing only wood portions for pulpwood production would have little impact on the self-serving mechanisms of the site nitrogen status.

3. Inorganic nitrogen and NO_3-N concentrations decreased rapidly with increasing soil depths in early spring and autumn. In early summer and mid-summer, however, their concentrations decreased little with increasing soil depths. NH_4-N concentrations decreased slowly with increasing soil depths in all seasons, and the concentration of NH_4-N in soil was highest in mid-summer and little different in other seasons. However, that of NO_3-N was highest in early spring and lowest in mid-summer. The concentration of inorganic nitrogen was highest in early spring and decreased in the following descending order; autumn, followed by mid-summer, and early summer. This pattern resulted from the fact that the loss of NO_3-N was greatly influenced by environmental factors. Thus, it was suggested that an application of active nitrogen fertilizer would be appropriate in spring.

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