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https://doi.org/10.5109/25208

出版情報：九州大学大学院農学研究院紀要. 57 (2), pp.473-479, 2012-09-20. Faculty of Agriculture, Kyushu University

J. Fac. Agr., Kyushu Univ., **57** (2), 473–479 (2012)

Effect of Thinning Intensity on Soil Nitrogen Dynamics in *Pinus densiflora* Stand

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(*Received April 27, 2012 and accepted May 10, 2012*)

The effects of thinning intensity on soil N dynamics of Red pine (*Pinus densiflora* S. et Z.) stands were investigated in four short–term thinning experiments in southern Korea. The measurement was conducted 7 years after the thinning treatment and the thinning intensity ranged from heavy thinning to no thinning. All thinned sites had higher average extractable NH_4^+ and NO_3^-–N ranges than that of the control, and the average of the lightly thinned site was significantly higher than that of the control for the other two thinning treatment. Average NH_4^+ concentrations were higher than the average NO_3^- concentrations in all study sites, and the of extractable NH_4^+ concentrations were higher in the growing season of Jun and July, and then declined in the late summer and fall seasons. Nitrification rates were comparatively low and net N mineralization differed significantly by thinning management, and showed seasonal variations. For net N mineralization and nitrification rate during the study period, the lightly thinned site had a significantly higher average than the other three sites.

Keywords: inorganic nitrogen, Korean red pine, nitrogen mineralization, nitrification

INTRODUCTION

Thinning is the main forestry means to increase tree growth by reducing stand tree density and competition for resources. A limited number of studies have examined the effects of thinning on stand growth (Mäkinen and Isomäki, 2004; Bradford and Palik, 2009), stand development (Suzuki *et al*., 2009; Harrington and Devine, 2011) and species diversity (Nonoda *et al*., 2008; Ares *et al*., 2010) in various forest ecosystem. Bradford and Palik (2009) reported that gross growth in *Pinus resinosa* stands treated with dominant thinning was greater than growth in stands treated with thinning from below. Thinning experiments among various silvicultural treatments have consistently shown increasing diameter and volume increments of individual trees with decreasing stand density (Ruha and varmola, 1997). Although Abetz and Unfried (1984) and Eriksson (1987) reported that inter–tree competition affects the diameter growth of all the trees in a Norway spruce stand, Braastad and Eikeland (1986) and Braastad and Tveite (2001) demonstrated that thinning did not accelerate or only slightly accelerated the growth of the largest trees. Generally, the effects of thinning on forest structure and function depend on soil conditions, climate, tree species and tree age (Blanco *et al*., 2006). Therefore forest response to thinning has to be assessed for each situation (Sheriff, 1996).

Red pine (*Pinus densiflora* S. et Z.) is economically and ecologically one of the most important tree species in Korea, and occupies more than 23.5% (1.5million ha) of Korean forest lands (KFS, 2011). In Korea, the study of *P. densiflora* forests has received a lot of attention, most studies have been carried on vegetation studies (Yang, 2002; Chun *et al*., 2007; Lee *et al*., 2009), biomass and net primary production (Seo and Lee, 2010), and site index equation (Pyo *et al*., 2009) of *P. densiflora* forests, but little information is available on its long–term responses to silvicultural treatments such as thinning.

It is well known that nitrogen (N) is the most limiting nutrients to plant growth (Davidson *et al*., 2004), and N cycling is the basic factor in forest soil N availability. Some data showed that thinning either did not affect (Mariani *et al*., 2006) or decreased the net mineralization of N (O'Connell *et al*., 2004). More information is needed because little is known about the effects of thinning on soil N dynamics.

The objective of this study was to determine the seasonal pattern of the extractable NH_4^+ and NO_3^- concentration, net NH_4^+ mineralization and nitrification rate of mineral soil related thinning intensity in Korean Red pine (*Pinus densiflora* S. et Z.) forest.

MATERIALS AND METHODS

Study site

The thinning experiment was conducted in a 35–year old Red pine (*Pinus densiflora*) stand located in the Jinju City, South Korea. The stands were even–aged and

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Table 1. Soil chemical properties in the study site

Treatment	pH [1] (H_2O)	OM [2] (%)	Total–N [3] (%)	Available P [4] (mg kg^{-1})	Exchangeable cations [5] (cmolc kg^{-1})			
					Ca^{2+}	Mg^{2+}	K^{+}	Na^{+}
Heavy	4.68b* (0.10)	10.63b (1.30)	0.07b (0.02)	3.98a (0.15)	5.11b (0.27)	1.27a (0.22)	0.26b (0.03)	0.19a (0.02)
Moderate	4.54b (0.12)	11.14b (1.24)	0.12ab (0.02)	4.41a (0.89)	4.23c (0.24)	1.37a (0.18)	0.26ab (0.05)	0.20a (0.02)
Light	4.93a (0.14)	14.09a (1.08)	0.16a (0.03)	4.58a (0.41)	6.34a (0.32)	1.41a (0.27)	0.32a (0.02)	0.20a (0.03)
Control	4.58b (0.05)	9.77b (1.17)	0.09b (0.01)	3.61a (0.29)	4.15c (0.16)	1.10a (0.09)	0.20b (0.04)	0.16a (0.02)

Note: Standard deviation of the mean is given in parenthesis. *Different letters on the columns indicate statistical differences at the 5% levels by Duncan's multiple range test. [1] pH was measured at a soil:deionized water of 1:2.5(w/w), [2] OM was estimated by loss on ignition at 450°C. [3] Total–N was measured by using a Kjeldahl method, [4] Available P was determined by molybdate blue method. [5] Exchangeable cations were measured by atomic absorption spectrophotometer.

almost pure Red pine stands growing on mineral soil. They had mainly been established by natural regeneration. The understory species in the study site were *Alnus firma, Rhus trichocarpa, Smilax china, Athyrium niponicum*, and *Carex humilis*. The elevation of the study site was between 120 and 180 m. Based on records from the nearby Jinju Weather Station, the annual average temperature is about 13.5°C (15.6°C in January, 37.5°C in August) with an annual average precipitation about 1645 mm. The precipitation is uneven throughout the year with a significant amount of precipitation during the summer due to rainy season. The average slope of the study site was 27–38°, and the soil of the study area was sandy loam with an average L layer and soil depth about 7 cm and 42 cm, respectively. The aspect of the study area was mainly southwest, except for the lightly thinned stand where it was northwest. A brief characterization of soils of the study sites was performed to better understand differences between the sites (Table 1).

Thinning experiment

The experiment had three thinning intensities (heavy, moderate, and light) and a control (unthinned). The area of the experiment was about 4 ha and the size of each treatment was 0.5 ha. All thinning treatments used the traditional health thinning. The thinning treatment took place in April 2005. The average numbers of residual stems and volume stocks per hectare after thinning were 475 (133.6 m^3), 575 (148.5 m^3), 650 (131.6 m^3), and 1559 (122.1 m^3) for the heavy, moderate, light, and control treatments, respectively. One 0.5 ha square permanent plot was established in October, 2010 within each treatment to monitor relationship between thinning intensities and soil N dynamics.

Soil sampling and analysis

In each study stand, soil samples were collected at 0–5 cm soil depth at randomly five selected points, passed through a 2–mm sieve to remove stones and root fragments, and refrigerated at 4°C until chemical analysis. Sampling was carried out monthly from April to November in 2011 growing season.

The concentrations of extractable NH_4^+ and NO_3^- in each sample were determined. Five 20 g soil were extracted by shaking with 2 N KCl, and then the extracts were filtered and stored. The concentrations of extractable NH_4^+ and NO_3^- were determined by an automated colorimetric method using the nitroprusside–catalysed indophenols reaction and analyzed as NO_2^- after reduction in a Cadmium column (UV–260, SHIMADZU). The concentrations of extractable NH_4^+ and NO_3^- were expressed as N milligram per kilogram of dry soil.

In the absence of direct methods for measuring N mineralization, a wide variety of methods that provide a comparative index of mineralization have been developed (Keeney, 1982). In this study, potential NH_4^+ mineralization and nitrification rate were determined after a 30–days aerobic incubations in the laboratory. Soils were incubated at 25°C, weighed periodically, and had water added to maintain a constant moisture content. At the end of the incubation period, samples were extracted and analyzed for NH_4^+ and NO_3^- as described above. Net NH_4^+ mineralization was determined as the difference between the initial and incubated sample. Similarly, the net nitrification was defined as the difference in NO_3^-–N in pre–incubation and post–incubation samples. Nitrogen availability is the sum of net NH_4^+ mineralization and the nitrification rate.

Statistical analysis

Comparison of all parameters between treatment levels were made using analysis of variance (ANOVA), using SAS software after correcting for homogeneity of variance. If a significant difference between thinning intensity was found, Duncan's multiple range test analysis among the thinning intensities were carried out for each site. The response of net N mineralization and nitrification rate to was determined by using the general linear model procedure for each site (SAS Institute Inc., 1999).

RESULTS

Extractable NH_4^+ and NO_3^- –N

The seasonal patterns and concentrations of extractable NH_4^+ and NO_3^- at each study site are shown in Fig. 1 and 2. At heavy, moderate, light, and control site, the concentrations of extractable NH_4^+ varied from 0.35 in Oct. to 1.52 mg kg^{-1}, 0.42 in Apr. to 1.72 mg kg^{-1}, 0.71 in Apr. to 2.16 mg kg^{-1} in Jun, and 0.28 in Oct. to 1.43 mg kg^{-1} in Jun, respectively. The concentrations of extractable NH_4^+ in all study sites were slightly high in May. Throughout the study period, average concentration were 0.86 mg kg^{-1} in heavily thinned site, 1.02 mg kg^{-1} in moderately thinned site, 1.42 mg kg^{-1} in lightly thinned site, and 0.81 mg kg^{-1} in control site. The concentrations of extractable NO_3^- at all study sites were relatively low throughout the study period, and showed significant seasonal variations. The concentrations of extractable NO_3^- at heavy, moderate, light, and control site ranged from 0.21 in Oct. and Sep. to 0.64 mg kg^{-1} in Jul., 0.16 in Apr. to 0.74 mg kg^{-1} in Jul., 0.25 in Oct. to 0.63 mg kg^{-1} in Aug., and 0.17 in May, to 0.50 mg kg^{-1} in Jul., respectively. Those were on 0.36 mg kg^{-1} at heavily thinned site, 0.38 mg kg^{-1} at moderately thinned site, 0.46 mg kg^{-1} at lightly thinned site, and 0.27 mg kg^{-1} at control site. The effects of thinning intensities on concentration of extractable NH_4^+ and NO_3^- can be clearly recognized in heavily thinned site. The concentration of extractable N of the thinned sites were significantly higher than that of the control sites. During the study period, average NH_4^+ concentrations at all study sites were higher than those of average NO_3^- concentrations. The concentrations of

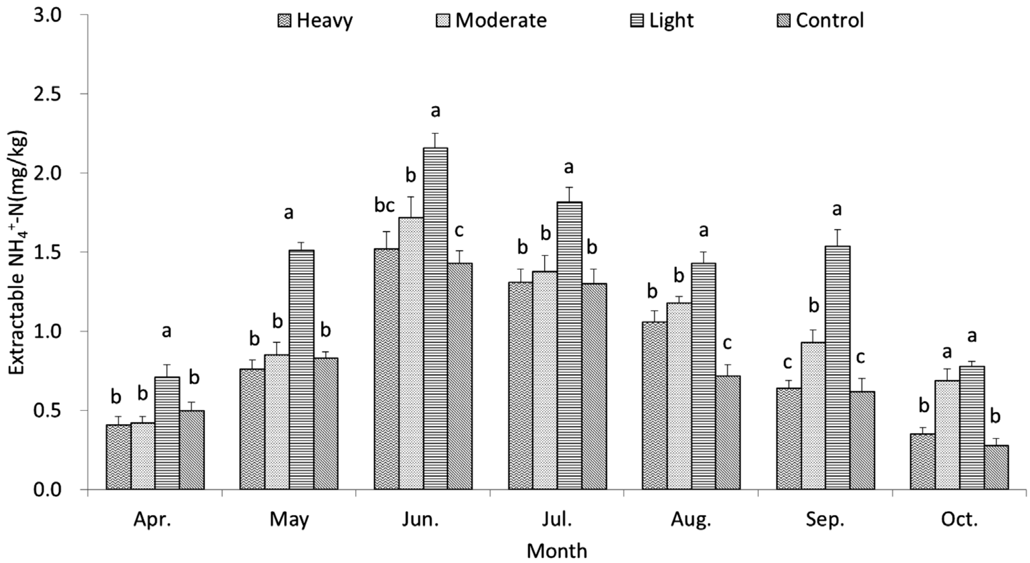

Fig. 1. Seasonal patterns of NH_4^+ concentration by thinning intensities in *P. densiflora* stand. Each histogram bar represents a mean. Standard errors of the means are shown. Treatment marked with the same letter are not significantly different at p<0.05.

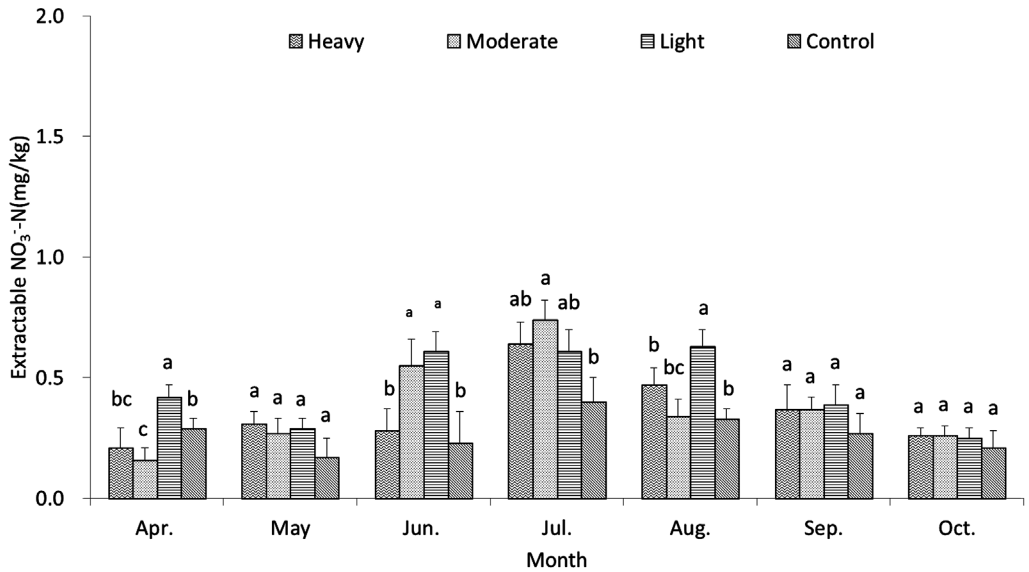

Fig. 2. Seasonal patterns of NH_4^+ concentration by thinning intensities in *P. densiflora* stand. Each histogram bar represents a mean. Standard errors of the means are shown. Treatment marked with the same letter are not significantly different at p<0.05.

extractable NH_4^+ were higher in the growing season of Jun and Jul, and declined throughout late summer and fall at all the study sites. The ratio of NO_3^- to total extractable N ranged from 24% at lightly thinned site to 30% at heavily thinned site.

Net N mineralization and nitrification

Net N mineralization differed significantly by thinning management and showed seasonal variations (Fig. 3). A conspicuous peak was found in Jul. in the heavily thinned and control site, and in Jun. at the moderately and lightly thinned sites, and then decreases in the spring and fall seasons. Net N mineralization ranged from 0.13 to 1.78 mg kg^{-1} at heavily thinned site, 0.08 to 2.16 mg kg^{-1} at moderately thinned site, 0.52 to 2.74 mg kg^{-1} at lightly thinned site, and 0.41 to 1.28 mg kg^{-1} at control site. Net N mineralization was significantly higher in the heavily thinned site compared with the other sites during the study period. Compared to the net N mineralization, nitrification rates were comparatively low but differed significantly by thinning management and showed seasonal variations (Fig. 4). Higher nitrification rates in all study sites were observed in growing season of Jun, Jul and Aug, and declined in spring and fall seasons. The average nitrification rates were 0.41, 0.46, 0.65, and 0.24 mg kg^{-1} at the heavily thinned site, moderately thinned site, lightly thinned site, and the control site, respectively. The percentage of nitrification rate to N

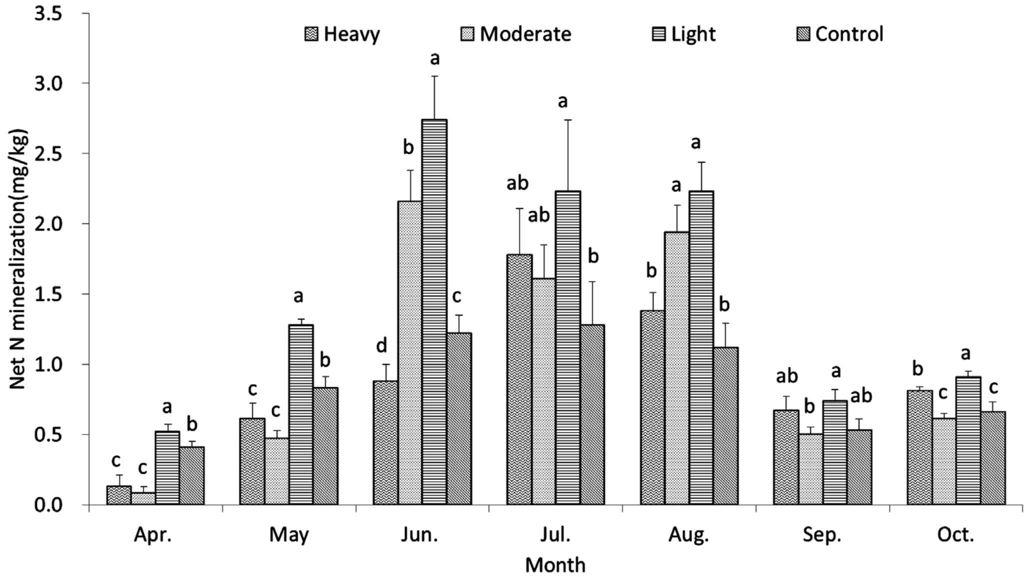

Fig. 3. Seasonal patterns of net N mineralization by thinning intensities in *P. densiflora* stand. Each histogram bar represents a mean. Standard deviations of the means are shown. Treatment marked with the same letter are not significantly different at $p<0.05$.

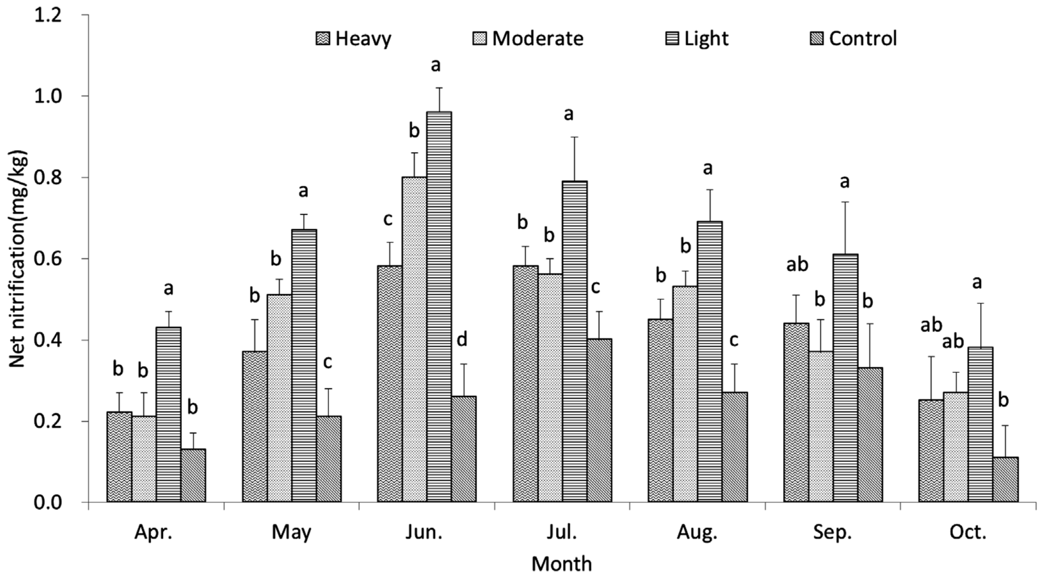

Fig. 4. Seasonal patterns of nitrification rate by thinning intensities in *P. densiflora* stand. Each histogram bar represents a mean. Standard deviations of the means are shown. Treatment marked with the same letter are not significantly different at $p<0.05$.

availability was ranged to 30–32% in the heavily thinned, moderately, and lightly thinned sites, while lower in the control site (21%). The lightly thinned site had higher nitrification rate than that of the other sites. The net N mineralization and nitrification rate were significantly affected by thinning management in *P. densiflora* stand.

Correlation between soil properties of mineral soil and soil N dynamics

The correlation between soil properties and soil N dynamics at all study sites are shown in Table 2. Here, the effects of soil moisture content on net N mineralization and nitrification rate were not analyzed, because moisture contents were kept uniform throughout the incubation period. Although extractable NH_4^+ showed a significant and positive correlation with net N mineralization, a relation between extractable NO_3^- and nitrification could not be found. This may be due to plant uptake and leaching. Extractable NH_4^+ and NO_3^- were influenced by soil pH, total N and organic matter. Net N mineralization gave also a positive correlation with organic matter and total N. There was also a significant positive correlation between net N mineralization and nitrification.

DISCUSSION

One such management practice is thinning, which is commonly used in forestry to reduce inter–tree competition, an important issue arising in nutrient–limited forests where fertilization is not economically or environmentally feasible (Blanco *et al.*, 2011). In general, thinning is a very common and recommended practice to improve tree growth and stand development of plantations (Allen, 2001) and natural forest (Oliver and Larson, 1996). However, little information is known about the effects of thinning treatment on soil N dynamics that is one of the most limiting factors of productivity in terrestrial ecosystems.

At all thinned sites had higher average extractable NH_4^+ and NO_3^- –N ranges than that of the control, and the average of the lightly thinned site was significantly higher than that for the other two thinning treatment. Baeumler and Zech (1998) reported that extractable NH_4^+ and NO_3^- increased after thinning treatment. The concentration of NH_4^+ and NO_3^- increased in the mineral soil after thinning due to reduction or cease of root uptake, and decreased again by nitrification and microbial immobilization of N.

Extractable NH_4^+ concentrations and net N mineralization showed conspicuous seasonal variations, with higher concentration in growing season, followed by loses in other month. The results are in agreement with other studies that suggest seasonal variation in NH_4^+ concentrations and net N mineralization tends to be similar regardless of forest (Zak and Pregitzer, 1990; Kim, 1995; Moon, 1999; Lee and Jose, 2006). The higher extractable NH_4^+ concentrations and net N mineralization in Jun. and Jul. suggests that litters had sojourned over the winter period, because of low microbial activity, provided a suitable substrate for microbial decomposition with the approach of warmer weather and consequent increase in soil temperature (Van Cleve *et al.*, 1993; Moon, 1999).

Extractable NO_3^- concentrations were relatively low at all study sites in *P. densiflora* stand. The relative low concentration of NO_3^- in other pine stands had been reported by previous studies (Vitousek and Matson, 1985; Zak and Pregitzer, 1990; Kim, 1995). It could be explained by low soil pH (Donaldson and Henderson, 1990), absorption by vegetation and soil microbes (Aber *et al.*, 1993) and leaching with soil water (Poovarodom *et al.*, 1988). The relatively low concentrations of NO_3^- suggested that the nitrification rate is inactive and that NO_3^- is not readily available for plant uptake (Moon, 1999). When one takes into account the reciprocal exchange between soil and vegetation, it is to be expected that red pine will mainly take up NH_4^+ as a source of N. However, Aciego–Pietri and Brookes (2008) and Inagaki and Yamada (2002) found that NO_3^- concentration and nitrification rate declined exponentially or linearly with increasing soil pH. The reason for this have not be clarified sufficiently, but may be due to variation in the quality and/or quantity of soil organic matter produced by vegetation and/or differences in habitat conditions and analysis method. The important finding in this study was that while positive nitrification occurred at all soil pH values, it was negligible at soil pH 4.3 in the control site and increased with increasing pH, being maximal at pH 5.1. We therefore conclude that the reason for the larger NO_3^- concentrations and at the all thinned sites were due to nitrification occurring in soils as high as pH 4.8.

Either net N mineralization or nitrification rate was affected by thinning treatment over thinned sites.

Table 2. Correlation coefficient between soil properties and soil N dynamics for mineral soil at all study sites

	pH	Moisture	Total–N	Organic matter	Extractable NH_4^+	Extractable NO_3^-	Net mineralization
Moisture	0.03^{ns}	–					
Total–N	0.11^{ns}		–				
Organic matter	0.16^{ns}	0.07^{ns}	0.47***	–			
Extractable NH_4^+	0.67***	0.03^{ns}	0.72***	0.53***	–		
Extractable NO_3^-	0.42***	-0.02^{ns}	0.56***	0.29**	0.10^{ns}	–	
Net mineralization	0.13^{ns}	–	0.45***	0.63***	0.58***	0.14^{ns}	–
Nitrification	0.33**	–	0.21*	0.26*	0.19^{ns}	0.07^{ns}	0.46***

n = 140, ns: not significant, *p<0.05, **p< 0.01, *** p<0.001.

Furthermore, variability in N transformations in lightly thinned site among sites with thinning treatment was considerably greater than were variations in heavily and moderately thinned site. The results in thinning treatment were in contrast with the results of Dahlgren and Driscoll (1994) and Knoepp and Swank (1993) who found higher net N mineralization and nitrification rate after clearcutting in mixed oak–pine stand. In addition, Johnson *et al.* (1985) and Frazer *et al.* (1990) reported that N mineralization and nitrification rate in clearcut site in hardwood and conifer forest was higher than in uncut site. The higher N mineralization and nitrification rate in the lightly thinned site than in other thinning treatments was against our expectation and that the opening of the canopy may produce changes in forest floor depth and soil microclimate, as well as reductions in plant N uptake resulting from the removal of tree (Johnson and Curtis, 2001). The difference observed in N availability between the present study and previous study could be attributed to the species–specific feedback mechanism via litterfall (Lee and Jose, 2006). The recalcitrant nature of the litter which favor immobilization of mineral N by microorganisms are known to lower net mineralization rates in conifer stands (Jansen, 1996). More methodical and long–term study should be needed to grasp the relationships between soil N dynamics and thinning treatment associated with tree growth and forest development.

CONCLUSIONS

Based on our finding from the Korean red pine forest thinning treatment, we conclude that the effects of thinning on soil inorganic N (NH_4^+ and NO_3^-) concentrations and N mineralization including net N mineralization and nitrification rate are seasonally dependent and strongly affected by light thinning. The effects of thinning intensity on soil inorganic N concentrations and N mineralization are closely linked to the changes in soil organic matter and total N. Our study indicates that thinning at light intensities is sustainable in terms of stand productivity and soil N cycling. These findings also have important implications for sustainable management of Korean red pine in South Korea.

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