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Effects of Canopy Removal on Cellulose Decomposition and Nitrogen Mineralization in *Quercus rubra* Stands

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임관 제거가 루브라참나무림의 셀룰로오스 분해와 질소 무기화에 미치는 영향

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ABSTRACT

Although many studies of nutrient cycling in forest ecosystems have reported that clearcutting creates increased organic matter decomposition and nitrogen (N) mineralization in soils, little is known about the change of these factors following various levels of canopy removal. A series of experimental plots with four levels of canopy cover, i.e., clearcut, 25%, 75%, and uncut, was established in northern red oak (*Quercus rubra* L.) stands in northern Lower Michigan, U.S.A. I examined decomposition of cellulose filter papers and N mineralization using an *in situ* soil incubation technique in the top 15cm of mineral soil during the second growing season (1992, May-October) following stand manipulation. Mass loss from cellulose filter papers was more rapid in the canopy removal treatments than in the uncut treatment. Similarly, net N mineralization was significantly greater in the canopy removal treatments than in the uncut treatment. There was no significant difference in net N mineralization rates among the three levels of canopy removal. Net N mineralization for the growing season was 58 kg /ha for the clearcut, 54 kg /ha for the 25% canopy cover, 51 kg /ha for the 75% canopy cover, and 22 kg /ha for the uncut treatment. These results indicated that even only small amounts of canopy removal (leaving 75% canopy cover) led to substantial increases of cellulose decomposition and the amount of available soil nitrogen.

Key words: Canopy cover, Cellulolytic activity, Nitrification, Nitrogen mineralization, *Quercus rubra*

INTRODUCTION

Many studies have reported increased rates of soil N mineralization and organic matter decomposition in forest ecosystems following complete canopy removal (Matson and and Vitousek 1981, Binkley 1984, Mader *et al.* 1989, Smethurst and Nambiar 1990). Partially open canopies, such as in gaps of older forests or in young stands, also generally showed increased rates of N mineralization and organic matter decomposition associated with increases in soil temperature and moisture (Piene and Van Cleve 1978, Mladenoff 1987, Frazer *et al.* 1990). However, Wallace and Freedman (1986) reported that organic matter decomposition after clearcutting hardwood stands did not change, while Yin *et al.* (1989) found that organic matter decomposition decreased in clearcut red oak stands compared to partial canopy cover or uncut stands.

Although several studies have reported N mineralization and organic matter decomposition rates after clearcutting oak stands (Matson and Vitousek 1981, Vitousek and Matson 1985, Yin *et al.* 1989), the rates in N mineralization and organic matter decomposition following various levels of canopy removal are still unknown. It is important to estimate the potential effects of canopy removal on organic matter decomposition and N mineralization because of its relationship to tree growth and nutrient availability (Edmonds 1991). In addition, canopy removal, such as clearcutting, shelterwood cutting, and thinning in oak stands, has held a considerable attention in terms of forest management. The objective of this study was to determine the effects of various levels of canopy removal on the processes of organic matter decomposition and soil N mineralization in mature northern red oak stands.

MATERIALS AND METHODS

Study site and experimental design

The study was conducted in Crawford County in northern Lower Michigan, U.S.A. Most of the area consists of second-growth forests that originated in the early part of this century following extensive logging and burning (Albert *et al.* 1986). Annual precipitation averages 770 mm/yr and includes considerable snowfall. Annual average temperature is 6.7℃ (Albert *et al.* 1986)

Experimental plots were located in two adjacent northern red oak stands on moderately productive upland sites (longitude 84° 45'W, latitude 44° 31'N, elevation 400m). Mean stand age was about 90 years and the aspect was north. The experimental design consisted of three blocks, each divided into four 66×66m plots randomly assigned one of four canopy cover treatments: clearcut, 25%, 75%, and uncut. Sampling was confined to the central 30 × 30m area of each plot, leaving an 18m buffer zone to reduce edge effects.

Canopy cover in all plots was measured with a concave spherical densiometer during July 1990, prior to canopy removal. Canopy cover in this study was defined as the proportion of the sky covered by tree crowns. Canopy was removed in August and September, 1990 by thinning from below, starting with trees that were a minimum of 2.5cm in diameter at breast height (DBH). All logging residues on the experimental plots were moved manually into the buffer strips. Mean basal area and percent canopy cover in the canopy cover treatment plots are presented in Table 1.

Table 1. Mean basal area and percent canopy cover in canopy cover treatments

	Canopy cover treatment			
	Clearcut	25%	75%	Uncut
Basal area (m^2/ha)	0	6.1 (0.8)	15.4 (0.8)	34.0 (0.7)
Canopy cover (%)	0	28 (0.7)	70 (0.6)	86 (1.5)

Mean values (basal area n=4, canopy cover n=16) of three blocks. One standard error is given in parentheses.

Soils were sandy, mixed frigid Alfic Haplorthods developed in pitted outwash. Selected soil physical and chemical properties based on samples collected from a soil pit near the center of each block are summarized in Table 2.

Cellulose decomposition

Cellulose filter paper bags, placed in 15×15cm fiber glass bags (mesh size 1.5mm), were used to allow comparisons of relative organic matter decomposition rates among canopy cover treatments. In general, the cotton strip method has been used for assessment of cellulose decomposition rates in soil profiles (French and Howson 1982, Hill *et al.* 1985), but cellulose filter paper is preferred because it is simple and easy to apply (Binkley 1984, McClellan *et al.* 1990). Twelve cellulose bags enclosed by cellulose filter papers of about 6g (Whatman #1 filter papers, 4 collection times × 3 replicates) were inserted vertically to a soil depth of 0~15cm in each canopy cover treatment plot (April 1992). The bags were collected on four occasions (May, June, August, and October 1992) during the growing season. Collected filter papers were oven-dried at 60℃ for 48 hours, cleaned by gentle brushing with a soft paintbrush to remove mineral soil or fine root residue on the surface, and weighed to determine cellulose mass loss rates. A subset of samples of papers from each treatment for each sampling month was ignited at 375℃ for 16 hours to determine ash content to correct for mineral contamination.

Table 2. Selected soil physical and chemical properties of study sites in northern Lower Michigan, U.S.A.

	A/E horizon	Bw horizon
Horizon depth (cm)	0~8 (2)*	8~50 (8)
Organic matter (%)	3.2 (1.06)	1.3 (0.07)
Sand (%)	96.0 (0.8)	94.0 (1.9)
Silt (%)	4.0 (0.7)	5.0 (0.6)
Clay (%)	0.0 (0.2)	1.0 (0.4)
Bulk density (g/cm^2)	1.05 (0.02)	1.34 (0.02)
pH	4.2 (0.2)	5.3 (0.2)
Total N (%)	0.070 (0.02)	0.019 (0.003)
Total P (%)	0.013 (0.003)	0.017 (0.004)
CEC (cmol/kg)	4.24 (1.33)	2.09 (0.21)

*Means (n=3). One standard error is given in parentheses.

Net N mineralization and nitrification

Net N mineralization and nitrification were estimated by using an *in situ* buried plastic bag technique. Four 15m transects were established in each canopy cover plot. Three pairs of undisturbed soil cores (5cm diameter × 15cm deep) were taken monthly in each canopy cover treatment during the 1992 growing season. One soil core from each pair was transported to the laboratory to measure initial NH_4^+ and NO_3^- concentrations. The other soil core was placed in a polyethylene bag (0.025mm thick), returned to the same sampling hole, the litter replaced, and then incubated for one month. All incubation bags were covered by wire cages to prevent damage by rodents. All soil cores (initial and incubated) were taken from the field and returned to the laboratory where they were immediately hand sorted to remove stones and large roots. Residual materials were mixed throughly by hand and stored at 4℃ in a cooler. A 5g subsample of mineral soil was extracted with 50ml of 2M KCl solution within 72 hours after sampling. Ammonium and NO_3^- concentrations were determined using Technicon Autoanalyzer II. Net N mineralization rates were determined by subtracting the initial soil N (NH_4^+ and NO_3^-) concentrations from concentrations after one month incubation. Net nitrification was calculated as the difference between final and initial NO_3^- in the same samples. Net N mineralization and nitrification were converted to mass per area (kg/ha) by bulk density measurements and correcting for coarse-fragment content.

From the each initial soil core sample, soil pH (1:1 soil:water suspension) was deter-

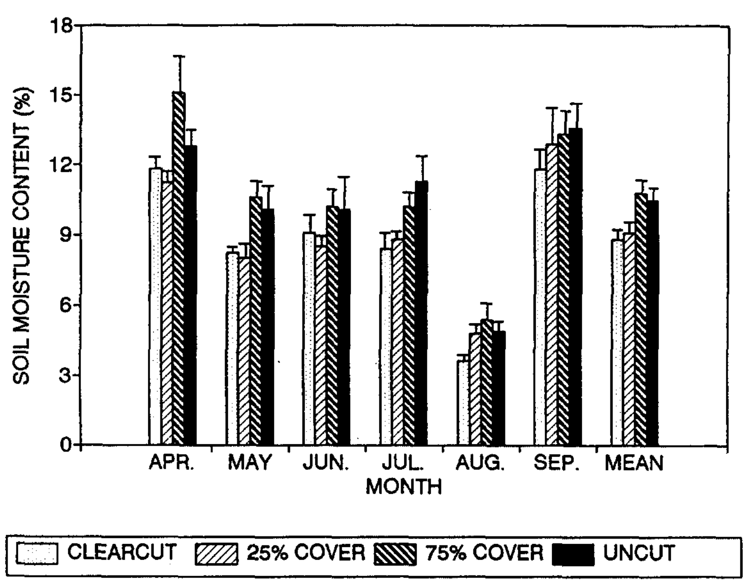

Fig. 1. Moisture content in the top 15cm of mineral soils at various levels of canopy cover. Means (n=9) and one standard error are presented.

mined (McLean 1982) and subsamples were oven-dried at 105℃ for 24 hours to determine oven-dry weight. Soil temperature (7.5cm depth) was recorded three times during summer between 3 PM and 5 PM under relatively clear skies by thermometers (Taylor Model 5859) placed within each canopy cover treatment.

Data analysis

The study used a randomized complete block design with four canopy cover treatments in three blocks. The data were analyzed using analysis of variance to determine significance of the main effect (canopy cover treatment). Homogeneity of variances was tested with the Hartley test and normal probability plots were examined to test for normality of residuals (Neter *et al.* 1990). Data that did not fit homogeneity of variance or a normal distribution were transformed. Where appropriate, comparison of treatment means was accomplished using Tukey's test. All analyses of variance for the data were executed with the General Linear Models procedure in SAS (SAS Institute, Inc. 1989)

RESULTS AND DISCUSSION

Soil moisture content and soil temperatures

Average soil moisture content during the growing season was not significantly different between the clearcut and the uncut treatment (Fig. 1). Many studies have reported temporary increases in soil moisture content following clearcutting due to decreased water uptake by trees. However, the extent of changes depended on the type of revegetation, soil texture, soil water holding capacity, and local climate (Yin *et al.* 1989, Liechty *et al.* 1992). The lack of a significant difference in soil water content between the clearcut and the uncut treatment may be attributed to changes in forest floor thickness associated with decreased litter production and/or increased regrowth of vegetation after canopy removal. Decreased litter production may enhance surface evaporation due to a decreased mulching effect of the forest floor (Child and Flint 1987).

Average soil temperatures in all canopy removal treatments were significantly higher than in the uncut treatment (Fig. 2). Increased soil temperatures were probably due to the increased amount of sunlignt reaching the forest floor after canopy removal.

Cellulose decomposition

All canopy removal treatments showed increased rates of cellulose decomposition compared to the uncut treatment (Fig. 3). Increased mass loss in the canopy removal treatments may be due to changes in environmental factors such as light, temperature, and nutrients as affecting the activity of soil microflora and fauna (Binkley 1984, Johnson *et al.* 1985, Beyer 1992). In this study there was no significant difference between soil moisture in the canopy removal treatments and in the uncut treatment (Fig. 1). This result suggested that the higher mass loss in canopy removal treatments may be attributed

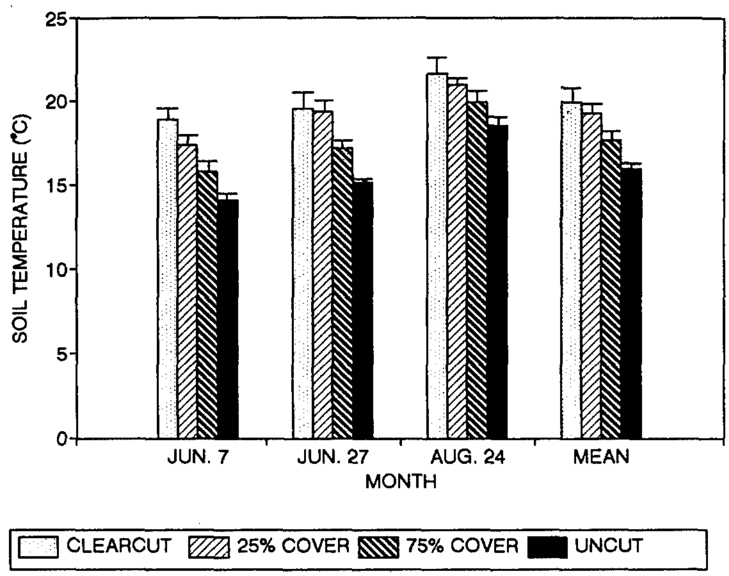

Fig. 2. Temperature at 7.5cm soil depth at various levels of canopy cover. Means (n=9) and one standard error are presented.

to increased soil temperatures. Other studies have suggested that both higher soil temperatures and higher soil moisture following canopy removal may result in accelerated decomposition (Piene and Van Cleve 1978, Binkley 1984). Brown and Howson (1988)

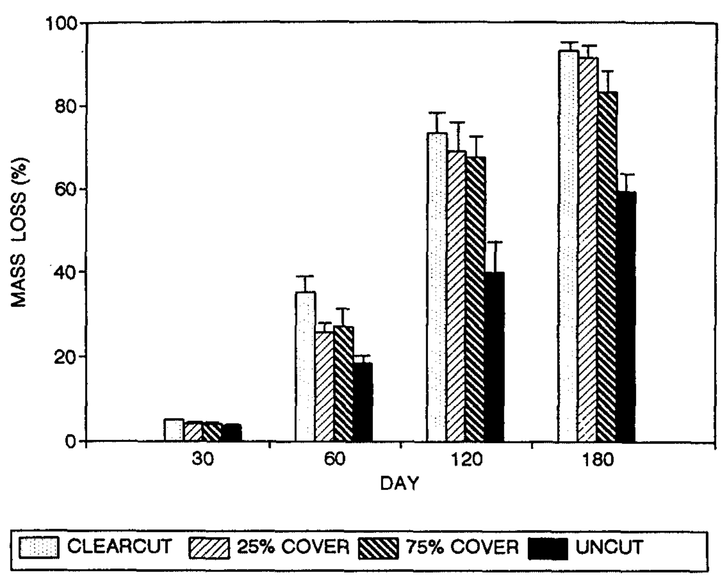

Fig. 3. Mean cellulose mass loss over the time at various levels of canopy cover. Means (n=9) and one standard error are presented. Initial incubation (day 0) was April 30, 1992.

reported that the decomposition potential of cellulose cotton strips was strongly related to appreciable populations of earthworms. However, in this study cellulolytic fungi may play a leading role in the degradation of cellulose because earthworms in all canopy treatment were very rarely observed on this highly acidic forest soils.

Nitrogen mineralization and nitrification

Nitrogen mineralization in all canopy cover treatments was generally higher during the spring and summer than during the fall (Fig. 4). The seasonal fluctuation in the N mineralization rates suggested that soil temperature may be the primary factor controlling the N mineralization process in this stand. There was no correlation ($r=0.10$, $p=0.892$) between monthly soil moisture content and monthly net N mineralization. Boone (1992) reported similar results that the seasonal patterns for N mineralization in maple forests in Massachusetts were related to seasonal changes in soil temperature.

Total net N mineralization summed during the growing season was significantly greater in all canopy removal treatments than in the uncut treatment (Fig. 5). In addition, there was no significant difference between net N mineralization and different degrees of canopy removal. Net N mineralization for the growing season was 58 kg /ha for the clearcut, 54 kg /ha for the 25% canopy cover, 51 kg /ha for the 75% canopy cover, and 22 ka /ha for the uncut treatments. Many studies have reported increased rates of N mineralization in forest ecosystems following canopy removal because the increased amount of sunlight

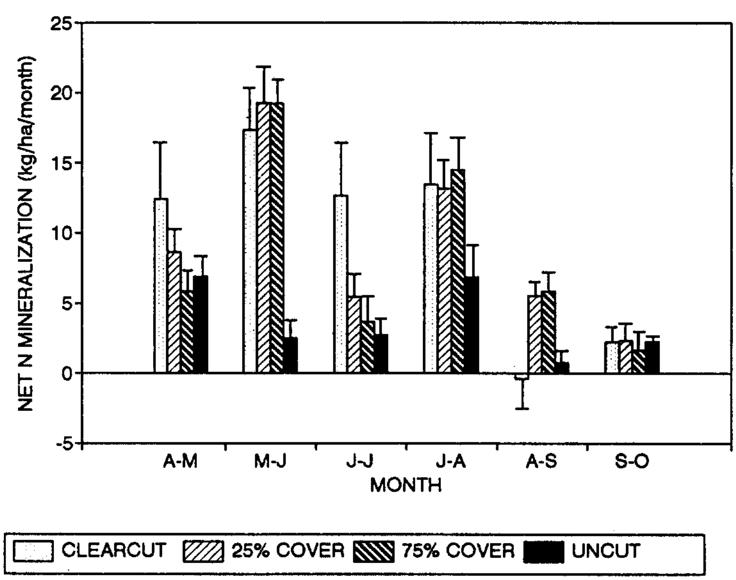

Fig. 4. Monthly net N mineralization in the top 15cm of mineral soil at various levels of canopy cover. Means ($n=9$) and one standard error are presented.

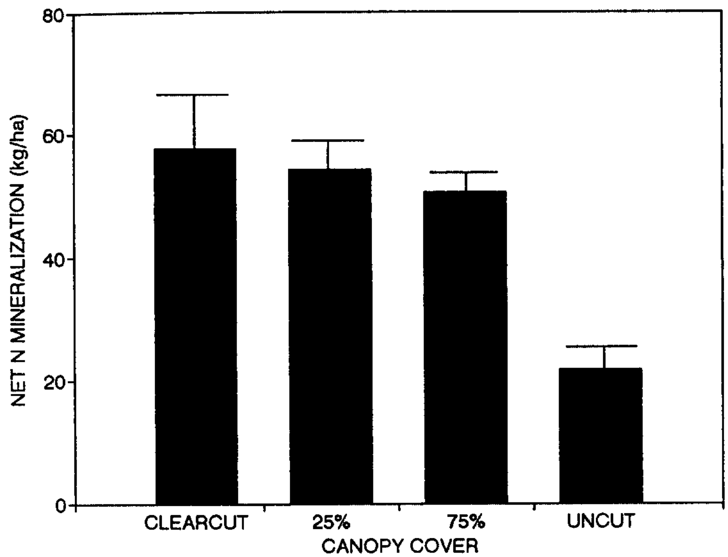

Fig. 5. Total net N mineralization in the top 15cm of mineral soil at various levels of canopy cover during the growing seasons. Means (n=9) and one standard error are presented.

reaching the forest floor and water infiltration stimulate microbial activity, facilitating decomposition and nutrient turnover (Matson and Vitousek 1981, Binkley 1984). There was no significant difference in average soil moisture determined from initial soil core samples (0~15cm depth) for the growing season between the clearcut and uncut treatments in this study. In contrast, soil temperatures were significantly higher in the clearcut treatment than in the uncut treatment, suggesting that increased soil temperatutre may lead to increased N mineralization rates in the clearcut. Stanford *et al.* (1973) reported a Q_{10} of about 2 for N mineralization potential. In this study the increase of about 5℃ in soil temperature in the clearcut compared to the uncut treatment was associated with a two-fold increase in N mineralization rates.

Total net N mineralization in the partial canopy cover treatments was significantly higher than in the uncut treatment. Increased rates of N mineralization in the partial canopy cover treatments could be partially attributed to increased soil temperatures (Fig. 2). However, the increase of about 2℃ in soil temperatures in the 75% canopy cover treatment compared to the uncut treatments was also associated with a two-fold increase in net N mineralization rates. This result suggests that N mineralization in this treatment may be more linked to other factors than microclimatic factors such as soil temperature and moisture content. Changes in the immobilization/mineralization rates of recently dead root caused by tree removal may have occurred during the sampling time in this treatment. Similarly, change in substrate quality was the most important in a *Pinus radiata* clearcut in Australia (Smethurst and Nambiar 1990).

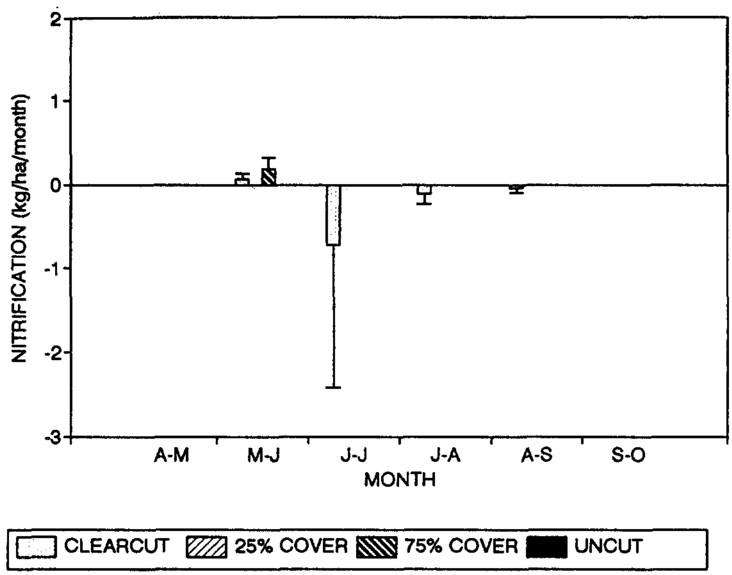

Fig. 6. Monthly net nitrification in the top 15cm of mineral soil at various levels of canopy cover. Means (n=9) and one standard error are presented.

Nitrification was negligible despite relatively elevated NH_4^+ availability following canopy removal (Fig. 6). Although nitrification or NO_3^- immobilization was dectected in the clearcut treatment, it was not significantly different from the other canopy cover treatments. Absence of nitrification in soil from the uncut treatment was not expected due to the strong acidity of soil in this study site. However, nitrification was also unaffected by increased soil temperature and pH after canopy removal (Fig. 2, Fig. 7). Low or undetectable NO_3^- levels from oak stands have been reported elsewhere (Vitousek and Matson 1985, Donaldson and Henderson 1990, Aber *et al.* 1993). The low levels or absence of nitrification may be attributed to the low pH, low soil NH_4^+ availability, presence of allelopathic compounds, or low population of nitrifying bacteria (Vitousek and Matson 1985, Donaldson and Hendensen 1990). However, Hart *et al.* (1994) suggested that 1-month soil incubation in *in situ* buried bag methods may be too short to accumulate a significant amount of NO_3^- because of microbial immobilization of NO_3^- produced. If any NO_3^- produced is assimilated by microorganisms, NO_3^- losses by leaching or denitrification following canopy removal in this stand would be low.

In conclusion, this result indicated that canopy removal is a key process affecting net N mineralization and cellulose decomposition in red oak stands. Even slight canopy reduction (i.e., 75% canopy cover) led to substantial increases in available soil N and cellulose decomposition. In contrast, nitrification was unaffected by canopy removal.

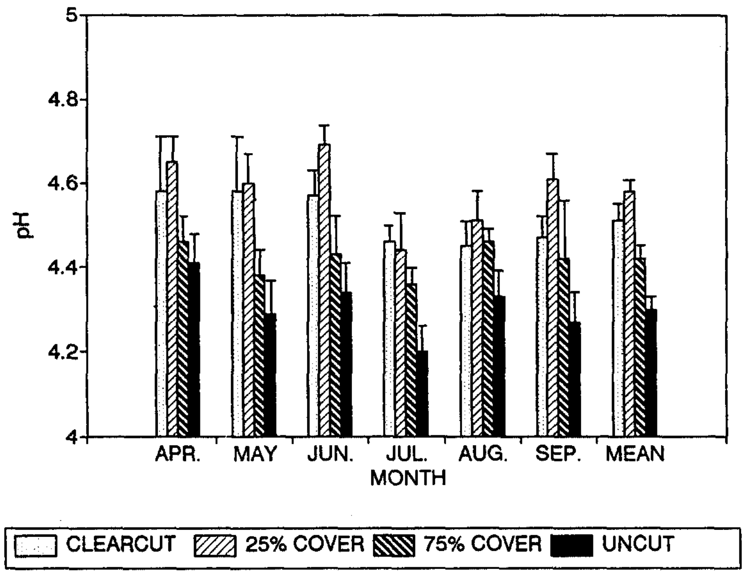

Fig. 7. pH in the top 15 cm of mineral soils at various level of canopy cover. Means (n=9) and one standard error are presented.

적 요

산림 생태계내 양료순환의 연구들은 임분에 개벌처리가 임지내 토양유기물의 분해나 질소 무기화를 증가하는 것으로 보고하고 있다. 그러나 임관제거의 여러 수준에서 이들 인자의 변화에 관하여는 잘 알려져 있지 않다. 루브라참나무 임분내에 4수준의 임관율 처리, 즉 개벌, 25% 처리구, 75% 처리구, 무처리구를 만든 후, 토양 상층부 15cm 에서의 셀룰로오스 분해와 비닐주머니를 이용한 질소 무기화율을 조사 하였다. 토양내 셀룰로오스의 분해는 임관제거 처리구가 무처리구보다 더 빨랐다. 질소 무기화율 또한 임관 제거 처리구가 무처리구에 비해 유의적으로 높게 나타났다. 그러나 임관 제거 처리의 3수준 사이에 질소 무기화율의 양은 유의적인 차이는 없었다. 임목 생장기동안 질소 무기화율의 양은 개벌처리구 58 kg/ha, 25% 임관처리구 54 kg/ha, 75% 임관처리구 51 kg/ha, 무처리구 22 kg/ha 으로 나타났다. 연구 결과에 따르면 적은 양의 임관 제거도 임지내 셀룰로오스 분해나 질소 무기화율에 상당한 증가를 초래하는 것으로 나타났다.

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