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Relationships between Cellulose Decomposition and Soil Environmental Factors in Three Coniferous Plantations

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3수종의 침엽수조림지내 셀룰로오스 분해와 토양 환경요인과의 관계

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ABSTRACT

This study was carried out to determine the relationships between cellulose decomposition and soil environmental factors in larch (*Larix leptolepis*) and pine (red pine: *Pinus densiflora*; rigitaeda pine: *P. rigida* × *P. taeda*) species planted in the same year (1963). The variation of cellulose mass loss with soil temperature, soil pH, soil CO_2 efflux rates, and soil water content was measured monthly for 4 months (July, August, September and October 2006) from three coniferous plantations. Mean mass loss rates during the study period were generally more rapid in rigitaeda pine (6.5 mg g^{-1} day^{-1}) than in red pine (6.2 mg g^{-1} day^{-1}) or larch (6.1 mg g^{-1} day^{-1}) plantations, although the mass loss rates were not significantly different among three tree species ($P > 0.05$). Cellulose mass loss rates among three tree species were positively correlated with soil temperature (red pine: $r = 0.77$, $P < 0.05$; rigitaeda pine: $r = 0.59$, $P < 0.05$; larch: $r = 0.48$, $P < 0.05$) at the 20 cm soil depth, while the mass loss rates were negatively correlated with soil pH (red pine: $r = -0.63$, $P < 0.05$; rigitaeda pine: $r = -0.47$, $P < 0.05$; larch: $r = -0.43$, $P < 0.05$). There was a significant correlation between cellulose mass loss and soil CO_2 efflux rates except for regitaeda pine plantation, while no significant correlation ($P > 0.05$) between cellulose mass loss and soil water content in larch or rigitaeda pine. The results suggest that cellulose mass loss rates in soil layers depend on the different soil environmental factors caused by tree species.

***Key words*: Cellulose degradation, Red pine, Soil water content, Soil pH, Soil respiration**

I. INTRODUCTION

The understandings of organic matter decomposition processes are very important in forest ecosystems as they mediate the carbon and nutrient cycling. However, it is not easy to compare the rates of decomposition among forest types because of the difference of chemical composition or quality of the organic matter, soil property, and decomposer community (Brown and Howson, 1988; Beyer, 1992; Kim, 2000; Neher *et al.*, 2003; Kim *et al.* 2010a). Cellulose filter papers or cotton strips, which can eliminate variation resulting from litter quality, were often used as a standard substrate to compare organic matter decomposition potential among forest types (Binkley, 1984; Kim, 2000; Thibodeau *et al.,* 2000) because this method allows the effects of

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Table 1. General characteristics of three coniferous plantations at the study sites (n=3)

Plantation	Location	Elevation (m)	Stand density (trees ha^{-1})	DBH* (cm)	Basal area ($m^2 ha^{-1}$)
L. leptolepis	35°27'26" N 127°38'30" E	674	350 [300-400]	31.1 [27.2-36.5]	27.6 [18.1-35.6]
P. densiflora	35°27'28" N 128°38'27" E	684	216 [200-250]	34.8 [31.3-36.3]	20.7 [19.7-21.3]
P. rigida × *P. taeda*	35°27'27" N 128°38'31" E	678	550 [450-650]	29.4 [28.5-30.3]	35.8 [29.9-41.3]

Values in brackets represent ranges. *DBH: diameter at breast height (1.2 m).

environmental factors to be isolated from factors related to the quality of the substrate. In addition, cellulose is a primary abundant structural component of plant litter and is decomposed by a wide variety of microorganisms.

The cellulose decomposition depends on several ecological factors and forest management activities such as forest types, climate, site quality, stand increment, stand age, stand density, fertilization, and thinning (Binkley, 1984; Beyer, 1992; Kim, 2000; Thibodeau *et al*., 2000; Kim *et al*., 2010a). Forest types can have a significant influence on cellulose decomposition because of the difference in soil property and microclimate produced by different species. However, it is not easy to compare organic matter decomposition of different forest types due to the difference of substrate quality. The decomposition of cellulose filter papers can be used as an index of the rate of organic matter decomposition in forest types (Drewnik, 2006).

Red pine (*Pinus densiflora*), rigitaeda pine (*P. rigida* × *P. taeda*), and larch (*Larix leptolepis*) have been the three most important coniferous tree species planted throughout Korea during the last forty years (Kim *et al*., 2010b). There is a need for information in evaluating the direction and rates of change in cellulose decomposition among these coniferous plantations because of considerable variation of soil organic matter storage during plantation development (Kim *et al*., 2010b). The objectives of this study were to determine the effects of tree species on cellulose decomposition with the evaluation of the relationships between cellulose decomposition and soil environmental factors such as soil temperature, soil pH, soil moisture, and soil CO_2 efflux.

II. MATERIALS AND METHODS

The study was conducted in the Sambong Exhibition Forests located in Hamyanggun, Gyeongsangnamdo, and administered by Seobu National Forest Office, Korea Forest Service. The annual mean precipitation in this area is 1,322 mm and the annual mean temperature is 12.8°C. Experimental plots consisting of one deciduous (larch) and two evergreen coniferous plantations (red pine and rigitaeda pine) were located adjacent to each other on moderately productive sites. All the three plantations were established in 1963 on northeast facing slopes (5-15°). The study sites consisted of identical macroclimatic condition, quality, and stand age. Data were collected from three 20 m × 10 m plots within each plantation. The general characteristics with mean stand densities, diameter at breast height (DBH), and basal area of the three coniferous plantations are shown in Table 1. The difference of DBH and stand basal area among the three plantations was due to the common forest management practices such as thinning.

Cellulose filter papers were used for comparisons of relative cellulose decomposition rates among three coniferous forest types. Oven-dried cellulose filter papers (Advantec No. 2, 15 cm diameter, about 6 g) at 60°C for 48 h were weighed to the nearest 0.01 g and placed into each numbered 15 cm × 15 cm nylon glass bag (mesh size 1.5 mm). Nine points within each plot from each forest type were randomly selected to install the cellulose bags. The bags at each month were inserted vertically into the mineral soil to a depth of 15 cm with a straight-blade shovel. The procedure was repeated monthly for four months (July 30, August 26, September 23, and October 26, 2006) with final collection in November 27, 2006. The bags were removed from the soil and transported to a laboratory. The filter paper were oven-dried at 60°C for 48 h, 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.

To evaluate the relationships of cellulose decomposition and soil environmental factors, soil samples adjacent to cellulose bags were collected monthly at 20 cm depth using an Oakfield soil sampler to measure soil pH and soil moisture. The soil core samples were placed in plastic bags, transported to a laboratory and dried in an oven for 48 h at 105°C to quantify the soil gravimetric water content. Soil pH (1:5 soil : water suspension) was determined by glass electrode. Soil CO_2 efflux was measured *in situ* using an infrared gas analyzer system (Model EGM-4, PP systems, Hitchin, UK) equipped with a soil respiration chamber (Model SRC-2, PP systems). Soil temperature was measured at a 20 cm depth adjacent to the soil respiration chamber using a soil temperature probe (Model STP-1) attached with EGM-4. Cellulose mass loss data were analyzed with analysis of variance for significant differences among tree species with Tukey's test for mean separation analysis at $P < 0.05$ (SAS Institute, 2003). Pearson correlation analysis was performed to determine the relationships between cellulose mass loss rates and soil environmental factors such as soil temperature, soil pH, soil CO_2 efflux and soil water content.

III. RESULTS AND DISCUSSION

Mean mass loss rates during the study period were generally more rapid in rigitaeda pine (6.5 mg g^{-1} day^{-1}) than in red pine (6.2 mg g^{-1} day^{-1}) or larch (6.1 mg g^{-1} day^{-1}) plantations, although the mass loss rates were not significantly different among three coniferous plantations ($P > 0.05$). Increased mass loss rates in the rigitaeda plantation could be attributed to the difference of soil temperature or soil pH compared with other two coniferous plantations, although the difference in cellulose mass loss among tree species can be controlled by several factors such as substrate quality, soil water content, soil temperature, soil pH, and nutrients as affecting the activity of soil micro-flora and fauna (Brown and Howson, 1988; Donnelly *et al*., 1990; Beyer, 1992;

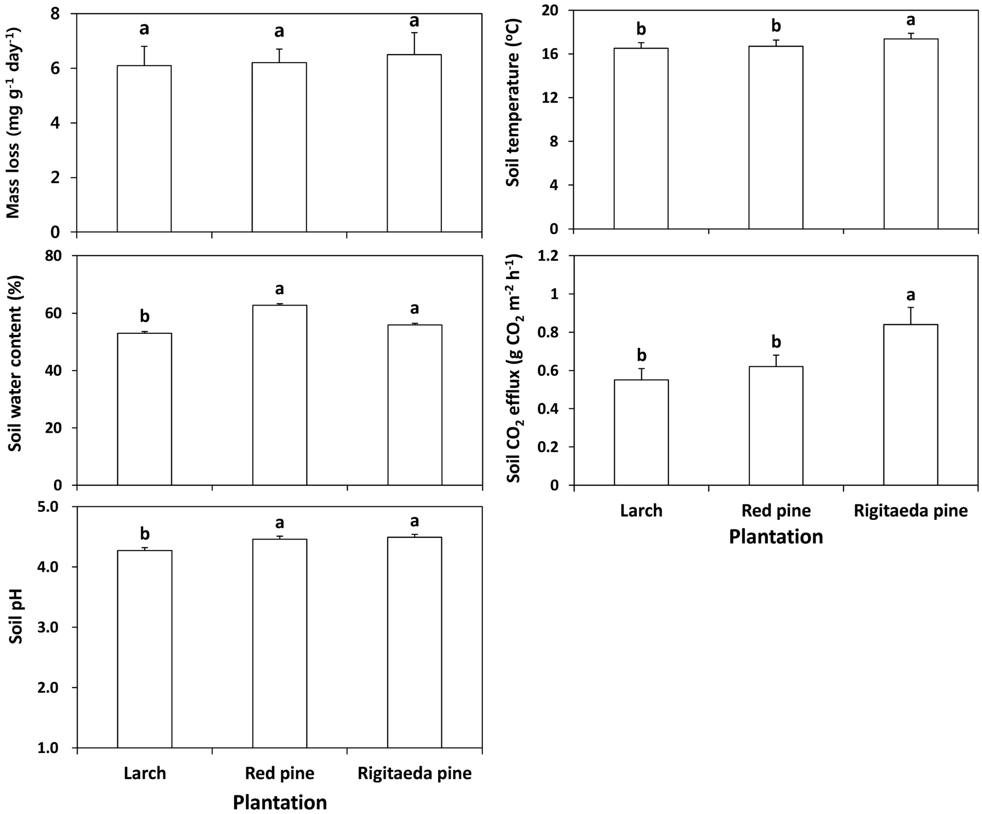

Fig. 1. Cellulose mass loss, soil temperature, soil water content, soil CO_2 efflux, and soil pH among three coniferous plantations (Mean±SE). Different letters on the bars denote significant differences among tree species treatments at $P < 0.05$.

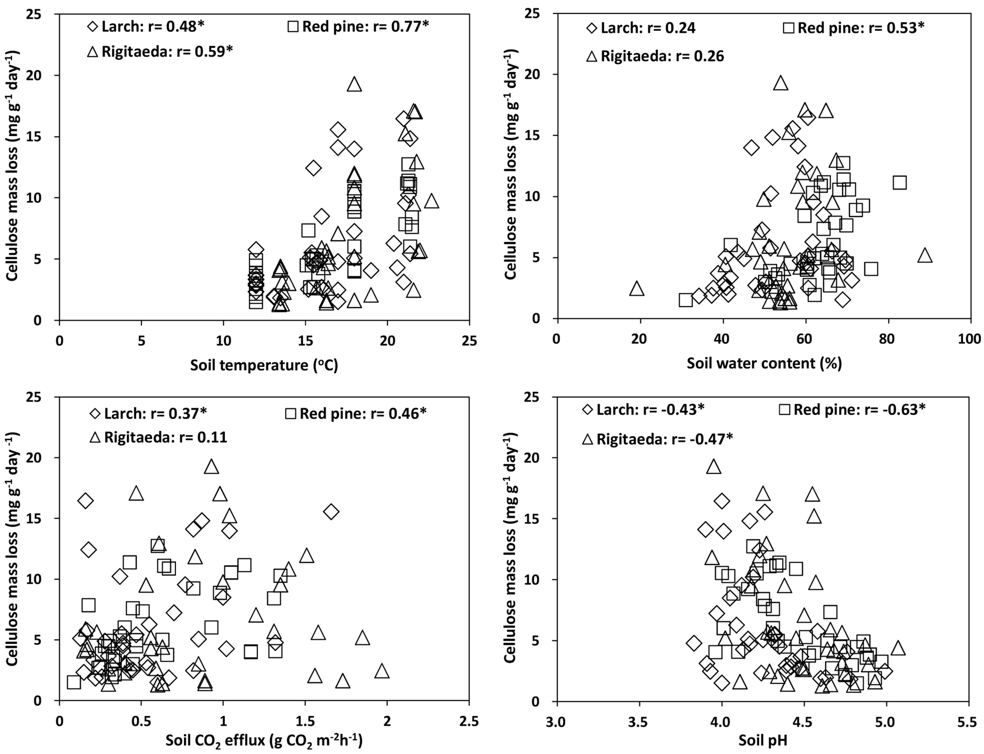

Fig. 2. Pearson correlation coefficient in cellulose mass loss rates and soil environmental factors among three coniferous plantations (*Significant at $P < 0.05$).

Thibodeau *et al.*, 2000; Kim *et al.*, 2010a). Mean soil temperature during the study period was significantly higher in regitaeda (17.4°C) than in red pine (16.7°C) or larch (16.5°C) plantations, but there were no observed differences in soil water content between the rigitaeda and larch plantations during the sampling times (Fig. 1). Also, mean soil pH during the study period was significantly lower in larch (pH 4.27) than in rigitaeda pine (pH 4.49) or red pine (pH 4.45) plantations. Similarly, Beyer (1992) found that cellulose decomposition was lower in spruce than in beech stands because of a lower pH and less available nitrogen in the soil solution.

Cellulose mass loss rates among each tree species were positively correlated with soil temperature (larch: $r = 0.48$, $P < 0.05$; red pine: $r = 0.78$, $P < 0.05$; rigitaeda pine: $r = 0.59$, $P < 0.05$) at the 20 cm soil depth (Fig. 2). Soil temperature was major biotic factor influencing cellulose decomposition in forest ecosystems (Donnelly *et al.*, 1990; Kim, 2000; Kim *et al.*, 2010a) because temperature has a definite effect on microbial community in soil. The favorable environmental conditions for the activity of soil micro-flora and fauna may be stimulated by high soil temperature. In addition, the cellulose decomposition and temperature in other pine forests were correlated positively in soil layers (Kim, 2000; Thibodeau *et al.*, 2000; Kim *et al.*, 2010a).

Soil CO_2 efflux rates were positively correlated with cellulose mass loss rates in the larch ($r = 0.37$, $P < 0.05$), and red pine ($r = 0.46$, $P < 0.05$), but not correlated in the rigitaeda pine ($r = 0.10$, $P > 0.05$). Cellulose mass loss could be a relative contributor of heterotrophic respiration because soil CO_2 efflux rates are determined by CO_2 released by organic matter decomposition (heterotrophic respiration) and by CO_2 released by living roots (autotrophic respiration). In addition, soil CO_2 efflux rates in forest ecosystems were significantly contributed to organic matter decomposition (Bowden *et al.*, 1993; Trumbore, 2000; Wickland *et al.*, 2010). However, no relationship in regitaeda pine could be due to another factor controlling relative contribution to total soil respiration. Autotrophic respiration might be high in rigitaeda pine because of high tree density and stand basal area compared with other two coniferous tree species (Table 1).

There was no significant correlation ($P > 0.05$) between cellulose mass loss and soil water content in larch ($r = 0.24$, $P > 0.05$) or rigitaeda pine ($r = 0.26$, $P > 0.05$), except for red pine ($r = 0.53$, $P < 0.05$). Soil water content plays the leading roles in the organic matter decomposition (Donnelly *et al.*, 1990; Kim, 2000). However, cellulose mass loss in this study was not attributed to the difference of soil water content among tree species because of high and fairly constant soil water over 50% occurred during the study periods (Fig. 1).

Soil pH was correlated negatively with cellulose mass loss rates (larch: $r = -0.43$, $P < 0.05$; red pine: $r = -0.63$, $P < 0.05$; rigitaeda pine: $r = -0.47$, $P < 0.05$). This result could be due to monthly incubation of cellulose bags because soil pH in forest ecosystems showed a seasonal fluctuation (Kim *et al.*, 2010a). Soil pH was depressed in the summer season when cellulose mass loss rates reached high values and was elevated in the winter season when cellulose mass loss rates reached low values (Kim *et al.*, 2010a). In addition, soil temperature and soil pH levels were correlated negatively ($r = -0.34$, $P < 0.05$) for study periods as soil pH decreased with increased soil temperature. In contrast to this result, high soil pH generally supported the great mass loss rates of organic matter because soil pH is closely related to microbial biomass activity and nutrient availability (Lee and Jose, 2003).

적 요

본 연구는 1963년도에 식재된 낙엽송, 소나무, 리기테다소나무 조림지를 대상으로 셀룰로오스 분해와 토양 환경인자 사이의 관계를 구명하기 위해 수행하였다. 셀룰로오스 분해에 영향을 미칠 수 있는 토양온도, 토양 수분함량, 토양 pH, 토양 이산화탄소 방출량을 2006년 7월부터 10월까지 4개월 동안 측정하였다. 셀룰로오스 분해율은 리기테다소나무(6.5mg g^{-1} day^{-1}), 소나무(6.2mg g^{-1} day^{-1}), 낙엽송(6.1mg g^{-1} day^{-1}) 순이었으나 수종간 유의적인 차이는 없었다($P > 0.05$). 셀룰로오스 분해율은 20cm 깊이의 토양 온도와 양의 상관(소나무: $r = 0.77$, $P < 0.05$; 리기테다소나무: $r = 0.59$, $P < 0.05$; 낙엽송: $r = 0.48$, $P < 0.05$)을 보였으나, 토양 pH와는 음의 상관(소나무: $r = -0.63$, $P < 0.05$; 리기테다소나무: $r = -0.47$, $P < 0.05$; 낙엽송: $r = -0.43$, $P < 0.05$)이 있었다. 토양이산화탄소방출량과 셀룰로오스 분해율은 소나무($r = 0.46$, $P < 0.05$), 낙엽송($r = 0.37$, $P < 0.05$), 토양 수분함량과 셀룰로오스 분해율은 소나무($r = 0.53$, $P < 0.05$)와 유의적인 양의 상관($P < 0.05$)이 있었다. 본 연구 결과에 따르면 셀룰로오스 분해는 각기 다른 침엽 수종으로부터 발생하는 토양 환경요인에 의해 영향을 받는 것으로 나타났다.

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