

The Effects of Thinning on Fine Root Distribution and Litterfall in a *Pinus koraiensis* Plantation

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ABSTRACT: The purpose of this study was to investigate the effects of thinning on fine root biomass and vertical distribution and litterfall amount in a 50 year old *Pinus koraiensis* plantation in Chuncheon, Kangwon Province. Fine root (< 2 mm in diameter) biomass (367 g/m²) in the site 'OC_75', thinning once in 1975, was 68% of those in the site 'CON', no thinning after planting, and in the site 'TC_00', thinning twice in 1975 and 2000. There were no significant differences of dead roots among treatments. Diameter 0~1 mm roots were vertically decreased only in the TC_00 site. The litterfall was very similar between OC_75 (5.2 Mg ha⁻¹ yr⁻¹) and TC_00 (4.7 Mg ha⁻¹ yr⁻¹), but the composition of litterfall was different: The proportion of leaves and branches was 80% and 13% in OC_75 and 56% and 36% in TC_00, respectively. Reduction of *P. koraiensis* density by thinning decreased leaf litter as well as fine roots of *P. koraiensis*, but increased fine roots production by neighboring understory plants offset the reduction of fine roots of *P. koraiensis*. We suggest that belowground as well as aboveground responses, including both over- and understory vegetation, should be considered to measure the responses of trees in thinned forest ecosystems.

Key words: Belowground, Fine root biomass, Litterfall, Species composition, Soil core, Stand density, Understory composition

INTRODUCTION

Thinning, reducing stand density of trees, primarily improves growth and timber quality of residual trees by increasing the availability of light, soil water and nutrients (Fisher and Binkley 2000, Nyland 2002). Furthermore, thinning increase the frequency of desirable genotypes in the population by removing the weak ones, enhances forest health, recovers potential mortality, and reduces fire hazard (Smith 1986, Yi et al. 2002).

The effects of thinning on aboveground physiological and ecological traits have been broadly studied (Harrington and Edwards 1999, Thomas et al. 1999, Tang et al. 2005, Blanco et al. 2008), and the responses of aboveground traits to thinning have also been well reported in domestic studies. The reduction of crown density by thinning decreased rainfall interception and evaporation in an *Abies holophylla* plantation in Gwangneung (Kim et al. 2003). Son et al. (2001) reported that moderate thinning increased biomass and nutrient contents of twigs at a 12-year old *Pinus koraiensis* plantation. Yi et al. (2002) reported that genetic characteristics of seeds were significantly improved after thinning.

Fine roots are as important as leaf litter in carbon and nutrient

biogeochemical cycling in terrestrial temperate ecosystems (Vogt et al. 1996). Fine roots comprise only a small portion of total biomass (Jackson et al. 1997, Park et al. 2007), but fine root production represents a large proportion of total production in most forest ecosystems (Fogel 1983, Joslin and Henderson 1987, Nadelhoffer and Raich 1992). Thinning influences on aboveground components in forest ecosystems have been largely studied as above mentioned, and a few studies have investigated belowground responses after thinning (Lopez et al. 2003, Tang et al. 2005). Thinning reduced litterfall in most forest types (Harrington and Edwards 1999, Blanco et al. 2008, Kim et al. 2009), but fine root biomass was dependent on forest types (Lopez et al. 2003, Tang et al. 2005). However, except one study of a ponderosa pine plantation in Sierra Nevada (Campbell et al. 2009) there are few studies that have measured or estimated litterfall simultaneously with fine roots after thinning, even though the two components are very important pathways of nutrient transfer to forest soil (Bray and Gorham 1964, Vitousek et al. 1995).

The purpose of this study was to investigate the effect of thinning on litterfall and fine root biomass in a 50 years *P. koraiensis* plantation. *P. koraiensis* is a suggested species for timber production in Korea and comprises 22% of total planted surface (Korea Forest Service 2008).

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MATERIALS AND METHODS

Study Sites

This study was conducted at a *P. koraiensis* plantation (N37° 52', E127° 52'), which is located in Dong-myun, Chuncheon, Kangwon Province, Korea. The area of the plantation is 118 ha. *P. koraiensis* seedlings were planted in 1960s and 1980s, which made V and III age-class, respectively (Yang's unpublished data).

All study sites have similar west or northwest aspects and average slopes of 25° (Table 1). The region is underlain by granite and soils are classified as dry brown forest soil (B1) with shallow depth and low organic content.

Three treatments were applied in this study (Table 1): no density manipulation after planting in 1960s (hereafter "CON"), thinning once in 1975 to improve composition, growth, and/or spacing of residual trees (hereafter "OC_75"), and thinning in 1975 and 2000 to improve the composition, growth, and/or spacing of residual trees (hereafter "TC_00").

Vegetation and Soil

Four 20 m × 20 m subplots were established in the 1.0 ha area for each treatment. Each subplot systematically has two sizes of sub-subplots to measure shrubs and herbaceous composition. Height, diameter at breast height (DBH), and stem basal area were measured for all trees higher than 5 cm at DBH in all 20 × 20 m subplots. Species and density of shrubs of trees smaller than 5 cm at DBH at 5 × 5 m sub-subplot and herbaceous were measured on 5 × 1 m sub-subplot.

For physical and chemical analysis of soils, 0.5 kg soil was sampled at 0~20 cm and 20~50 cm depths at four randomly selected locations which had no indication of recent disturbance. Soil samples were analyzed at the KFRI (Korea Forest Research Institute) soil lab (National Institute of Agricultural Science and Technology 2000). Soil texture was measured by hydrometer method at 30°C and organic matter contents were analyzed by Tyurin method. Soil pH was observed by 10 g soil mixing with distilled

water at a 1:5 ratio. Total N and CEC were analyzed by Micro-Kjeldahl method with 1 g soil and by Brown method with 1 N HN₄OAc and 1 N CH₃COOH extracts.

Litterfall

Eight circular litter traps with area of 0.25 m² were systematically installed at 1 m above from the forest floor every 10 m distance. We collected litterfall monthly from the traps starting in July 2005. Unfortunately, litterfall in the control plot was not included in this study owing to an experimental error. Collected litterfall was air dried in the shade and separated into leaf litter, twigs, wood debris (including seeds), and other. Dry mass was measured after drying samples for 5 days at 65°C.

Fine Roots

PVC soil corers were made to collect fine roots. One edge of the 60 cm length with Ø 5 cm was sharpened to reduce soil compaction during hammering soil corers into soils. Soil cores were systematically collected at 8 locations every 20 m distance in each plot. However, areas with clear signs of recent disturbance, such as tip-up mounds, were excluded. A soil probe was used to choose coring locations to avoid large roots and rocks. Two root cores at 2 m distance were extracted (i.e. 16 cores per plot).

We did not collect Oi layer because there were no roots there. Organic layer (Oe + Oa) was separated by soil color and mineral soil was divided into 0~10 cm and 10~20 cm depth increments. Soil cores were kept cool during transportation. The depth increments were composited across the two cores in a location, to make $n=8$ per plot.

Soil cores were processed within a week of collection. Fine roots (< 2 mm in diameter) were picked from the soil samples. Picked roots were washed with tap water, and washed live roots were sorted into two diameter classes: 0~1 mm and 1~2 mm. Dead roots < 2 mm in diameter were distinguished from live roots by color, resilience, hardness of bark and xylem (Park 2006). Sorted roots were oven dried at 65°C for a week and weighed.

Table 1. Sites description of *P. koraiensis* plantation in Chuncheon

Site	Latitude	Longitude	Elevation (m)	Aspect	Slope (°)	Density (trees/ha)	Average DBH (cm)	Treatment
CON	N37° 53'	E127° 52'	346	W	30	1,156	19.5	No thinning after planting in 1960s.
OC_75	N37° 53'	E127° 52'	329	W	16	675	26.4	Improvement thinning (15% of trees removed) in 1975 after planting 1960s.
TC_00	N37° 52'	E127° 52'	427	SW	28	338	31.9	Thinning in 2000 (25% of trees removed) and improvement thinning in 1975 (15% of trees removed) after planting 1960s.

Statistical Analysis

Fine root biomass and litterfall were compared among treatments by one-way analysis of variance (ANOVA). Fine root vertical distribution were tested among two main factors, site and soil depth, with Duncan's multiple comparison tests.

Correlation analyses were used to test the relationship between fine root biomass and litterfall. All probabilities were tested at the 5% significant level.

RESULTS AND DISCUSSION

Litterfall

The litterfall amounts were not statistically different between treatments, 5.2 Mg/ha/yr at site OC_75 and 4.7 Mg/ha/yr at site TC_00 (Fig. 1), but the annual litterfall was 10% lower at the recently thinned site. As Hennessey et al. (1992) reported that the litterfall amounts were proportional to the tree basal area, we found a similar relationship with the decrease of litterfall less than that of stem basal area (Fig. 2).

In contrast, the composition of litterfall was different between the two thinned sites. The proportion of leaves and branches in litterfall was 80% and 13% at site OC_75. However, at site TC_00 the proportion of leaf litterfall decreased to 56% and that of twigs increased to 36%. The different composition of litterfall was explained by thinning effects. Thinning improves light, water, and nutrient availability resulting in increased leaf area index per tree and photosynthetic rate (Martinez and Perry 1997, Prescott 1997). Thinning increased length and dry weight of twigs in a 12 year-old pine plantation (Son et al. 2001) and leaf litter nitrogen concentrations, which were negatively correlated with annual leaf litterfall

(Trofymow et al. 1991, Carlyle 1998, Inagaki et al. 2008). Furthermore, thinning abruptly changed microclimates such as winds and direct radiation in the canopy, which can damage residual trees.

Fine Root Biomass

We hypothesized that fine root biomass would not be different among treatments; however, live fine root (< 2 mm in diameter) biomass was 68% lower at site OC_75 than at the other sites (Fig. 3) ($P = 0.08$). There were no statistical differences in dead roots among treatments ($P = 0.32$). Average dead roots were 12% of live root biomass.

Fine root biomass of this study was as low as one half of Japanese larch and pitch pine plantation in central Korea (Hwang et al. 2007). However, the amount was similar to, or a little lower than those observed in the coniferous forests located in Washington State (Keyes and Grier 1981), Massachusetts (Magill et al. 1997), New Hampshire (Yanai et al. 2006), and Maine (Safford and Bell 1972). Because fine root biomass varies with stand age, nutrient availability, climate, and slope and aspect (Fogel 1983, Aber et al. 1985, Vogt et al. 1996), direct comparison of data in diverse studies should be careful even in the same forest type. Furthermore, time of root sampling and the picking process in the lab are considerable factors in fine root studies (Singh et al. 1984, Makkonen and Helmisaari 2001).

Usually, thinning reduced the living fine roots of crop trees because of the decrease in stem density after thinning (Santantonio and Santantonio 1987, Tang et al. 2005), but Lopez et al. (1998) reported thinning increased fine roots in the top 20 cm of soil in a Mediterranean forest. In this study we didn't separate understory roots from *P. koraiensis* because it is difficult and time consuming

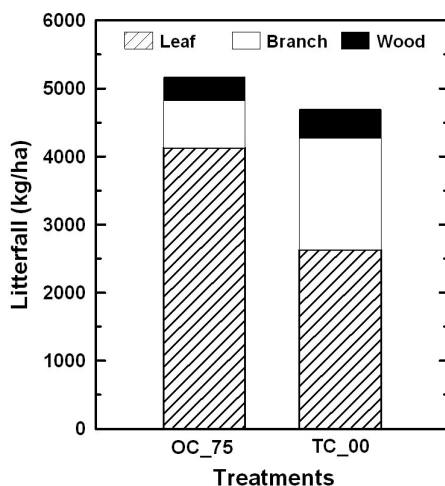


Fig. 1. Litterfall including leaf litter, branch (branch + twig), and woods in a *P. koraiensis* plantation in Chuncheon.

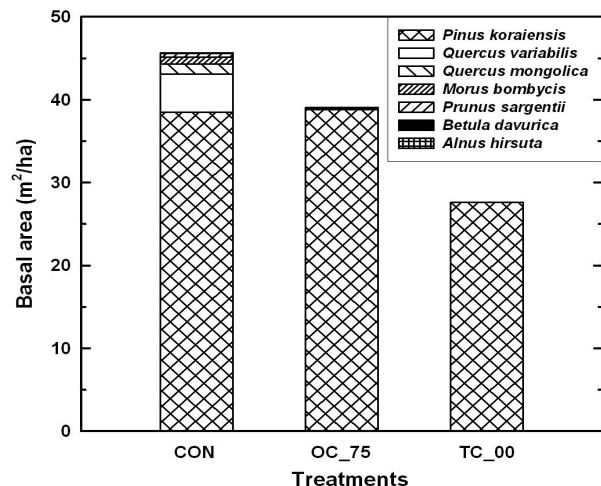


Fig. 2. Stem basal area (m²/ha) of dominant and codominant trees at the *P. koraiensis* plantation in Chuncheon.

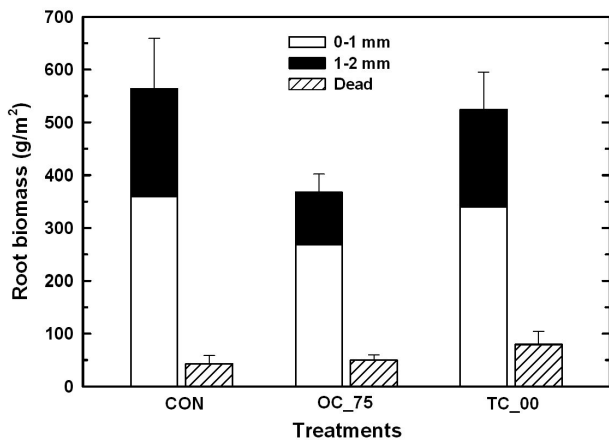


Fig. 3. Fine root (< 2 mm in diameter) biomass and dead root mass in a *P. koraiensis* plantation in Chuncheon. Vertical bars represent one standard errors.

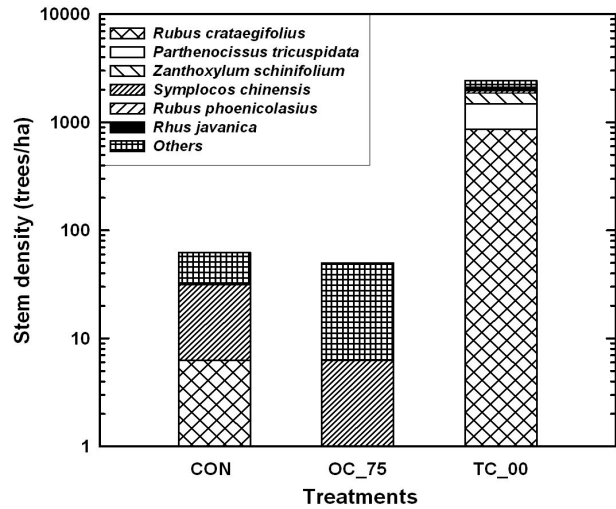


Fig. 4. Density (trees/ha) of understory trees at the *P. koraiensis* plantation in Chuncheon.

to identify them (Yanai et al. 2008). Based on our results, possible explanations of the lowest fine root biomass at the OC_75 site were the lower basal area of *P. koraiensis* relative to site CON (Fig. 2) as well as lower density of understory relative to site TC_00 (Fig. 4). Our results showed the same pattern with those of Campbell et al. (2009), which reported that thinning reduced coarse root biomass, but increased fine roots by rapid increase of shrubs.

Fine Root Distribution

Generally, fine root biomass declines with soil depth (Park 2006, 2007). However, only the biomass of the finer roots (0~1 mm in diameter) declined at site TC_00 ($P=0.09$). Over 70% of finest roots were in the top 10 cm of mineral soil at site TC_00, but only

half of finer roots were found at those depths at the other sites (Fig. 5). We observed no differences in fine root depth distribution in other sites and 1~2 mm roots.

In this study, there was no correlation between soil properties and fine root characteristics. Thinning did not affect physical and chemical properties of the soil (Table 2). Recently thinned sites showed a little higher organic matter and total N at 0~20 cm soil depth, but there were no statistical differences among treatments. However, other studies showed higher total carbon and nitrogen concentrations in thinned sites than a control site (Inagake et al. 2008).

It appears that there is no treatment effect on fine root distri-

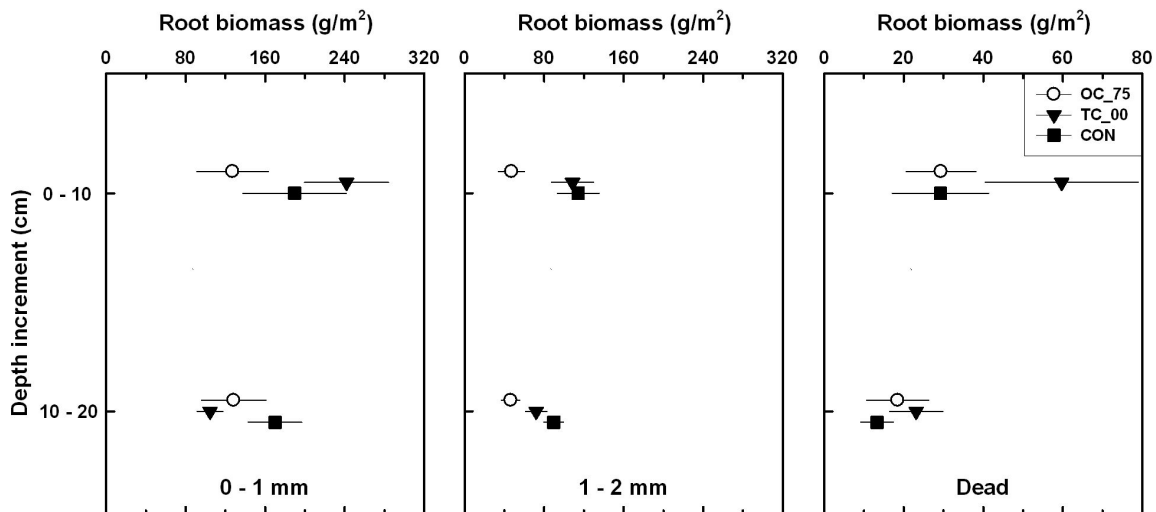


Fig. 5. Fine root (< 2 mm in diameter) biomass distribution with soil increment in a *P. koraiensis* plantation in Chuncheon. Horizontal bars represent one standard errors.

Table 2. Soil physical and chemical characteristics of *P. koraiensis* plantation in Chuncheon

Soil depth (cm)	Treatment	Soil texture			pH	Organic matter (%)	Total N (g/kg)	CEC (cmol _e /kg)
		Sand (%)	Silt (%)	Clay (%)				
0~20	CON	40 (2)	43 (1)	17 (1)	5.4 (0.1)	1.9 (0.6)	0.55 (0.05)	15.5 (0.3)
	OC_75	43 (4)	35 (6)	22 (1)	5.5 (0.1)	1.5 (0.6)	0.69 (0.15)	13.3 (0.3)
	TC_00	56 (6)	29 (4)	15 (2)	5.4 (0.0)	2.2 (0.0)	0.90 (0.03)	13.4 (2.0)
20~40	CON	40 (4)	42 (2)	18 (2)	5.3 (0.1)	1.7 (0.6)	0.85 (0.17)	16.4 (1.2)
	OC_75	43 (7)	35 (6)	21 (0)	5.3 (0.1)	1.6 (0.1)	0.94 (0.23)	14.2 (0.8)
	TC_00	56 (9)	28 (4)	16 (4)	5.6 (0.0)	1.3 (0.3)	0.77 (0.01)	14.4 (0.1)

Parentheses represent one standard errors ($n = 4$)

bution of *P. koraiensis*. However, reduced density of *P. koraiensis* by thinning improved light availability in the ground (Lopez et al. 1998, Rambo and North 2009) resulting in increased density of understory plants (Fig. 4). Stem density and basal area of trees larger than 5 cm in DBH at site TC_00 were clearly lower than those of other sites. However, the density of the understory at site TC_00 was 43 times greater than the other sites (Fig. 4) or as reported in other studies (Wolk and Rocca 2009). Because fine root depth distribution differs by species (Gale and Grigal 1987, Finzi et al. 1998, Yanai et al. 2008), the increase of the understory population can influence root distribution with soil depth. Therefore, it is possible that the high understory density at site TC_00 increased finer root biomass in the top 10 cm of mineral soil.

Like live roots, the distribution of dead roots differed by site. Dead roots declined more steeply with depth at site TC_00 than at other sites (Fig. 5). Average dead roots were more concentrated near the surface (68% of total dead roots) than live roots (57% of total live roots).

In this *P. koraiensis* plantation, reduced density of trees was associated with a decrease in fine root biomass of *P. koraiensis* as well as leaf litter. However, the increased density of other plants in the understory at the recent thinning sites made up for the reduction of fine roots by increasing finer roots in the top mineral soil. Litter traps were higher than the height of the majority of understory trees; therefore, traps were ineffective at collecting their litter. Total litterfall amount would not be decreased if that of the understory was included. Lower height of litter traps should be developed to include litterfall of understory species.

Reduction of *P. koraiensis* density in the canopy decreased leaf litter as well as fine roots of *P. koraiensis*, but stimulation of the understory plants offset the reduction of fine roots of *P. koraiensis*. More research is required to better understand the effects of thinning on responses of understory vegetation to adequately estimate their

impact on ecosystem-level carbon balance. We suggest that considering belowground as well as aboveground responses, including both over- and understory vegetation to measure carbon allocation in thinned forest ecosystems.

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