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Net Fine Root Carbon Production in *Pinus densiflora*, *Pinus koraiensis*, *Larix leptolepis* and *Quercus acutissima* Stands, Gongju area, Chungnam Province, Korea

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This study was carried out to estimate annual carbon production by fine root in *Pinus densiflora*, *Pinus koraiensis*, *Larix leptolepis* and *Quercus acutissima* stands of Gongju region, Korea. Soil samples were taken at 0–30 cm, 30–60 cm, and 60–90 cm soil depths from April to November (monthly increment method) in 2007 using soil sampler. Fine root carbon biomass was higher at 0–30 cm soil depth than in the other soil depths. Total fine root carbon biomass at 0–90 cm soil depth was highest in *Larix* leptolespis stand among the four study stands. Net fine root carbon production (kg ha^{-1} yr^{-1}) in *Pinus densiflora*, *Pinus koraiensis*, *Larix leptolepis* and *Quercus acutissima* stands were 889 kg, 2,266 kg, 851 kg, and 1,121 kg at 0–30 cm soil depth, respectively. Total net fine root carbon production (kg ha^{-1} yr^{-1}) was highest in Pinus koraiensis stand among the four study stands. Fine root turnover rates in the four stands were ranged from 0.59 to 2.63 at 0–30 cm, 30–60 cm, and 60–90 cm soil depth.

INTRODUCTION

After the earth's average air temperature reached an all–time high recently, many scientist expressed concern about the potential for significant global warming as a result of the increased carbon dioxide (CO_2) and other greenhouse gases (CFC_s, CH_4, and N_2O) within the coming century (Schlesinger, 1991; Hansen, 1993). Even small changes in temperature can have dramatic impacts on the earth complex atmosphere, ocean, land, and life systems (Hair and Sampson, 1992). Increasing population and economic activity will increase the concentration of CO_2 in the atmosphere and may accelerate changes in global climate which may have important consequences for the earth's ecology.

Forests have received considerable attention because they are a major sink for C cycle. The carbon sinks of plants include roots, shoots, and when plants are exposed to large seasonal climatic changes, storage reserves for maintenance during and after the period of dormancy. Not like a shoots, fine root carbon dynamics are seldom measured directly because these studies are labor intensive (Burke and Raynal, 1994) and also sampling methods are not standardized (Laurenroth *et al*., 1986; Nadelhoffer and Raich, 1992; Singh *et al*., 1984; Vogt *et al*., 1986). However, it is true that a large part of the carbon in deciduous forests is allocated in fine root, yet this process is seldom measured (Burke and Raynal, 1994).

The objective of this study was to estimate the amount of annual C production by fine root in *Pinus densiflora*, *Pinus koraiensis*, *Larix leptolepis*, and *Quercus acutissima* stands of Gongju region, Chungnam Province, Korea.

MATERIALS AND METHODS

This study was conducted in 2007 in *Pinus densiflora*, *Pinus koraiensis*, *Larix leptolepis* and *Quercus acutissima* stands at the Gongju city of Chungnam Province, Korea. Annual mean air temperature is 11.9 ˚C and total annual precipitation averages 1,534 mm. The elevation range of the study site was 94~214 m. The average age of the *Pinus densiflora* stand was 36 years and the number of trees per ha are 1,331. The average age of the *Pinus koraiensis* stand was 39 years and the number of trees per ha was 1,206. The average age of the *Larix leptolepis* stand was 36 years and the number of trees per ha was 588. The average age of the *Quercus acutissima* stand was 42 years and the number of trees per ha was 363. The study sites was dominated by *Smilax china*, *Oplismenus undulatifolius*, *Corylus heterophylla*, *Rhus trichocarpa*, *Lindera obtusiloba* and *platycarya strobilacea*. The soil is brown forest soil, a representative soil of Korea.

For this study, three 10 m×10 m permanent plots, which was established on a relatively similar slope, aspect and soil, were randomly selected in each stand. Fine root biomass was established by monthly soil coring from April to November at five random locations in each plot (Hwang 1996; Makkonen and Helmisaari, 1999). Sample points for coring were randomly selected from the permanent grid. A stainless steel core (7.4 cm diameter and

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Table 1. Equations used for estimating fine root production (Fairely and Alexander, 1985)

△Live root biomass	△Dead root biomass	Production equations
Increase	Increase	$P = {}^{\triangle}B_{live} + {}^{\triangle}B_{dead}$
Decrease	Increase	$P = 0$ or ${}^{\triangle}B_{live} + {}^{\triangle}B_{Dead}$
Increase	Decrease	$P = {}^{\triangle}B_{live}$
Decrease	Decrease	$P = 0$

All analysis was conducted using the general linear model procedure of the statistical analysis system(SAS, 1988). Tukey's HSD test was used to statistically separate mean test of significance were at the 0.05 level unless otherwise stated.

30 cm long) was used to take soil sample.

Samples were returned to the laboratory and stored at 4 ˚C until they were processed (Hwang, 1996; Burke and Raynal, 1994). Roots from mineral soil were wet sieved using a 2 mm mesh screen and fragmented root that passed the screen were hand sorted(Hwang, 1996; Burke and Raynal, 1994). Fine roots (<2 mm) were sorted and classified as live and dead on the basis of morphology, flotation and color with careful microscopic observation. Roots were then dried to a constant mass at 65 ˚C and weighed. Dried fine root samples were ground for carbon concentration.

In this study, fine root production was calculated by balancing the monthly live and dead fine root biomass according to the decision matrix presented by Fairly and Alexander (1985) (Table 1). Fine root turnover was calculated as the ratio of fine root production to biomass (Burke and Raynal, 1994). Fine root subsamples were used for organic matter analysis by loss on ignition.

RESULTS AND DISCUSSION

The average fine root carbon biomass (live + dead) in *Pinus densiflora*, *Pinus koraiensis*, *Larix leptolepis* and *Quercus acutissima* stands was higher at the 0~30 cm soil depth than in the other soil depths (Tables 2, 3, 4 and 5). The average fine root carbon biomass (kg ha^{-1}) in *Pinus densiflora*, *Pinus koraiensis*, *Larix leptolepis* and *Quercus acutissima* stands were 889 kg, 2,266 kg, 851 kg, and 1,121 kg at 0–30 cm soil depth, respectively. The fine root carbon biomass was similar with in *Pinus rigida* plantation of Korea (1,322 kg ha^{-1}; Hwang, 1996) and hardwood stands of Northeast U.S.A (1,150 kg ha^{-1}; Burke and Raynal, 1984). The total fine root carbon biomass was ranged from 1,703.1 kg to 2,151.7 kg at 0–90 cm soil depth in the four study stands. As shown in Tables 2, 3, 4 and 5, the total fine root carbon biomass was highest in *Larix leptolepis* among the study stands.

Seasonal changes in fine root carbon biomass of the *Pinus densiflora*, *Pinus koraiensis*, *Larix leptolepis* and *Quercus acutissima* stands varied among sampling times. Major peak in fine root carbon biomass was found in April and July in the *Pinus densiflora* stand (Table 2), April in *Pinus koraiensis* stand (Table 3), June in *Larix leptolepis* Stand (Table 4) and also May and August in *Quercus acutissima* stands (Table 5). However, Burke and Raynal (1994) reported the fine

Table 2. Fine root carbon biomass (kg ha^{-1}) in *Pinus densiflora* stand at 0–30 cm, 30–60 cm, and 60–90 cm soil depths. The number in parenthesis is one standard error of the mean (n=12 at 0–30 cm and 30–60 cm, n=6 at 60–90 cm)

Soil depth	22 Apr.	20 May.	20 Jun.	22 Jul.	22 Aug.	21 Sep.	20 Oct.	23 Nov.	Mean
0–30 cm	1556.3 (353)	1056.1 (103)	1267.8 (176)	1495.8 (385)	977.0 (131)	786.3 (148)	623.5 (91)	763.0 (175)	1065.7
30–60 cm	482.7 (55)	279.2 (62)	369.9 (83)	474.6 (143)	393.1 (72)	314.1 (45)	230.3 (36)	551.3 (137)	386.9
60–90 cm	412.5 (60)	318.7 (57)	228.0 (56)	323.4 (125)	230.3 (35)	183.8 (49)	141.9 (38)	165.2 (42)	250.5
0–90 cm									1703.1

Table 3. Fine root carbon biomass (kg ha^{-1}) in *Pinus koraiensis* stand at 0–30 cm, 30–60 cm, and 60–90 cm soil depths. The number in parenthesis is one standard error of the mean (n=12 at 0–30 cm and 30–60 cm, n=6 at 60–90 cm)

Soil depth	22 Apr.	20 May.	20 Jun.	22 Jul.	22 Aug.	21 Sep.	20 Oct.	23 Nov.	Mean
0–30 cm	2097.0 (349)	1447.0 (439)	1756.4 (293)	853.8 (143)	1751.7 (143)	774.7 (140)	904.9 (151)	1214.3 (226)	1350.0
30–60 cm	405.0 (113)	188.4 (50)	318.7 (81)	269.9 (68)	337.3 (61)	321.0 (56)	258.2 (66)	309.4 (72)	301.0
60–90 cm	74.0 (32)	134.9 (29)	148.9 (71)	162.8 (45)	300.1 (92)	225.7 (76)	193.1 (46)	144.2 (57)	173.9
0–90 cm									1844.8

Table 4. Fine root carbon biomass (kg ha^{-1}) in *Larix leptolepis* stand at 0–30 cm, 30–60 cm, and 60–90 cm soil depths. The number in parenthesis is one standard error of the mean (n=12 at 0–30 cm and 30–60 cm, n=6 at 60–90 cm)

Soil depth	22 Apr.	20 May.	20 Jun.	22 Jul.	22 Aug.	21 Sep.	20 Oct.	23 Nov.	Mean
0–30 cm	1326.0 (195)	1340.0 (181)	1833.1 (146)	1542.3 263)	1770.3 (202)	1765.7 (343)	1279.5 (222)	663.0 (110)	1440.0
30–60 cm	519.7 (107)	274.5 (54)	497.8 (122)	483.9 (173)	593.2 (123)	339.6 (71)	481.5 (82)	428.0 (114)	452.3
60–90 cm	160.9 (67)	437.3 (120)	214.0 (68)	239.6 (81)	244.3 (110)	181.5 (47)	323.4 (57)	274.5 (71)	259.4
0–90 cm									2151.7

Table 5. Fine root carbon biomass (kg ha^{-1}) in *Quercus acutissima* stand at 0–30 cm, 30–60 cm, and 60–90 cm soil depths. The number in parenthesis is one standard error of the mean (n=12 at 0–30 cm and 30–60 cm, n=6 at 60–90 cm)

Soil depth	22 Apr.	20 May.	20 Jun.	22 Jul.	22 Aug.	21 Sep.	20 Oct.	23 Nov.	Mean
0–30 cm	1493.5 (172)	1677.3 (244)	1565.6 (127)	1107.3 (144)	1777.3 (316)	1267.8 (187)	895.6 (120)	665.3 (138)	1306.2
30–60 cm	469.9 (85)	467.6 (95)	465.3 (72)	362.9 (84)	586.2 (165)	325.7 (57)	456.0 (151)	402.5 (67)	442.0
60–90 cm	323.4 (93)	430.4 (117)	307.1 (85)	172.1 (56)	367.6 (134)	162.8 (409)	172.1 (52)	69.8 (56)	250.7
0–90 cm									1998.9

root biomass in Northeast hardwood stands of U.S.A. was peak in May. Also, McClaugherty *et al*. (1982) reported highest fine root biomass in spring season.

Net fine root carbon production (kg ha^{-1} yr^{-1}) in *Pinus densiflora*, *Pinus koraiensis*, *Larix leptolepis* and *Quercus acutissima* stands were 889 kg, 2,266 kg, 851 kg, and 1,121 kg at 0–30 cm soil depth, respectively (Table 6, 7, 8, and 9). The net fine root carbon production was more than in *Pinus rigida* plantation forests of Korea (671 kg at 0–20 cm; Hwang, 1997) and more or lower than in Northeast hardwood stands of U.S.A. (1,100 kg ha^{-1}; Burke and Raynal, 1994). The net fine root carbon production in the four study stands was also higher at 0–30cm soil depth than in other soil depths. As shown in Tables 6, 7, 8 and 9, the net fine root carbon production 0–30 cm soil depth was highest in *Pinus koraiensis* stand among the study stand.

Total fine root NPP at 0–90 cm were 1,731 kg, 3,092 kg, 2,249 kg and 2,068 kg in *Pinus densiflora*, *Pinus koraiensis*, *Larix leptolepis* and *Quercus acutissima* stands, respectively (Tables 6, 7, 8 and 9). These were very similar to those for Northeast hardwood stands of U.S.A. (2,000–2,500 kg at 0–100 cm soil depths; Raynal and Burke, 1994). Park (2001) reported that net primary carbon production by leaves was 1,100 kg, 1,200 kg, and 1,200 kg in *Quercus mongolica* stands in Gongju, Pohang, and Yanyang area of Korea. This result indicates the important role of fine root to carbon cycle in for-

Table 6. Net fine root carbon production (kg ha^{-1} yr^{-1}) in *Pinus densiflora* stand of Gongju area at 0–30 cm, 30–60 cm, and 60–90 cm soil depths

Soil depth (cm)	22 Apr. ~20 May.	20 May. ~20 Jun.	20 Jun. ~22 Jul.	22 Jul. ~22 Aug	22 Aug. ~21 Sep.	21 Sep. ~20 Oct.	20 Oct. ~23 Nov.	Total
0–30	0	212	330	0	0	0	347	889
30–60	0	91	105	0	0	0	435	630
60–90	0	0	95	0	0	0	116	212
0–90								1731

Table 7. Net fine root carbon production (kg ha^{-1} yr^{-1}) in *Pinus koraiensis* stand of Gongju area at 0–30 cm, 30–60 cm, and 60–90 cm soil depths

Soil depth (cm)	22 Apr. ~20 May.	20 May. ~20 Jun.	20 Jun. ~22 Jul.	22 Jul. ~22 Aug	22 Aug. ~21 Sep.	21 Sep. ~20 Oct.	20 Oct. ~23 Nov.	Total
0–30	0	309	0	1333	0	130	493	2266
30–60	0	130	0	167	0	0	142	440
60–90	140	14	14	219	0	0	0	387
0–90								3092

Table 8. Net fine root carbon production (kg ha^{-1} yr^{-1}) in *Larix leptolepis* stand of Gongju area at 0–30 cm, 30–60 cm, and 60–90 cm soil depths

Soil depth (cm)	22 Apr. ~20 May.	20 May. ~20 Jun.	20 Jun. ~22 Jul.	22 Jul. ~22 Aug	22 Aug. ~21 Sep.	21 Sep. ~20 Oct.	20 Oct. ~23 Nov.	Total
0–30	14	439	0	344	0	0	0	851
30–60	0	244	0	330	0	142	0	717
60–90	293	0	26	65	0	298	0	681
0–90								2249

Table 9. Net fine root carbon production (kg ha^{-1} yr^{-1}) in *Quercus acutissima* stand of Gongju area at 0–30 cm, 30–60 cm, and 60–90 cm soil depths

Soil depth (cm)	22 Apr. ~20 May.	20 May. ~20 Jun.	20 Jun. ~22 Jul.	22 Jul. ~22 Aug	22 Aug. ~21 Sep.	21 Sep. ~20 Oct.	20 Oct. ~23 Nov.	Total
0–30	249	0	0	872	0	0	0	1121
30–60	0	0	0	344	0	130	0	475
60–90	153	0	0	319	0	0	0	472
0–90								2068

Table 10. Fine root turnover rate (%/yr) in *Pinus densiflora*, *Larix leptolepis*, *Pinus koraiensis*, and *Quercus acutissima* Stand in Gongju area at 0-30cm, 30-60cm, and 60-90cm soil depths.

Soil depth (cm)	Pinus densiflora	Pinus koraiensis	Larix leptolepis	Quercus acutissima
0-30	0.83	1.68	0.59	0.86
30-60	1.63	1.46	1.58	1.07
60-90	0.85	2.24	2.63	1.88

est ecosystems like other reports (Hansen, 1993; Cooper, 1983; Burke and Raynal, 1994). As shown in Tables 6, 7, 8 and 9, the total net fine root carbon production in 0–90 cm soil depth was highest in *Pinus koraiensis* stand among the study stand.

Fine root turnover rate (yr) was ranged from 0.59 to 2.63 (Table 10). This rate was in the range of the rate reported by Vogt and Bloomfield (1991). In this study, the fine root turnover rates were lower at 0–30 cm soil depth than the other soil depths except *Pinus koraiensis* stand. It was reported that low rates of fine root turnover was on relatively poor site (Mooney and Gulman, 1982). However, fine root turnover may vary with site quality and species composition (Shaver and Billings, 1975).

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