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# Net Fine Root Carbon Production in *Quercus* Natural Forest Ecosystems of Korea

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This study was carried out to estimate annual carbon production by fine root in *Quercus variabilis* and *mongolica* natural stands of Chungju region, Korea. Soil samples were taken at 0～30 cm, 30～60 cm, and 60～90 cm soil depths from April to December(monthly increment method) in 2002. Fine root carbon biomass was higher at 0～30 cm soil depth than in the other soil depths. Net fine root carbon production (kg $ha^{-1}$) were 2,587 kg in *Quercus variabilis* stands and 3,810 kg in *Quercus mongolica* stands at 0～90 cm soil depth. Fine root turnover rates were ranged from 0.66 to 1.94 in the two forest ecosystems. Nitrogen, P, K, Ca and Mg input per year into the soil(kg $ha^{-1}$) due to fine root turnover at 0～90 cm soil depth in this study were 17.0 kg, 1.0 kg, 8.5 kg and 21.5 kg, and 4.2 kg in the *Quercus variabilis* stand, and 24.0 kg, 1.9 kg, 9.9 kg, 28.1 kg, and 5.8 kg in the *Quercus mongolica* stand, respectively.

## 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 (CFCs, $CH_4$, 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 *Quercus variabilis* and *mongolica* natural forest ecosystems of Korea.

## MATERIALS AND METHODS

This study was conducted in *Quercus variabilis* and *mongolica* natural stands at the Chungju city of Chungbuk Province, Korea. Annual mean air temperature is 11.4 °C, and total annual precipitation averages 1261 mm. The elevation range of the *Quercus* stands was 300～660 m. The average age of the *Quercus variabilis* stand was 40 years, the number of trees per ha are 835. The average age of the *Quercus mongolica* stand was 39 years, the number of trees per ha was 907. The study site was dominated by *Quercus variabilis*, *Quercus mongolica*, *Pinus densiflora*, *Acer saccharum*, *Lespedeza bicolor*, *Cornus kousa*. The soil is brown forest soil, a representative soil of Korea.

For this study, five 20 m×20 m permanent plots, which was established on a relatively similar slope, aspect and soil, were randomly selected. Fine root biomass was established by monthly soil coring from April to December 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 30 cm long) was used to take soil cores.

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 N, P, K, Mg and Ca concentration using ICP.

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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). Nutrient fluxes with fine roots were calculated assuming that there was no translocation of nutrients during senescence (Nambier, 1987; Hwang, 1996). 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.

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.

## RESULTS AND DISCUSSION

The average fine root biomass (live + dead) was higher at the 0~30 cm soil depth than in the other soil depths in the two *Quercus* stand (Tables 1 and 2). These were higher fine root biomass than in *Pinus rigida* plantation of Korea and hardwood stands of Northeast U.S.A (1,322 kg $ha^{-1}$ and 1,150 kg $ha^{-1}$) (Hwang, 1996; Burke and Raynal, 1984) in similar soil depths.

Seasonal changes in fine root carbon biomass of the *Quercus variabilis* stands varied among sampling times. Major peak in fine root carbon biomass was found during the early growing season in May in the *Quercus variabils* stand (Table 1 and 2) and also May and August in *Quercus mongolica* stands. Burke and Raynal (1994) reported the fine root biomass in Northeast hardwood stands of U.S.A. was peak in May. Also, McClaugherty etc (1982) reported highest fine root biomass in spring season. Carbon concentration in fine root was 46% of the dry mass.

Net fine root carbon production (kg $ha^{-1}$) was 1,104 kg at 0~30 cm, 749 kg at 30~60 cm, and 734 kg at 60~90 cm soil depths in *Quercus variabilis* stands (Table 3). At 0~30 cm soil depth, these was more than in *Pinus rigida* plantation forests of Korea (671 kg,

**Table 1.** Fine root carbon biomass (kg $ha^{-1}$) in *Quercus variabilis* natural stand of Chungju area at 0~30 cm, 30~60 cm, and 60~90 cm soil depths. The number in parentheses is one standard error of the mean (n=5).

| Soil depth | 19 Apr. | 17 May. | 18 Jun. | 19 Jul. | 20 Aug. | 29 Sep. | 22 Oct. | 16 Nov. | 13 Dec. | Mean |
|---|---|---|---|---|---|---|---|---|---|---|
| 0–30 cm | 1911<br>(483) | 2075<br>(488) | 1527<br>(684) | 1732<br>(716) | 1309<br>(417) | 1715<br>(427) | 1491<br>(394) | 1584<br>(449) | 1676<br>(426) | 1669<br>(498) |
| 30–60 cm | 716<br>(443) | 634<br>(373) | 715<br>(416) | 1120<br>(776) | 584<br>(304) | 520<br>(341) | 693<br>(550) | 593<br>(261) | 622<br>(194) | 682<br>(411) |
| 60–90 cm | 474<br>(535) | 458<br>(306) | 336<br>(242) | 422<br>(296) | 351<br>(242) | 501<br>(334) | 343<br>(251) | 717<br>(350) | 330<br>(149) | 437<br>(301) |
| 0–90 cm | – | – | – | – | – | – | – | – | – | 2788<br>(1210) |

**Table 2.** Fine root carbon biomass (kg $ha^{-1}$) in *Quercus mongolica* natural stand of Chungju area at 0~30 cm, 30~60 cm, and 60~90 cm soil depths. The number in parentheses is one standard deviation of the mean.

| Soil depth | 19 Apr. | 17 May. | 18 Jun. | 19 Jul. | 20 Aug. | 29 Sep. | 22 Oct. | 16 Nov. | 13 Dec. | Mean |
|---|---|---|---|---|---|---|---|---|---|---|
| 0-30 cm | 1515<br>(683) | 2055<br>(614) | 1526<br>(654) | 1874<br>(916) | 2222<br>(555) | 1784<br>(626) | 1776<br>(861) | 1750<br>(595) | 1986<br>(1196) | 1832<br>(744) |
| 30-60 cm | 380<br>(222) | 631<br>(424) | 722<br>(447) | 692<br>(461) | 870<br>(563) | 633<br>(240) | 609<br>(321) | 1117<br>(487) | 1123<br>(697) | 753<br>(429) |
| 60-90 cm | 323<br>(274) | 493<br>(313) | 563<br>(468) | 595<br>(342) | 612<br>(514) | 409<br>(392) | 289<br>(373) | 672<br>(706) | 890<br>(695) | 538<br>(453) |
| 0–90 cm | – | – | – | – | – | – | – | – | – | 3123<br>(1626) |

**Table 3.** Fine root carbon production (kg $ha^{-1}$) in *Quercus variabilis* natural stand of Chungju area at 0~30cm, 30~60cm, and 60~90 cm soil depths.

| Soil depth | 19 Apr. ~17May | 17 May. ~18Jun. | 18 Jun. ~19Jul. | 19 Jul. ~20Aug. | 20 Aug. ~29Sep. | 29 Sep. ~22Oct. | 22 Oct. ~16Nov. | 16 Nov. ~13Dec. | Total |
|---|---|---|---|---|---|---|---|---|---|
| 0-30cm | 210 | 0 | 205 | 0 | 406 | 0 | 93 | 190 | 1104 |
| 30-60cm | 0 | 105 | 405 | 0 | 0 | 0 | 239 | 0 | 749 |
| 60-90cm | 102 | 0 | 87 | 0 | 171 | 0 | 374 | 0 | 734 |
| 0–90 cm | – | – | – | – | – | – | – | – | 2587 |

Hwang, 1997) and in Northeast hardwood stands of U.S.A. (1,100 kg ha$^{-1}$, Burke and Raynal, 1994). The net fine root carbon production in *Quercus mongolica* stands was also higher at 0~30 cm soil depth than in other soil depths.

Total fine root NPP at 0~90 cm were 2,587 kg and 3,810 kg in *Quercus variabils* and *mongolica* stand, respectively (Tables 3 and 4). These were very similar to those for Northeast hardwood stands of U.S.A. (2,000 ~2,500 kg, Raynal and Burke (1994), at 0~100 cm soil depths). 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 of korea. This result indicate the important role of fine root to carbon cycle in forest ecosystems like other reports (Hansen, 1993; Cooper, 1983; Burke and Raynal, 1994).

Fine root turnover rate (yr) was ranged from 0.66 to 1.94 (Table 5). 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. 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).

The average fine root N, P, K, Ca and Mg concentration (%) during the growing season were 0.66, 0.05, 0.26, 0.74, and 0.15 in *Quercus variabilis* natural stands, respectively (Table 6). The average fine root N, P, K, Ca, and Mg concentration (%) during the growing season were 0.63, 0.04, 0.33, 0.83, and 0.16 in *Quercus mongolica* natural stands, respectively (Table 7). These values were within the range reported for other coniferous or deciduous forest (Yin and Perry, 1991; Burke and Raynal, 1994; Jackson *et al.*, 1997; Pyo *et al.*, 2002; Hwang, 1996). Other study reported seasonal nutrient fluctuations in fine roots, and they speculated that nutrient retranslocation in fine roots and soil nutrient availability could explain the pattern (Stevenson and Day, 1996; Hwang, 1996).

Nitrogen, P, K, Ca, and Mg inputs (kg ha$^{-1}$) through fine root turnover during the growing season were 17.0, 1.0, 8.5, 21.5 and 4.2 in *Quercus variabilis* stands at 0

**Table 4.** Fine root carbon production (kg ha$^{-1}$) in *Quercus mongolica* natural stand of Chungju area at 0~30 cm, 30~60 cm, and 60 ~90 cm soil depths.

| Soil depth | 19 Apr. ~17May | 17 May. ~18Jun. | 18 Jun. ~19Jul. | 19 Jul. ~20Aug. | 20 Aug. ~29Sep. | 29 Sep. ~22Oct. | 22 Oct. ~16Nov. | 16 Nov. ~13Dec. | Total |
|---|---|---|---|---|---|---|---|---|---|
| 0–30cm | 540 | 0 | 349 | 383 | 0 | 50 | 0 | 319 | 1641 |
| 30–60cm | 251 | 105 | 0 | 179 | 0 | 0 | 508 | 81 | 1124 |
| 60–90cm | 170 | 89 | 0 | 131 | 0 | 0 | 383 | 272 | 1045 |
| 0–90 cm | – | – | – | – | – | – | – | – | 3810 |

**Table 5.** Fine root turnover rate (%/yr) in *Quercus variabilis* and *Quercus mongolica* natural stand of Chungju area at 0~30 cm, 30~60 cm, and 60~90 cm soil depths.

| Soil depth | *Quercus variabilis* | *Quercus mongolica* |
|---|---|---|
| 0–30 cm | 0.43 | 0.90 |
| 30–60 cm | 0.96 | 1.49 |
| 60–90 cm | 1.03 | 1.94 |

**Table 6.** Nutrient concentrations (%) of fine root in *Quercus variabilis* natural stand of Chungju area at 0~30 cm soil depths. Values are expressed as per cent by weight (mean ± standard deviation of the mean, expressed as per cent by weight).

| Nutrient | 19 Apr. | 17 May. | 18 Jun. | 19 Jul. | 20 Aug. | 29 Sep. | 22 Oct. | 16 Nov. | 13 Dec. | Mean |
|---|---|---|---|---|---|---|---|---|---|---|
| N | 0.70<br>(0.01) | 0.66<br>(0.01) | 0.73<br>(0.03) | 0.66<br>(0.01) | 0.80<br>(0.06) | 0.67<br>(0.02) | 0.68<br>(0.01) | 0.71<br>(0.01) | 0.69<br>(0.01) | 0.66<br>(0.02) |
| P | 0.04<br>(0.01) | 0.04<br>(0.01) | 0.04<br>(0.01) | 0.04<br>(0.01) | 0.04<br>(0.01) | 0.04<br>(0.01) | 0.04<br>(0.01) | 0.05<br>(0.01) | 0.05<br>(0.01) | 0.04<br>(0.01) |
| K | 0.34<br>(0.03) | 0.33<br>(0.01) | 0.32<br>(0.01) | 0.31<br>(0.01) | 0.35<br>(0.01) | 0.28<br>(0.01) | 0.33<br>(0.01) | 0.32<br>(0.02) | 0.35<br>(0.01) | 0.33<br>(0.01) |
| Ca | 0.82<br>(0.02) | 0.81<br>(0.01) | 0.79<br>(0.01) | 0.81<br>(0.01) | 0.85<br>(0.02) | 0.90<br>(0.02) | 0.85<br>(0.04) | 0.83<br>(0.03) | 0.79<br>(0.03) | 0.83<br>(0.02) |
| Mg | 0.15<br>(0.01) | 0.15<br>(0.01) | 0.15<br>(0.01) | 0.15<br>(0.01) | 0.16<br>(0.01) | 0.17<br>(0.01) | 0.17<br>(0.01) | 0.16<br>(0.01) | 0.17<br>(0.01) | 0.16<br>(0.01) |

**Table 7.** Nutrient concentrations (%) of fine root in *Quercus mongolica* natural stand of Chungju area at 0~30 cm soil depths. Values are expressed as per cent by weight (mean ± standard deviation of the mean, expressed as per cent by weight).

| Nutrient | 19 Apr. | 17 May. | 18 Jun. | 19 Jul. | 20 Aug. | 29 Sep. | 22 Oct. | 16 Nov. | 13 Dec. | Mean |
|---|---|---|---|---|---|---|---|---|---|---|
| N | 0.71<br>(0.01) | 0.65<br>(0.01) | 0.762<br>(0.01) | 0.65<br>(0.01) | 0.62<br>(0.01) | 0.61<br>(0.01) | 0.61<br>(0.01) | 0.61<br>(0.01) | 0.59<br>(0.01) | 0.63<br>(0.01) |
| P | 0.05<br>(0.01) | 0.05<br>(0.01) | 0.05<br>(0.01) | 0.06<br>(0.01) | 0.05<br>(0.01) | 0.05<br>(0.01) | 0.05<br>(0.01) | 0.05<br>(0.01) | 0.04<br>(0.01) | 0.05<br>(0.01) |
| K | 0.30<br>(0.01) | 0.24<br>(0.03) | 0.26<br>(0.01) | 0.25<br>(0.01) | 0.25<br>(0.01) | 0.25<br>(0.01) | 0.26<br>(0.01) | 0.27<br>(0.01) | 0.26<br>(0.01) | 0.26<br>(0.01) |
| Ca | 0.74<br>(0.02) | 0.68<br>(0.01) | 0.68<br>(0.03) | 0.76<br>(0.06) | 0.73<br>(0.01) | 0.79<br>(0.02) | 0.72<br>(0.01) | 0.73<br>(0.02) | 0.79<br>(0.01) | 0.74<br>(0.02) |
| Mg | 0.15<br>(0.01) | 0.14<br>(0.01) | 0.14<br>(0.01) | 0.17<br>(0.01) | 0.16<br>(0.01) | 0.16<br>(0.01) | 0.14<br>(0.01) | 0.15<br>(0.01) | 0.17<br>(0.01) | 0.15<br>(0.01) |

**Table 8.** Annual N, P, K Ca and Mg input into the soil (kg $ha^{-1}$) due to fine root turnover in *Quercus variabilis* natural stand of Chungju area at 0~30 cm, 30~60 cm, and 60~90 cm soil depths.

| Soil depth | N | P | K | Ca | Mg |
|---|---|---|---|---|---|
| 0~30 cm | 7.3 | 0.4 | 3.6 | 9.2 | 1.8 |
| 30~60 cm | 4.9 | 0.3 | 2.5 | 6.2 | 1.2 |
| 60~90 cm | 4.8 | 0.3 | 2.4 | 6.1 | 1.2 |
| 0~90 cm | 17.0 | 1.0 | 8.5 | 21.5 | 4.2 |

**Table 9.** Annual N, P, K Ca and Mg input into the soil (kg $ha^{-1}$) due to fine root turnover in *Quercus mongolica* natural stand of Chungju area at 0~30 cm, 30~60 cm, and 60~90 cm soil depths.

| Soil depth | N | P | K | Ca | Mg |
|---|---|---|---|---|---|
| 0~30cm | 10.3 | 0.8 | 4.3 | 12.1 | 2.5 |
| 30~60cm | 7.1 | 0.6 | 2.9 | 8.3 | 1.7 |
| 60~90cm | 6.6 | 0.5 | 2.7 | 7.7 | 1.6 |
| 0~90cm | 24.0 | 1.9 | 9.9 | 28.1 | 5.8 |

~90 cm soil depth, respectively (Table 8 and 9). More input of nutrition to soils by fine root turnover was found in *Quercus mongolica* stands than in *Quercus variabilis* stands. These were similar or lower than 14.6 kg of N, 0.7 kg of P, 4.1 kg of K, and 10.3 kg of Ca for White Oak forest stands reported by Joslin and Henderson (1987) at 0~30 cm soil depth.

Cole and Rapp (1981) reported that average nutrient input by litterfall to soil were 61.4 of N, 4.0 of P, 41.6 of K, and 67.6 of Ca in 14 sites of temperate deciduous forests. These were higher than in the amount of nutrient input by fine root turnover in this study. However, there are no doubt fine root is important in nutrient cycle of the belowground.

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