Organic Carbon Distribution of the *Pinus densiflora* Forest on Songgye Valley at Mt. Worak National Park

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ABSTRACT: The organic carbon (OC) distribution of *Pinus densiflora* forest in Songgye valley at Mt. Worak National Park were studied as a part of the National Long-Term Ecological Research in Korea. In order to investigate the OC distribution, OC in plant biomass, litterfall, litter layer on forest floor, and soil were estimated. The density of *P. densiflora* forest was 1,300 trees/ha, average DBH was 15.2±6.17 cm and average tree height was 10.7±2.56 m. The shrub layer was dominated by shrubby *Quercus variabilis*, *Fraxinus sieboldiana* and *Indigofera kirilowii* with low frequency, and herb layer was dominated by *Pteridium aquilinum* and *Miscanthus sinensis*. Total amount of OC stored in this pine forest was 142.78 ton C/ha. Organic carbon stored in soil and plant biomass accounted for 59.2% and 37.8%, respectively. Amount of OC distributed in trees, shrubs, herbs and litter layer in this pine forest was 51.79, 2.03, 0.12 and 4.29 ton C/ha, respectively. Amount of OC returned to forest floor *via* litterfall was 1.50 ton C ha^{-1} yr^{-1}. Soil organic carbon (SOC) decreased along the soil depth. Total amount of SOC within 50 cm soil depth was 84.55 ton C ha^{-1} 50 cm-$depth^{-1}$.

Key words: Carbon distribution, Litterfall, Organic carbon (OC), *Pinus densiflora*, Soil organic carbon (SOC)

INTRODUCTION

There is an increasing demand for countries to assess their contributions to sources and sinks of CO_2 and to evaluate processes that control CO_2 accumulation in the atmosphere (Roxburgh et al. 2006). Terrestrial ecosystems are one of the major sinks for atmospheric carbon. Forest ecosystems have been a particular focus of carbon accounting research because they represent the largest stock of terrestrial ecosystem carbon (Schlesinger 1997). Schlesinger (1997) reported that forests account for 75% of organic carbon (OC) which are stored in terrestrial ecosystems, and 40% of carbon exchange between the atmosphere and terrestrial ecosystems. CO_2 removed from the atmosphere by the photosynthetic process, and stored in the above- and below-ground plant biomass (Kimble et al. 2003a). Over time, some of the plant biomass are converted into humus or stable soil carbon (Kimble et al. 2003b). Schimel (1995) reported that the atmosphere contain 750 Pg (1 petagram = 10^{15} g) carbon. Within the terrestrial ecosystems, there is approximately 610 Pg C in the living vegetation biomass (Schimel 1995). The soil carbon pool is estimated to range between 1,200 to 1,600 Pg or higher to a depth of 1 m as soil organic carbon (SOC) (Batjes 1999).

Heath et al. (2003) reported that a large amount of carbon can be sequestered for long periods of time above-ground by trees and below-ground in coarse roots. Tans et al. (1990) also reported that temperate forests play an important role for sequestration of atmospheric CO_2. In order to understand the capacity of carbon sequestration of forest ecosystems over time, it is necessary to quantify organic carbon stored in various components of forest ecosystem. Unlike cropland and grasslands, carbon in forest trees can be harvested, and some of them can be stored for a long periods of time as wood products (Skog and Nicholson 1998).

Most of the carbon in forest is usually in soil, with some forest types having a greater percentage in the soil than other types (Vitousek 1991, Morris and Paul 2003, Lee and Mun 2005). The amounts of carbon allocated to forest components such as tree biomass, litter layer and soil may be influenced by dominant species, tree ages and density of dominant species, composition of understory vegetation, etc.

As a part of National Long-Term Ecological Research Program in Korea, we began the study of carbon cycling in major plant communities, *Pinus densiflora, Quercus variabilis,* and *Q. mongolica,* at Mt. Worak National Park in Chungbuk Province since April 2005. The objective of this study was to obtain primary data for OC distribution in *P. densiflora* forest. For this study, we estimated standing carbon of above- and below-ground plant biomass, carbon returned to forest floor *via* litterfall, carbon in litter layer, and SOC. Based on these results, we presented compartment model for OC distribution among the components of this *P. densiflora* forest.

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MATERIALS AND METHODS

Study Area

The Mt. Worak National Park is located between Mt. Soback and Mt. Sogri (N 36°47'～36°55', E 128°4'～128°12'), and streches over both Gyeongsangbuk-do and Chungcheongbuk-do. The higest peak of the Mt. Worak National Park, Munsubong, is 1,162 m above sea level.

The study site of *P. densiflora* forest is located at altitude of 380 m, south-west direction of Songgye valley (N 36°51'17", E 128° 64'41"). In April 2005, 10 m × 20 m permanent quadrat was established in the study area. Tree density was 1,300 trees/ha, average DBH was 14.6±5.98 cm, and average tree height was 9.8±2.98 m. In April 2006, tree DBH and height in permanent quadrat were remeasured. Average DBH was 15.2±6.17 cm, and average tree height was 10.7±2.56 m. In shrub layer, shrubby *Q. variabilis, Fraxinus sieboldiana* and *Indigofera kirilowii* were distributed with low frequency. Herb layer was dominated by *Pteridium aquilinum* and *Miscanthus sinensis*. According to the Jechon meteorological station, about 30 km distance from the study area, annual average temperature and precipitation for thirty years from 1976 through 2005 was 10.1℃ and 1,349.8 mm, respectively.

Carbon in Plant Materials

Standing biomass of above-ground trees was calculated using the allometric equation developed by Kim and Yoon (1972). Root biomass was rated as a quarter of above-ground biomass (Johnson and Risser 1974). To determine the above-ground biomass of the understory vegetation, harvest method was used. In August 2006. shrubs and herbs in three 1 m × 2 m quadrats, which were in the outside of the permanent quadrat, were harvested. Plants were sorted into shrub and herb, and weighed after drying to constant weight at 80 ℃. Litter production was measured with five circular litter traps, opening area was 0.5 m^2, at every month from May 2005 to October 2006, except for January and February. Carbon in plant materials and in annual litter production was rated as 45% of each dry weight (Houghton et al. 1983). Seasonal litter weight on forest floor was determined with five 25 cm × 25 cm quadrats in March, June, September, December. Litter sampling in each quadrat was done divided into L and F layer. Litter samples weighed after drying to constant weight at 80℃, and ground with mixer. Contents of organic matter in litter was determined by loss on ignition with 600 ℃ electric furnace. And then organic matter in litter layer was converted to OC by dividing 1.724 (Black 1965).

Soil Sampling and OC in Soil

Soil sampling was carried out at randomly chosen three sites outside of the permanent quadrat in March, June, September and December. Soil sampler, stainless cylinder 5 cm in diameter and 10 cm in height, was used to collect samples for bulk density and organic matter determination. The cylinder was pressed into the soil in a straight line as possible at every 10 cm intervals till 50 cm depth. Soil samples were dried to constant weight in 105℃ oven and weighed, and then divided by their volume to determine soil bulk density. Soil organic matter was determined by loss on ignition with 600℃ electric furnace. Soil organic matter was converted to OC by dividing 1.724 (Black 1965).

RESULTS AND DISCUSSION

Organic Carbon in Plant Materials

Amounts of OC contained in plant materials are summarized in Table 1. In tree layer, OC in leaves, branches, stems and roots were 2.70, 4.32, 34.41 and 10.36 ton C/ha, respectively. In case of shrub and herb layers, only above-ground OC was estimated. Amounts of OC contained in shrub and herb layer were 2.03 and 0.12 ton C/ha, respectively. Amounts of OC contained in plant materials in this pine forest was 53.94 ton C/ha. OC contained in tree amounted to 96.0% of the total OC in plant materials in this pine forest.

Kim (2006) reported that the amount of OC in above-ground biomass of 42 year-old *P. densiflora* plantation was 32.5 ton C/ha, and Kim and Cho (2004) reported that the amount of OC in above-ground biomass of 42 year-old *P. rigida* plantation was 77.02 ton C/ha. Lee (2004) reported that above- and below-ground OC of 30 year-old *P. rigida* plantation was 81.8 ton C/ha. The amount of OC in above-ground plant biomass in forests seemed to be related to tree species and age, tree density and soil nutrients (Lee and Mun 2005, Choi et al. 2006a, b).

Table 1. Carbon distribution among the plant components in the study area (ton C/ha)

		2006
Tree layer	Leaf	2.70
	Branch	4.32
	Stem	34.41
	Root	10.36
	Sub-total	51.79
Shrub layer	Above-ground	2.03
Herb layer	Above-ground	0.12
Total		53.94

Organic Carbon in Litterfall

Litter production continued throughout year, but showed peaks in autumn and winter. As shown in Fig. 1, most of the OC returned to forest floor *via* litterfall was from leaf litter. Others were usually leaf litter of shrub species. Amount of OC returned to forest floor *via* litterfall of trees and shrubs was 1.38 ton C ha^{-1} yr^{-1}. The above-ground standing biomass of herb layer must be added to forest floor at the end of the growing season. This will amount to 0.12 ton C ha^{-1} yr^{-1} (Table 1). Therefore, total amount of OC returned to forest floor *via* litterfall will amount to 1.50 ton C ha^{-1} yr^{-1}.

Hwang (2004) and Kim (2006) reported that the amount of OC returned to forest floor of 40 year-old *Larix leptolepis* plantation and 42 year-old *P. densiflora* plantation *via* litterfall was 2.06 and 1.76 ton C ha^{-1} yr^{-1}, respectively, which were somewhat higher than this study site. Shin et al. (2006) reported that the amount of OC returned to forest floor in *Q. variabilis* and *Q. mongolica* forests was 2.29 and 2.59 ton C ha^{-1} yr^{-1}, respectively. Carbon in litterfall affect SOC through litter decomposition. Soil organic carbon in *Q. variabilis* and *Q. mongolica* forests were much higher than this *P. densiflora* forest (Choi et al. 2006b, Our unpublished data).

Organic Carbon in Litter Layer

Organic carbon in litter layer of the forest floor was summarized in Table 2. Amount of OC in litter layer in December and March were 4.7±1.18 and 4.8±0.43 ton C/ha, respectively, which were higher than those in June and September (Table 2). Amount of OC in litter layer in September was the lowest with a value of 3.2±0.38 ton C/ha. This is because litterfall showed peaks in October and December in this pine forest (Fig. 1), and the rate of litter decomposition must be low due to the cold temperature in winter season. After spring season, the rate of litter decomposition must be increased due to the increasing both air and soil temperature (Lee and Mun 2005). The average amount of OC in litter layer of this pine forest was 4.3±0.99 ton C/ha. Amount of OC in F layer was higher than L layer except for June.

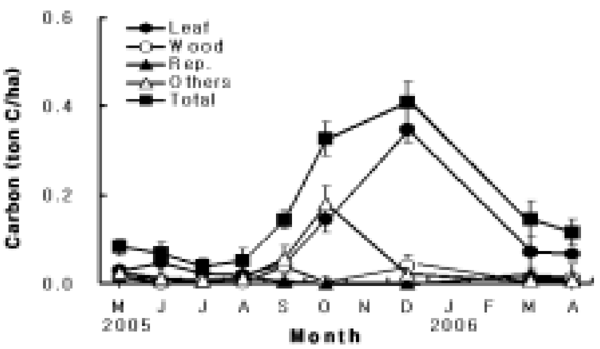

Fig. 1. Seasonal organic carbon (ton C/ha) returned to forest floor *via* litterfall in the pine stand. Rep. indicates reproductive organs. Others are mainly shrub leaves.

Park and Lee (1981) reported that the amount of OC in litter layer of *P. densiflora* forest on Mt. Jiri and Mt. Hanla was 7.62 and 7.88 ton C/ha, respectively, which was much higher than this study area. In case of *Q. variabilis* (Choi et al. 2006a) and *Q. mongolica* (our unpublished data) forests in Mt. Worak National Park, OC in litter layer was 4.65, 4.63 ton C/ha, respectively, which were similar with this result. However, amount of annual litterfall in *Q. variabilis* and *Q. mongolica* forests were much higher than this *P. densiflora* forest. Therefore, this suggest that litter decomposition in *Q. variabilis* and *Q. mongolica* forests must be much faster than *P. densiflora* forest.

Bulk Density and OC in Soil

For the quantitative determination of OC and nutrients content of soil, the knowledge of bulk density is of particular importance. Soil bulk densities of top soil and 50 cm-depth soil in this *P. densiflora forest* were 0.86±0.05 and 1.02±0.04 g/cm^3, respectively (Fig. 2). It increased along the soil depth. Choi et al. (2006b) reported that soil bulk density of top soil and 50 cm-depth soil in the *Q. variabilis* forest was 0.82±0.07 and 0.90±0.05 g/cm^3, respectively, which was lower than that of this study. Soil bulk density mainly seemed to be related to organic matter content of soil.

Seasonal SOC along the soil depth was summarized in Table 3. Average SOC in top soil and 50 cm-depth soil was 21.49 and 15.10 ton C ha^{-1} 10 cm-$depth^{-1}$, respectively. As shown in Table 3, SOC in March was the highest with a value of 104.82 ton C ha^{-1} 50 cm-$depth^{-1}$. It decreased till September and then increased in December. Average amount of SOC within 50 cm soil depth in this pine forest was 84.55 ton C ha^{-1}50 cm $depth^{-1}$.

Kim and Cho (2004) reported that SOC in 42-year-old *P. rigitaeda* and *Larix leptolepis* plantations was 94.2 and 91.2 ton C ha^{-1} 30 cm-$depth^{-1}$, respectively. Kim (2006) also reported that SOC in a 42-year-old *P. densiflora* plantation was 102.6 ton C ha^{-1} 30 cm-$depth^{-1}$. Amount of SOC in this study area was similar with those

Table 2. Seasonal organic carbon in litter layer of the study area (ton C/ha) (mean±SD)

	Jun. 2005	Sep. 2005	Dec. 2005	Mar. 2006	Mean
L-layer	2.3±0.82	1.3±0.17	2.2±0.44	2.1±0.19	2.0±0.68
F-layer	2.1±0.49	1.9±0.41	2.5±0.84	2.7±0.24	2.3±0.60
Total	4.4±0.85	3.2±0.38	4.7±1.18	4.8±0.43	4.3±0.99

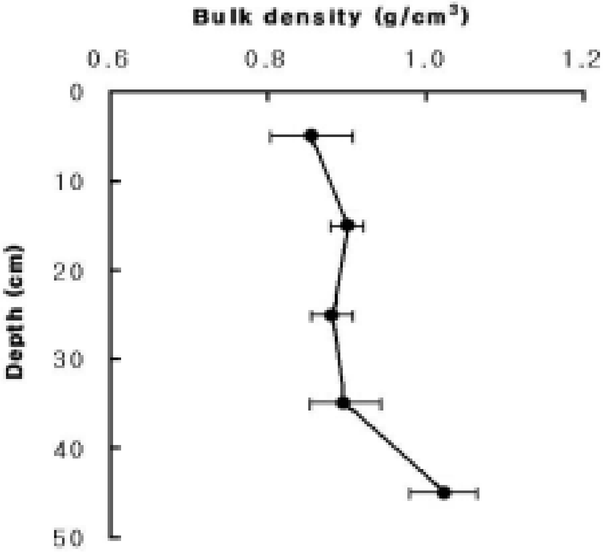

Fig. 2. Bulk density along the soil depth of the pine stand.

Table 3. Seasonal soil organic carbon along the soil depth (C ton ha^{-1} 10 cm $depth^{-1}$) and seasonal total soil organic carbon (C ton ha^{-1} 50 cm $depth^{-1}$) in the pine stand (mean±SD)

Depth (cm)	Jun. 2005	Sep. 2005	Dec. 2005	Mar. 2006	Average
10	17.7± 2.40	19.3±1.90	21.9± 2.48	26.9±2.95	21.5± 4.33
20	14.4± 3.65	16.2±0.54	17.0± 1.33	23.3±0.71	17.7± 4.04
30	13.9± 3.93	13.7±0.79	14.9± 3.28	19.6±2.40	15.5± 3.51
40	13.1± 3.55	12.3±1.27	14.8± 3.32	18.6±1.00	14.7± 3.34
50	14.4± 2.93	11.7±0.94	17.9± 4.74	16.4±1.00	15.1± 3.15
Total	73.6±13.71	73.3±3.68	86.5±10.18	104.8±1.18	84.6±15.78

above studies. However, it was greater than the average SOC (67.0 ton C/ha) of forest soil in Korea (Jeong et al. 1998). Soil organic carbon in the *Q. variabilis* forest was higher than that of this study (Choi et al. 2006b).

SOC is an important component of carbon storage in most forest ecosystems (Vogt 1991, Eswaran et al. 1993, Dixon et al. 1994). More than 50% of terrestrial carbon storage is contained in soils, and quantities are probably underestimated because many studies do not measure carbon storage in the lower soil profile (Eswaran et al. 1993, Kern 1994). Storage of carbon in forest soils is dependent on plant production rates, allocation pattern of carbon among the plant organs, decomposition rate of litter entering the soil, and stabilization within the soil by aggregation, absorption, and humification (Morris and Paul 2003). The largest contribution to soil carbon pools are above- and below-ground litterfall. Measurement of above-ground litterfall are available for many forest ecosystems, but values for below-ground litter production are difficult to obtain (Nadelhoffer and Raich 1992, Zak and Pregitzer 1998).

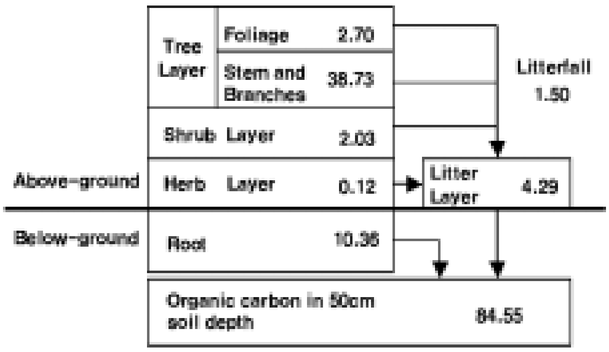

Fig. 3. Compartment model showing the organic carbon distribution in the pine stand (ton C/ha).

Organic Carbon Distribution

OC distribution in each component of this pine forest summarized in Fig. 3. Total amount of OC stored in this pine forest was 142.78 ton C/ha. OC stored in soil and plant biomass accounted for 59.2% and 37.8%, respectively, of the total OC in this pine forest. Heath et al. (2003) reported that 51% of OC in forests is in the soil. This is lower than the estimate of this study. In temperate forest, SOC account for about 63% of the total OC of the ecosystem (Kimble et al. 2003b).

Percentage of SOC is increasing trend from the tropics (50.5%) to the temperate (62.9%), to the boreal (84.3%) forests (Heath et al. 2003, Kimble et al. 2003b). The estimate of SOC in this study was somewhat lower than that of temperate forest (Kimble et al. 2003 b). In this study, we estimate SOC within 50 cm soil depth instead of 1m. In addition, soil carbon density could be differ from forests according to their biomass production, rate of litter decomposition, climate etc. (Morris and Paul 2003).

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LITERATURE CITED

Batjes NH. 1999. Management options for reducing CO_2 concentrations in the atmosphere by increasing carbon sequestration in the soil. Report 410-200-031. Dutch Nationmal Research Programe on Global Air Pollution and Climate Change. Technical Paper 30. the Netherlands.

Black CA. 1965. Methods of Soil Analysis, Part 2. American Society of Agronomy, Inc., Madison, Wisconsin.

Choi HJ, Jeon IY, Shin CH, Kim HS, Kim SW, Kim GH, Mun HT. 2006a. Organic carbon distribution in *Quercus variabilis* forest at Mt. Worak National Park. Integrative Bioscience 10 (Suppl.) p 193.

Choi HJ, Jeon IY, Shin CH, Mun HT. 2006b. Soil properties of *Quercus variabilis* forest on Youngha valley in Mt. Worak National Park. J Ecol Field Biol 29: 439-443.

Dixon RK, Brown S, Houghton RA, Solomon AM, Trexler MC, Wisniewski J. 1994. Carbon pools and flux of global forest ecosystems. Science 263: 185-190.

Eswaran H, Van Den Berg E, Reich P. 1993. Organic carbon in soils of the world. Soil Sci Soc Am J 57: 192-194.

Heath LS, Smith JE, Birdsey RA. 2003. Carbon trends in U.S. forestlands: A context for the role of soils in forest carbon sequestration. *In*: Kimble JM, Heath LS, Birdsey RA, Lai R (eds). The Potential of U.S. Forest Soils to Sequester Carbon and Mitigate the Greenhouse Effect. CRC Press, New York. pp 35-45.

Houghton RA, Hobbie JE, Melillo JM, Moore B, Peterson BJ. Shaver GR, Woodwell GM. 1983. Changes in the carbon content of terrestrial biota and soils between 1860 and 1980: a net release of CO_2 to the atmosphere. Ecol Monogr 53: 235-262.

Hwang J. 2004. Belowground carbon dynamics after thinning, liming and litterlayer treatments in *Pinus rigida* and *Larix leptolepis* Plantations (PhD thesis). Korea University, Seoul.

Jeong JH, Kim C, Lee WK. 1998. Soil organic carbon content in forest soils of Korea. J For Sci 57: 178-183.

Johnson FL, Risser PG. 1974. Biomass, annual net primary production and dynamics of six mineral elements in a post oak-blackhack oak forest. Ecology 55: 1246-1258.

Kern JS. 1994. Spatial patterns of soil organic carbon in the contiguous United States. Soil Sci Soc Am J 58: 439-455.

Kim C and Cho HS. 2004. Quantitative comparisons of soil carbon and nutrient storage in *Larix leptolepis, Pinus densiflora* and *Pinus rigitaeda* plantations. Korean J Ecol 27: 67-71.

Kim C. 2006. Soil carbon cycling and soil CO_2 efflux in a red pine (*Pinus densiflora*) stand. J Ecol Field Biol 29: 23-27.

Kim JH, Yoon SM. 1972. Studies on the productivity and the productive structure of the forests II. Comparison between the productivity of *Pinus densiflora* and *Quercus mongolica* stand located near Choon-Chun city. Korean J Bot 15: 71-78.

Kimble JM, Heath LS, Birdsey RA, Lal R. 2003a. The potential of U.S. forest soils to sequester carbon and mitigate the greenhouse effect. CRC Press, New York. 429 p.

Kimble JM, Birdsey RA, Lal R, Heath LS. 2003b. Introduction and general description of U.S. forests. *In*: Kimble JM, Heath LS, Birdsey RA, Lai R. (eds). The potential of U.S. forest soils to sequester carbon and mitigate the greenhouse effect. CRC Press, New York. pp 3-14.

Lee KJ, Mun HT. 2005. Organic carbon distribution in an oak forest. Korean J Ecol 28: 265-270.

Lee KJ. 2004. A study on the organic carbon distribution in forest ecosystems. (MS thesis). Kongju National University, Kongju.

Morris SJ, Paul EA. 2003. Forest soil ecology and organic carbon. *In*: Kimble JM, Heath LS, Birdsey RA, Lai R. (eds). The potential of U.S. forest soils to sequester carbon and mitigate the greenhouse effect. CRC Press, New York. pp. 109-125.

Nadelhoffer KJ, Raich JW. 1992. Fine root production estimates and belowground carbon allocation in forest ecosystems. Ecology 73: 1139-1147.

Park BK, Lee IS. 1981. A model for litter decomposition of the forest ecosystem in South Korea. Korean J Ecol 4: 38-51.

Roxburgh SH, Wood SW, Mackey BG, Woldendorp G, Gibbons P. 2006. Assessing the carbon sequestration potential of managed forests: a case study from temperate Australia. J Appl Ecol 43: 1149-1159.

Schimel DS. 1995. Terrestrial ecosystems and the carbon cycle. Global Change Biol. 1: 77-91.

Schlesinger WH. 1997. Biogeochemistry: An analysis of global change. Academic Press, San Diego, California.

Shin CH, Jeon HJ, Choi MH, Han AR, Kim SJ, Mun HT. 2006. Litter production and nutrients concentration in *Quercus mongolica, Q. variabilis* and *Pinus densiflora* forests. Integrative Bioscience 10 (Suppl) p 200.

Skog KE, Nicholson GA. 1998. Carbon cycling through wood products: the role of wood and paper products in carbon sequestration. For Prod J 48: 75-83.

Tans PP, Fung IY, Takahashi T. 1990. Observational constraints on the global atmospheric CO_2 budget. Science 247: 1431-1438.

Vitousek PM. 1991. Can planted forests counteract increasing atmospheric carbon dixide? J Environ Qual 20: 348-354.

Vogt K. 1991. Carbon budgets of temperate forest ecosystems. Tree Physiol 9: 69-86.

Zak DR, Pregitzer KS. 1998. Integration of ecophysiological and biogeochemical approaches to ecosystem dynamics, *In*: Pace ML, Groffman PM. (eds). Success, limitations and frontiers in ecosystem science. Springer, New York. pp 372-403.

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