J. Ecol. Field Biol. 32 (1): 27～31, 2009

Distribution of Organic Carbon in Pitch Pine Plantation in Kongju, Korea

Han, A-Reum and Hyeong-Tae Mun*
Dept. of Biology, Kongju National University, Kongju 314-701, Korea

ABSTRACT: Organic carbon (OC) distribution in 32-year-old pitch pine plantation at Mt. Hotae in Kongju, Korea, was studied from August 2007 to July 2008. In order to investigate the OC distribution, OC in plant biomass, litterfall, litter layer on forest floor, and soil within 50cm depth were estimated. The density of *P. rigida* plantation was 3,200 trees/ha, average DBH was 18.7 ± 5.53 cm and average tree height was 11.1 ± 1.85 m. Organic carbon stored in plant biomass, litterlayer on forest floor and soil in 2008 was 89.46 ton C/ha (46.09%), 4.32 ton C/ha (2.23%) and 100.32 ton C ha^{-1} 50cm-$depth^{-1}$ (51.68%), respectively. Amount of OC returned to forest floor *via* litterfall was 2.21 ton C ha^{-1} yr^{-1}. Total amount of OC stored in this *P. rigida* plantation was 194.1 ton C/ha. Net increase of OC in above- and below-ground biomass in this pitch pine plantation was 4.82 ton C ha^{-1} yr^{-1}.

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

INTRODUCTION

Forests store carbon in biomass, dead organic matter, litter, and soil organic matter (Dixon et al. 1994, Boyland 2006). Interest in increasing carbon storage has increased as a method of reducing atmospheric CO_2 concentration (Boyland 2006). Therefore, 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). Under the provisions of the Kyoto Protocol, numerous countries worldwide agreed to mitigate global climate change by controlling greenhouse gases. The governments and industries of these nations would reduce greenhouse gases by sequestering atmospheric CO_2, or by reducing CO_2 emissions (Wright et al. 2000, Amichev et al. 2008).

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). 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 (Schlesinger 1997). CO_2 is removed from the atmosphere by the photosynthetic process, and stored in plant biomass (Kimble et al. 2003a). Over time, some of the plant biomass is converted into humus or stable soil carbon (Kimble et al. 2003b).

Heath et al. (2003) reported that a large amount of carbon can be sequestered for long periods of time in plant biomass. Tans et al. (1990), Jeon et al. (2007), Namgung et al. (2008) also reported that temperate forests play an important role in 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 over time (Kimble et al. 2003b).

Fast growing forest plantations and also secondary forests are highly efficient systems in terms of carbon sequestration (Laclau 2003). Huntington (1995) documented that the reforestation of former agricultural lands resulted in a significant accumulation of carbon in the soil and suggested this could be an important regional carbon sink. Gucinski et al. (1995) reported that conifer forests are major carbon reservoirs among the different terrestrial ecosystems. In Korea, the conifer forests are about 2,700,000 ha, and afforestation area of pitch pine (*Pinus rigida* Mill.) amounted to 481,000 ha (Korea Forest Service 2007). Pitch pine is native to North America, and grows well in dry or wet soil condition. It was afforested for erosion control during 1970's in Korea. Most of the pitch pine plantations are older than 30 years (Korea Forest Service 2007), and their growth rate weakened because they are in harvesting time.

The objective of this study was to quantify the carbon sequestration potential of pitch pine plantations. 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 soil organic carbon (SOC) within 50 cm depth.

MATERIALS AND METHODS

Study Area

The Mt. Hotae is located in the vicinity of Kongju National University in Kongju, Chungcheongnam-do, Korea (Fig. 1). The

* Corresponding author; Phone: +82-41-850-8499, e-mail: htmun@kongju.ac.kr

highest peak of the Mt. Hotae is 93 m above sea level. Most of the area of the Mt. Hotae is covered by 32-year-old pitch pine plantation. In July 2007, three 10 × 20 m permanent quadrats were established in the study area (N 38° 50′ 51.6″, W 94° 47′ 49.5″). Average tree density, DBH and tree height was 3,200 trees/ha, 18.7 ± 5.53 cm and 11.1 ± 1.85 m, respectively. In shrub layer, shurby *Quercus variabilis, Zanthoxylum schinifolium, Smilax china* were distributed with low frequency. In herb layer, *Pteridium aquilinum* and *Miscanthus sinensis*. were distributed with low density. According to the Buyeo meteorological station, about 32 km distance from the study area, annual average temperature and precipitation for thirty years from 1978 through 2007 was 12.1℃ and 1,147.0 mm, respectively.

Carbon in Plant Materials

Standing biomass of above-ground trees was calculated using the allometric equation developed by Kim (1971). 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 2007 and July 2008, shrubs in three 1 × 2 m quadrats, which were in the outside of the permanent quadrat, were harvested. Plants were divided into leaves and woody material, and weighed after drying to constant weight at 80℃ oven. Litter production was measured with five circular litter traps, opening area was 0.5 m^2, at every month from August 2007 to July 2008. Seasonal litter weight on forest floor was determined with five 25 × 25 cm quadrats in March, June, September, December. Litter layer was divided into L and F layer. Litter samples weighed after drying to constant weight at 80℃, and were grinded with mixer. Carbon % in plant materials, litterfall, and litter on forest floor were determined by Elementalanalyzer (EA1112, Thermofisher Scientific Inc.).

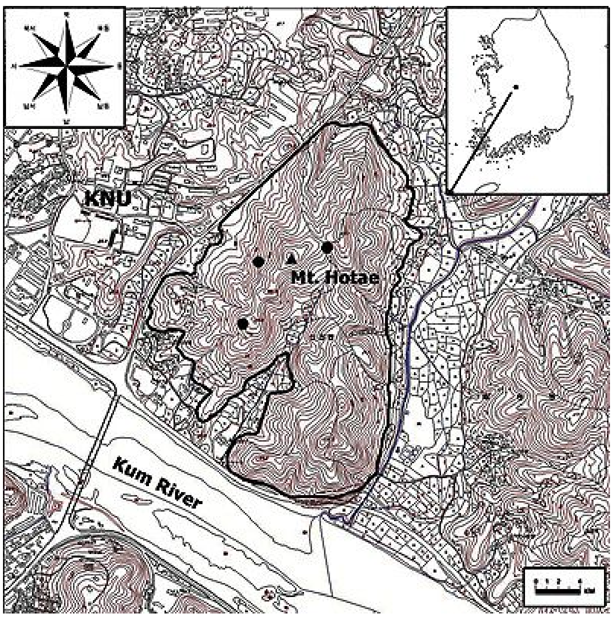

Fig. 1. A map showing the study area. Closed circles indicate the location of the permanent quadrats in the pitch pine plantation. KNU: Kongju National University.

Soil Sampling and OC in Soil

Soil sampling was carried out in 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 carbon 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 at 105℃ oven and weighed, and then divided by their volume to determine soil bulk density. Soil organic carbon (SOC) (%) was determined by Elementalanalyzer (EA1112, Thermofisher Scientific Inc.).

RESULTS AND DISCUSSION

Organic Carbon in Plant Materials

Percent of organic carbon in needle leaf, stem, branch and root of *P. rigida* was 47.3%, 46.6%, 48.4% and 47.4%, respectively. Average % of OC in *P. rigida* was 47.1 ± 2.36%. Houghton et al. (1983) reported that organic carbon % of tree stems was 45%, which was similar with our result. Percent of organic carbon in leaves and woody materials in shrub was 47.6% and 47.0%, respectively. Amount of OC contained in plant biomass in *P. rigida* plantation are summarized in Table 1. In 2007, OC in needle leaves, branches, stems and roots was 9.47, 16.16, 41.15 and 16.28 ton C/ha, respectively. In 2008, OC in needle leaves, branches, stems and roots was 9.90, 17.20, 43.39 and 17.18 ton C/ha, respectively. OC in shrub layer in 2007 and 2008 was 1.58 and 1.79 ton C/ha, respectively. Total amount of OC in 2007 and 2008 in this *P. rigida* plantation was 84.64 and 89.46 ton C/ha, respectively. Net increase of OC in above- and below-ground biomass in this *P. rigida* plantation was 4.82 ton $\triangle C\ ha^{-1}\ yr^{-1}$.

Jeon et al. (2007) reported that amount of organic carbon in tree layer of *Pinus densiflora* forest at Mt. Worak National Park was 51.79 ton/ha, and 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, which was quite lower than our result. Tree density of Jeon et al. (2007), 1,300 trees/ha, was quite lower than our study area. 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) also reported that above- and below-ground

Table 1. Carbon distribution among the plant components in 2007 and 2008 (ton C/ha), and net increase of organic carbon (ton △C ha^{-1} yr^{-1}) in the study area

		2007	2008	△C
Tree layer	Leaf	9.47	9.90	0.43
	Branch	16.16	17.20	1.04
	Stem	41.15	43.39	2.24
	Root	16.28	17.18	0.90
Shrub layer		1.58	1.79	0.21
Total		84.64	89.46	4.82

OC of 30 year-old *P. rigida* plantation was 81.8 ton C/ha, which was similar with our result. The amount of OC in above-ground plant biomass in forests seemed to be related to tree species, tree density and soil nutrients (Lee and Mun 2005, Choi et al. 2006).

Organic Carbon in Litterfall

Litter production continued throughout the year, but showed peaks in November and May (Fig. 2). In November, needle litter showed the highest proportion with the value of 84.1%. However, in May, proportion of reproductive organ was the highest with the value of 45.6%. As shown in Fig. 2, most of the OC returned to forest floor *via* litterfall was from needle leaf litter. Others were usually leaf litter of shrub species. Percent of organic carbon in needle litter, woody material, reproductive organ and others was 50.1%, 50.0%, 45.5% and 48.1%, respectively. Total amount of OC returned to fotest floor *via* litterfall of trees and shrubs was 2.21 ton C ha^{-1} yr^{-1}. Of the total organic carbon returned to forest floor *via* litterfall, needle litter, branch and bark, reproductive organ and the others occupied 59%, 16%, 14% and 11%, respectively. Jeon et al. (2007) reported that organic carbon returned to forest floor *via* litterfall was 1.38 ton C ha^{-1} yr^{-1}, which was lower than that of our result. However, Mun et al. (2006) reported that the amount of OC returned to forest floor in *Q. variabilis* and *Q. mongolica* forests at Mt. Worak National Park was 2.29 and 2.59 ton C ha^{-1} yr^{-1}, respectively.

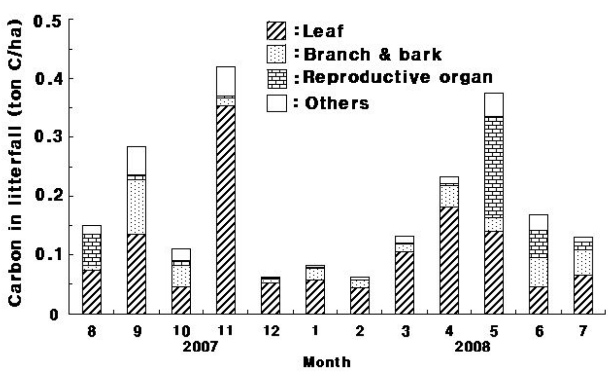

Fig. 2. Seasonal organic carbon of litterfall in the pitch pine plantation of the study area.

Organic Carbon in Litter Layer

Average percent of organic carbon in needle litter, woody material, reproductive organ and others in litter layer was 45.1%, 48.0%, 44.9% and 44.5%, respectively. Organic carbon in litter layer of the forest floor was summarized in Table 2. Amount of OC in litter layer in September, December, March and June was 4.40, 4.55, 4.32 and 4.00 ton C/ha, respectively (Table 2). Amount of OC in litter layer in December was the highest, and that of June was the lowest. This is because litterfall showed peak in Autumn (Fig. 2). The average amount of OC in litter layer of this pitch pine plantation was 4.32 ± 0.25 ton C/ha. Amount of OC in F layer was higher than that of in L layer.

Bulk Density and SOC

For the quantitative determination of SOC, the knowledge of soil bulk density is of particular importance. Soil bulk density of top soil and 50 cm-depth soil in this pitch pine plantation was 0.94 ± 0.06 and 1.47 ± 0.02 g/cm^3, respectively (Fig. 3A). Soil bulk density increased along the soil depth. Choi et al. (2006) reported that soil bulk density of top soil and 50 cm-depth soil in the *Q. varia-*

Table 2. Seasonal organic carbon (ton C/ha) in litter layer of *Pinus rigida* plantation of the study area

Items		Organic carbon (ton C/ha)			
		2007		2008	
		September	December	March	June
Leaf	L	0.33	0.32	0.31	0.25
	F	0.42	0.43	0.46	0.26
Branch & bark	L	0.32	0.20	0.20	0.11
	F	0.05	0.06	0.07	0.10
Rep. organ	L	0.11	0.08	0.07	0.10
	F	0.34	0.11	0.03	0.56
Others	L	1.13	1.57	1.46	0.93
	F	1.70	1.78	1.72	1.69
Total	L	1.89	2.17	2.04	1.39
	F	2.51	2.38	2.28	2.61
	Total	4.40	4.55	4.32	4.00

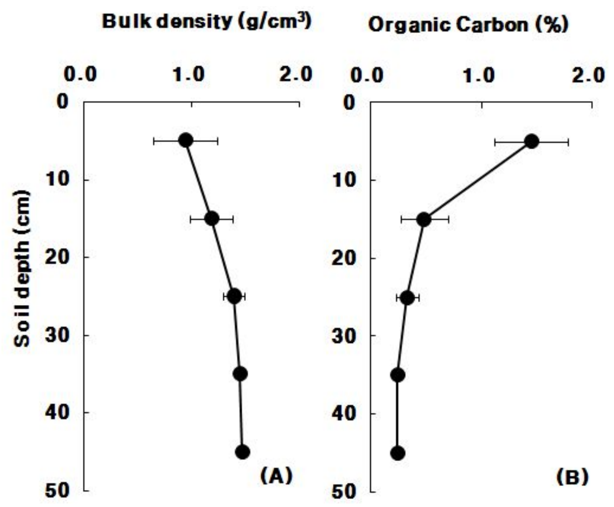

Fig. 3. Bulk density (g/cm^3) (A) and soil organic carbon (%) (B) along the soil depth in the pitch pine plantation of the study area.

bilis forest was 0.82 ± 0.07 and 0.90 ± 0.05 g/cm^3, respectively, which was lower than that of this study. Jeon et al (2007) also reported that soil bulk density of top soil and 50 cm-depth soil in the *P. densiflora* forest was 0.86 ± 0.05 and 1.02 ± 0.04 g/cm^3, respectively. Soil bulk density mainly seemed to be related to organic matter content of soil (Huntington et al. 1989). SOC (%) decreased along the soil depth (Fig. 3B). SOC of top soil and 50 cm-depth soil in this pitch pine plantation was 1.46 ± 0.06 and 0.25 ± 0.02 %, respectively. SOC is a complex mixture of carbon compounds derived from plants, animals, and microbes, which vary greatly in their amount and decomposition dynamics (Schwendenmann and Pendall 2008).

Seasonal SOC along the soil depth was summarized in Table 3. Average SOC in top soil and 50 cm-depth soil was 52.90 ± 7.90 and 9.65 ± 1.74 ton C ha^{-1} 10 cm-$depth^{-1}$, respectively. Jeon et al. (2007) reported that average SOC in top soil and 50 cm-depth soil in *P. densiflora* forest was 21.5 ± 4.33 and 15.1 ± 3.15 ton C ha^{-1} 10 cm-$depth^{-1}$, respectively. Seasonal SOC seemed to be related to site variation. Average amount of SOC within 50 cm soil depth in this pitch pine plantation was 100.32 ton C ha^{-1} 50 cm-$depth^{-1}$, which was greater than that of Jeon et al. (2007). Namgung et al. (2008) reported that SOC within 50 cm soil depth in *Q. variabilis* forest was 119.14 ton C ha^{-1} 50 cm-$depth^{-1}$, which was greater than that of this study.

Table 3. Seasonal soil organic carbon (ton C/ha) in the *Pinus rigida* plantation of the study area

Soil depth (cm)	2007		2008		Mean ± SD
	Sep.	Dec.	Mar.	June	
0～10	58.15	41.19	57.04	55.23	52.90 ± 7.90
10～20	18.75	12.95	12.87	18.06	15.66 ± 3.19
20～30	12.99	9.78	12.92	14.83	12.63 ± 2.10
30～40	8.52	7.31	10.74	11.32	9.60 ± 2.05
40～50	8.73	7.67	10.91	11.30	9.65 ± 1.74
Total	107.14	78.90	104.48	110.74	100.32 ± 14.51

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 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 (119.14 ton C ha^{-1} 50 cm-$depth^{-1}$) was higher than that of this study (Namgung et al. 2008).

Organic Carbon Distribution

OC distribution in each component of this pitch pine plantation was summarized in Fig. 4. Total amount of organic carbon stored in this pitch pine plantation was 194.1 ton C/ha. Jeon et al. (2007) reported that OC stored in pine forest was 142.78 ton C/ha, which was lower than that of this study. Namgung et al. (2008) reported that OC stored in *Q. variabilis* forest was 193.96 ton C/ha, which was similar with that of this study.

Percentage of OC stored in soil and plant biomass accounted for 53.2% and 43.4%, respectively, of the total OC in this pitch pine plantation. Heath et al. (2003) reported that 51% of OC in forests is in the soil, which is similar with the result of this study. Morrison et al. (1993) reported that 55～68% of carbon in three mature

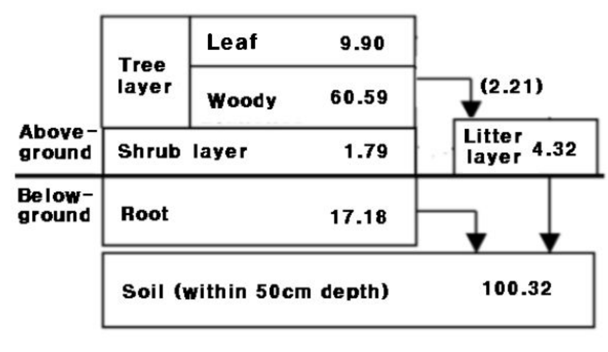

Fig. 4. Organic carbon distribution in the pitch pine plantation (ton C/ha) of the study area. Numerals in parenthesis indicate the organic carbon (ton C ha^{-1} yr^{-1}) returned to forest floor *via* litterfall.

forests of Ontario, Canada was located in the soil. In temperate forest, SOC accounts 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, Namgung et al. 2008). In this study, we estimate SOC within 50 cm soil depth instead of 1m soil depth. 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).

ACKNOWLEDGEMENTS

This study was supported by Korean Research Foundation Grant (KRF-2007-313- C00737).

Literature cited

Amichev BY, Burger JA, Rodrigue JA. 2008. Carbon sequestration by forests and soils on mined land in the Midwestern and Appalachian coalfields of the U.S. For Ecol Manag 256: 1949-1959.

Boyland M. 2006. The economics of using forests to increase carbon storage. Can J For Res 36: 2223-2234.

Choi HJ, Jeon IY, Shin CH, Mun HT. 2006. 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.

Gucinski H, Vance E, Reiners WA. 1995. Potential effects of global climate change. In Ecophysiology of Coniferous Forests (Smith WK, Hinckley TM, eds). Academic Press, New York, pp 309- 331.

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 The potential of U.S. Forest Soils to Sequester Carbon and Mitigate the Greenhouse Effect (Kimble JM, Heath LS, Birdsey RA, Lai R, eds). 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.

Huntington TG. 1995. Carbon sequestration in an aggrading forest ecosystem in the southeastern USA. Soil Sci Soc Am J 59: 1459-1467.

Huntington TG, Johnson CE, Johnson AH, Siccama TG, Ryan DF. 1989. Carbon, organic matter, and bulk density relationships in a forested spodosol. Soil Sci 148: 380-386.

Jeon IY, Shin CH, Kim GH, Mun HT. 2007. Organic carbon distribution of the *Pinus densiflora* forest on Songgye valley at Mt. Worak National Park. J Ecol Field Biol 30: 17-21.

Jeong JH, Kim C, Lee WK. 1998. Soil organic carbon content in forest soils of Korean. 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- blackjack oak forest. Ecology 55: 1246-1258.

Kim C, 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. 1971. Studies on the productivity and the production structure of the forests. I. On the productivity of *Pinus rigida* plantation. Korean J Bot 14: 155-162.

Kimble JM, Birdsey RA, Lal R, Heath LS. 2003 a. Introduction and general description of U.S. forests. In The Potential of U.S. Forest Soils to Sequester Carbon and Mitigate the Greenhouse Effect (Kimble JM, Heath LS, Birdsey RA, Lai R, eds). CRC Press, New York, pp 3-14.

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

Korea Forest Service. 2007. Forestry statistics at a glance. Korea Forest Service.

Laclau P. 2003. Biomass and carbon sequestration of ponderosa pine plantations and native cypress forests in northwest Patagonia. For Ecol Manag 180: 317-333.

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

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

Morris SJ, Paul EA. 2003. Forest soil ecology and organic carbon. In The Potential of U.S. Forest Soils to Sequester Carbon and Mitigate the Greenhouse Effect (Kimble JM, Heath LS, Birdsey RA, Lai R, eds). CRC Press, New York, pp 109-125.

Morrison IK, Foster NW, Hazlett PW. 1993. Carbon reserves, carbon cycling, and harvesting effects in three mature forest types in Canada. NZ J For Sci 23: 403-412.

Mun HT, Kim SJ, Shin CH. 2007. Litter production and nutrient contents of litterfall in oak and pine forests at Mt. Worak National Park. J Ecol Field Biol 30: 63-68.

Namgung J, Choi HJ, Han AR, Mun HT. 2008. Organic carbon distribution and budget in the *Quercus variabilis* forest in the Youngha valley of Worak National Park. Korean J Environ Biol 26: 170-176.

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.

Schlesinger WH. 1997. Biogeochemistry: An Analysis of Global Change. Academic Press, San Diego, California.

Schwendenmann L, Pendall E. 2008. Response of soil organic matter dynamics to conversion from tropical forest to grassland as determined by long-term incubation. Biol Fertil Soils 44: 1053-1062.

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

Wright JA, DiNicola A, Gaitan E. 2000. Latin American forest plantations: opportunities for carbon sequestration, economic development, and financial returns. J Forestry 98: 20-23.

(Received January 31, 2009; Accepted February 13, 2009)