Integrative Biosciences 10: 191-196, 2006

Integrative
Biosciences
http://www.ibiosci.or.kr

Carbon storage, Litterfall and Soil CO_2 Efflux of a Larch (*Larix leptolepis*) Stand

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Abstract: This study was carried out to evaluate soil carbon cycling of a 36-year-old larch (*Larix leptolepis*) stand in Korea. The aboveground and soil organic carbon storage, litterfall, and soil respiration rates were measured over two-year periods. The estimated aboveground biomass carbon storage and increment were 4220 gC m^{-2} and 150 gC m^{-2} yr^{-1}, respectively. Mean organic carbon inputs by needle and total litterfall were 118 gC m^{-2} yr^{-1} and 168 gC m^{-2} yr^{-1}, respectively. The aboveground carbon increment of the stand was similar to the annual input of carbon from total litterfall. The soil respiration rates correlated exponentially with the soil temperature at a depth of 20 cm ($R^2 = 0.86$). In addition, the exponential regression equation indicated a relatively strong positive relationship between the soil respiration rates and soil temperature, while there was no significant relationship between the soil respiration rates and the soil moisture content. The annual mean and total soil respiration rates were 0.40 g CO_2 m^{-2} h^{-1} and 3010 g CO_2 m^{-2} yr^{-1} over the two-year study period, respectively.

Key words: Carbon cycling, carbon dynamics, soil carbon, soil respiration

Carbon cycling in forests has been the focus of research (Nakane, 1995; Davis et al., 2003; Laporte et al., 2003), because forests play an important role in global climate change, as defined in a recent IPCC report (Watson et al., 2000). However, the role and the importance of forests as sources or sinks for carbon are likely to vary widely according to the region, the type of forest, age of the trees and forest management activities (Johnson, 1992; Nakane, 1995; Lee and Jose, 2003; Pypker and Fredeen, 2003). Forests have been considered as potential carbon sinks that may play a role in storing some of the carbon dioxide emitted in the atmosphere (Watson et al., 2000; Janssens et al., 2002). In addition, the evaluation of carbon storage and soil respiration changes in forest stands is a key factor in understanding the soil carbon cycling, because both factors are an important process in the flow of carbon in forest stands (Bowden et al., 1993; Raich, 1998; Kim, 2004).

The larch stands constitute the most common type of artificial forest in Korea. This tree was planted in an area of about 600 thousand hectares between the year of 1957 and 1990 (Forest Administration, 1994) and has been one of the major planting species for reforestation and managed intensively throughout the country. Fox (2000) suggested that intensively managed forests are a major sink to carbon dioxide in the atmosphere. There have, however, been few attempts to study quantitatively the cycling of carbon in larch stands (Son and Kim, 1996; Hwang, 2004). The objectives of this study were to evaluate soil carbon cycling such as organic carbon storage (aboveground biomass and 50 cm of soil depth), carbon inputs (litterfall production), and soil respiration rates in a 36-year-old larch (*Larix leptolepis*) stand.

MATERIALS AND METHODS

The study was conducted in the Sambong Exhibition Forests (35° 27' N, 127° 38' E, 690 m) located in Hamyang-gun, Gyeongsangnam-do, the southern part of Korea. The study site was administered and managed intensively by the Western National Forest Office, Korea Forest Service. The annual average precipitation in this area was 1322 mm yr^{-1} and the annual average temperature was 12.8°C. Experimental plots were located in two adjacent 36-year-old *Larix leptolepis* stands on a moderately productive upland site (Site Index 15). The experimental design consisted of eight 20 m × 10 m plots. The stands were located within 1,000 m of each other. The dominant understory species were *Viburnum dilatatum, Lindera erythrocarpa, Rubus parvifolius, Quercus serrata, Q. acutissima, Schizandra chinensis,*

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Staphylea bumalda, Zanthoxylum schinifolium, Juglans mandshurica, Styrax japonica, Stephanandra incisa, Z. schinifolium, Cornus controversa, and *Rhus sylvetris* etc.

The soil in the study site was characterized as a well-drained, slightly wet brown forest soil. The soil texture was silt loam with a pH 4.9. The mean stand density of the stand was 487 trees ha^{-1}. The mean tree diameter and height were approximately 23.0 cm and 20.9 m, respectively. The average stand basal area was 22.8 cm^{-2} m^{-2}.

The level of carbon storage in the aboveground tree species was measured using the following equations (Dry matter (kg) = −0.9251 (DBH) + 0.3152 (DBH)^2, $R^2 = 0.90$) for estimating the level of dry matter, which were developed from the Korea Forest Research Institute (Kim et al., 1998). The level of aboveground carbon storage was calculated by assuming a carbon concentration of 50% of the dry matter (McPherson and Simpson, 1999; Davis et al., 2003).

Soil samples were collected in November 2003 from three randomly selected points in each plot. At each point, a 100 cm × 100 cm soil pit was dug in order to collect the soil samples at three depths (0-15 cm, 15-30 cm, 30-50 cm). The soil bulk density at each soil depth was determined after drying (105°C) the samples stored in 100 cc stainless steel cans. Five bulk soil samples used to measure the soil carbon content were collected at three depths (0-15 cm, 15-30 cm, 30-50 cm). The collected soil samples were air-dried and sifted through a 2 mm sieve prior to soil carbon analysis. Forest floor samples were collected using a 200 cm^2 stainless steel core from four random points per plot. The forest floor samples were oven-dried at 65°C and ground with a Wiley mill in order to pass through a 40 mesh stainless sieve. The loss on ignition at 375°C for 16 hours (Soon and Abboud, 1991) was determined for the mineral soil samples and was converted to a carbon percentage (Davis et al., 2003).

The organic carbon input by litterfall was measured by installing three circular litter traps each with 0.25 m^2 surface area from each plot at 60 cm above the forest floor. Litter was collected at monthly intervals from May 2002 to May 2004. The litter from each trap was transported to a laboratory and oven-dried at 65°C for 48 hours. All the dried samples were separated into needle, bark, fruit, branches and miscellaneous components, and each portion was weighed.

The soil CO_2 efflux was measured *in situ* using an infrared gas analyzer system (Model EGM-4, PP systems, Hitchin, UK) that was equipped with a flow-through closed chamber (Model SRC-2, same manufacturer). At the time of the measurement, the forest floor was removed and the chamber was inserted into the soil to a 3 cm depth. The measurements were performed between 10 : 00 a.m. and 2 : 00 p.m. over two-year periods (from August 2002 to July 2004) except for the snow season (December or January). During the measurement, the soil temperature was measured at a depth of 20 cm adjacent to each chamber. In addition, volumetric soil water content was measured at a 12 cm depth using a Hydrosence soil moisture meter (Cambell Scientifics, Inc. Logan. UT). The soil respiration data collected over the two-year periods were used to test for a linear relationship between the soil temperature, soil moisture content, and soil CO_2 efflux.

RESULTS

Aboveground and soil carbon storages

The estimated aboveground organic carbon storage and the increment in this stand were 4220 gC m^{-2} and 150 gC m^{-2} yr^{-1}, respectively (Table 1). Soil organic carbon storage was 18170 gC m^{-2} at a depth of 50 cm (Table 2). Soil organic carbon content was higher in the surface depth (0~15 cm) than in the subsurface depth (15~50 cm).

Table 1. Aboveground organic carbon storage and increment in a larch plantation (n = 8)

Year	DBH (cm)	Aboveground carbon storage	Aboveground carbon increment
		(gC m^{-2})	(gC m^{-2} yr^{-1})
Dec. 2002	23.7 ± 0.96	4070 ± 320	-
Dec. 2003	24.1 ± 0.97	4220 ± 330	150 ± 13

-: not determined. Mean ± standard error.

Table 2. Soil organic carbon content and storage in a larch plantation (n = 8)

Depth	Bulk density (g cm^{-3})	Rock percentage (g kg^{-1})	Carbon content (gC kg^{-1})	Carbon storage (gC m^{-2})
Forest floor	-	-	385.4 ± 9.8	457 ± 19
1-15 cm	0.82 ± 0.05	113 ± 16	63.3 ± 4.4	7345 ± 310
15-30 cm	0.81 ± 0.06	122 ± 23	45.5 ± 3.3	5220 ± 310
30-50 cm	0.93 ± 0.05	147 ± 20	40.1 ± 3.4	5147 ± 350
Total	-	-	-	18170 ± 750

-: not determined. Mean±standard error

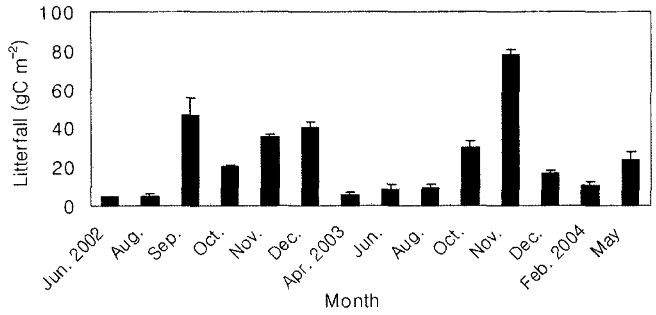

Fig. 1. Monthly variation of organic carbon inputs by litterfall in a larch plantation (n = 24). Vertical bar indicate standard errors.

Table 3. Organic carbon inputs by litterfall in a larch plantation (n = 24)

Components	May 2002-May 2003	May 2003-May 2004	Yearly mean
		(gC m^{-2} yr^{-1})	
Needle litterfall	118 ± 5.0	118 ± 4.1	118 ± 4.4
Non-needle litterfall	42 ± 6.9	58 ± 6.1	50 ± 5.2
Total litterfall	160 ± 10.9	176 ± 8.1	168 ± 8.3

Mean ± standard error

Litterfall inputs

Figure 1 shows the seasonal organic carbon inputs by litterfall. The organic carbon inputs showed a typical unimodal pattern which had a maximum values in the late autumn (November) between May 2003 and May 2004. The mean organic carbon inputs over two-year periods by needle and the total litter were 118 gC m^{-2} yr^{-1} and 168 gC m^{-2} yr^{-1}, respectively (Table 3). Needle litter accounted for approximately 70% of the total annual litterfall. The annual input of organic carbon by total litterfall was similar to the aboveground carbon increment (150 gC m^{-2} yr^{-1}) of this stand.

Soil respiration

The soil CO_2 efflux rates showed clear seasonal variations. The rates increased during the spring and summer season, and reached a maximum in July and August (Fig. 2). The soil CO_2 efflux rates began to decline during the fall (September and October), reaching values close to those in spring (April and May). The exponential regression coefficient of each CO_2 efflux against the corresponding soil temperature at a 20 cm depth (Fig. 3) was significant ($R^2 = 0.862, p < 0.05$). However, the regression between the soil CO_2 efflux rates and the soil moisture content was not significant ($p > 0.05$), and the strength of this relationship was quite low ($R^2 = 0.08$). The annual mean soil respiration rates during the two-year study periods were 0.40 g CO_2 m^{-2} h^{-1}.

DISCUSSION

The aboveground organic carbon storage and increment of this 36-year-old larch stand were 4220 gC m^{-2} and 150 gC m^{-2} yr^{-1}, respectively. The value was similar to the aboveground carbon storage (4630 gC m^{-2} with a stand basal area of 26.4 cm^2 m^{-2}) in a 42-year-old larch stand near the study site (Kim and Cho, 2004). However, the carbon storage and increment in this stand was lower than in other pine stands or in temperature coniferous forests. For example, the carbon storage and increment in a 31-year-old *Pinus rigida* stand in Gwangnung in the central Korea were 8170 gC m^{-2} and 323 gC m^{-2} yr^{-1}, respectively (Kim and Jeong, 2001). Melillo et al. (1994) reported that annual carbon increment in temperate coniferous forests averaged 470 gC m^{-2} yr^{-1}. The difference of carbon storage in coniferous stands was attributed largely to change in aboveground biomass carbon by the difference in the stand basal area as a result of common forest management practices such as the thinning intensity, by the difference in site quality (Kim and Jeong, 2001), or by the difference in tree stand types (Kim and Cho, 2004).

The belowground soil carbon storage (12570 gC m^{-2}) at a 30 cm depth was slightly higher than in other adjacent coniferous stands near the study site. Soil carbon storage at a 30 cm depth was 9120 gC m^{-2} in a 42-year-old larch, 10260 gC m^{-2} in a 42-year-old *Pinus densiflora* and 9420 gC m^{-2} in a 42-year-old *P. rigitaeda* stands, respectively (Kim and Cho, 2004). The soil carbon storage in this stand was also higher than the 6700 gC m^{-2} observed in Korean forest soils (Jeong et al., 1998). Soil carbon storage was affected by litterfall inputs, litter decomposition rates, and/or understory vegetation cover rates among tree species compositions (Kim and Cho, 2004; Borken and Beese, 2005).

The organic carbon inputs by litterfall showed a maximum values in the late autumn (November) because autumn is a natural senescence season of the needles in temperate forest (Bray and Gorham, 1964). However, an unexpected peak of litterfall was observed in September, 2002, which was attributed to a heavy storm by Typhoon Rusa (30 August-1 September 2002). The storm provoked abnormally high litterfall compared with the same time in other years. The annual organic carbon inputs by litterfall remained relatively constant during the 2-year study period as a result of canopy closure of this plantation. Bray and Gorham (1964) concluded that after canopy closure, there are only slight variations in the annual amount of litterfall over several decades. The mean organic carbon inputs over two-year periods by needle and total litter were 118 gC m^{-2} yr^{-1} and 168 gC m^{-2} yr^{-1}, respectively. The annual litterfall obtained in this study site was less than that (206 gC m^{-2} yr^{-1}) observed in a 40-year-old larch stand in Gyounggi Province in central Korea (Hwang, 2004).

The soil CO_2 efflux rates in this stand showed clear seasonal variations. In addition, the temporal variation in the

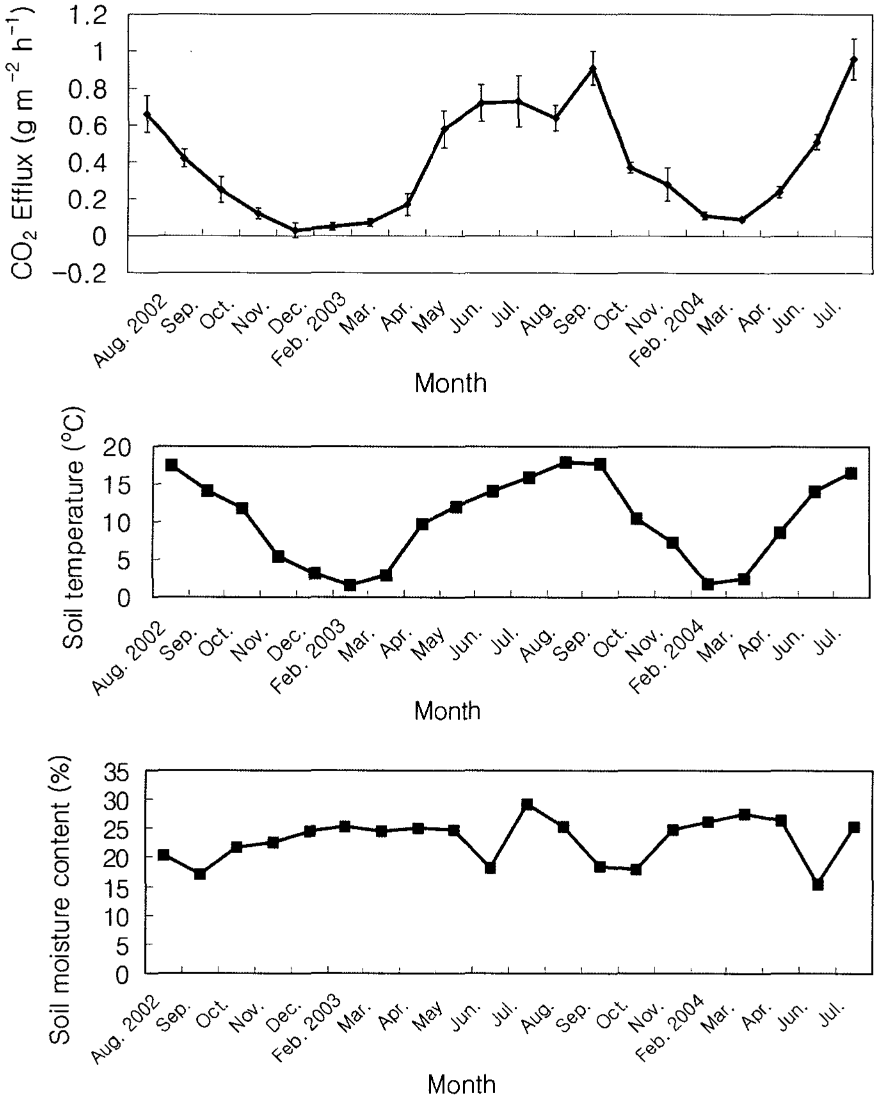

Fig. 2. Monthly variation of soil CO_2 efflux, soil temperature at 20 cm depth, and volumetric soil moisture content at 12 cm depth in a larch plantation (n = 24). Vertical bar indicate standard errors.

CO_2 efflux rates was closely related to the soil temperature fluctuation rather than to variations in the soil moisture content (Fig. 2). Many studies reported that soil CO_2 efflux in temperate forests is typically higher in summer and lower in winter, which correspond to changes in the ambient temperature because roots and soil organisms (bacterial and fungal detritivores) contribute to the soil CO_2 efflux through respiration (Son and Kim, 1996; Ohashi et al., 1999; Wiseman and Seiler, 2004). Seasonal trends in soil CO_2 efflux in this larch stand appeared to correlate strongly with soil temperature (Fig. 3). In addition, an exponential increase in soil respiration with respect to soil temperature was observed in this larch stand. An exponential increase in soil CO_2 efflux rates with respect to soil temperature has been observed over limited range of temperature in other forest ecosystems (Son and Kim, 1996; Ohashi et al., 1999; Hwang, 2004). However, the regression between the soil CO_2 efflux rates and the soil moisture content was not significant because the soil CO_2 efflux was relatively less sensitive to change in the soil moisture than to changes in the soil temperature content. Previous studies reported similar results that soil CO_2 efflux in forest ecosystem correlated strongly with the soil temperature, but weakly with the level of soil moisture (Son and Kim, 1996; Ohashi et al., 1999; Laporte et al., 2003; Lee and Jose, 2003). Although the most significant factors affecting soil respiration were the soil temperature and soil moisture content (Ohashi et al., 1999; Wiseman & Seiler, 2004), the effect of these factors varied according to the geographical location and season (Ohashi et al., 1999).

The annual mean CO_2 efflux rates during the two-year study periods were 0.40 g CO_2 m^{-2} h^{-1}. This value was

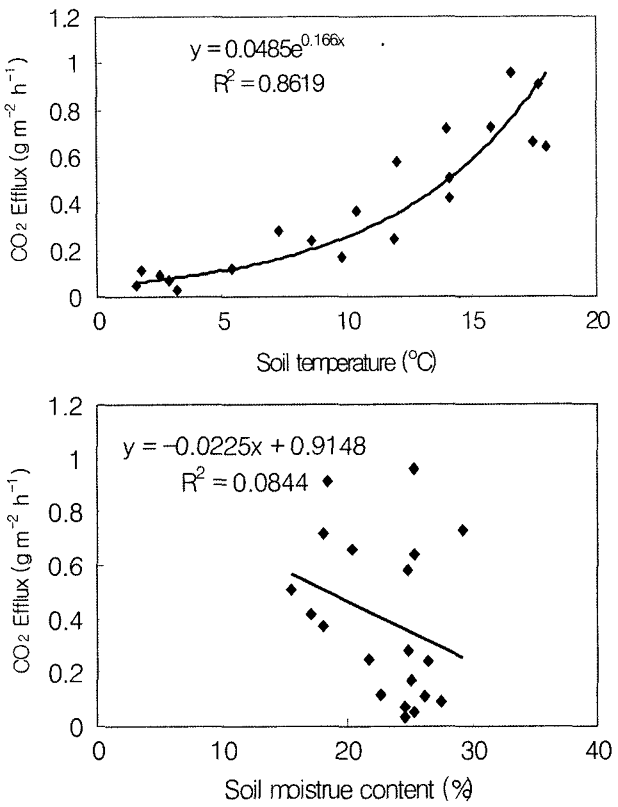

Fig. 3. Relationships between soil CO_2 efflux and soil temperature or soil moisture content in a larch plantation (n = 24).

similar to other larch and pine stands in Korea. The total soil respiration rates were 3010 g CO_2 m^{-2} yr^{-1}. This value was higher than in other larch or pine forests, while lower than in oak forests (Table 4). Son and Kim (1996) observed that the annual soil respiration in a 40-year-old larch stand ranged from 2370 to 2680 g CO_2 m^{-2} yr^{-1} in Yangpyoung in central Korea. Also, this estimate was slightly higher than the average (2374-2550 g CO_2 m^{-2} yr^{-1}) reported by Raich and Schlesinger (1992) in a review of reports on temperate deciduous and coniferous forests.

Measurements of aboveground litterfall can estimate soil CO_2 efflux released from decomposition of aboveground litter with assuming that respiration by decomposing litterfall is equal to litterfall carbon (Bowden et al., 1993). Aboveground litterfall (168 g C m^{-2} yr^{-1}) contributed to 20.5% of soil CO_2 efflux (821 g C m^{-2} yr^{-1}) within the range of values (19-22%) reported elsewhere (Ewel et al., 1987; Rey et al., 2002; Sulzman et al., 2005). Also, Davidson et al. (2002) presented the regression equation (Annual soil respiration = 139 + 4.16× annual litterfall carbon, R^2 = 0.81) of annual soil respiration and annual aboveground litterfall carbon in young forests (<45 years of age). The soil respiration rates estimated by the equation with annual litterfall of 168 g C m^{-2} yr^{-1} were 837 g C m^{-2} yr^{-1}. The value by the equation was similar to soil respiration rates (821 g C m^{-2} yr^{-1}) of this larch stand.

ACKNOWLEDGMENTS

This work was supported by the Korea Research Foundation Grant funded by the Korean Government (MOEHRD) (R05-2002-000-00869-0). I also thank the Muju National Forest Station for providing the study site.

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Table 4. Soil respiration rates in Korean forest stands

Stand	Stand age (yr)	Stand density (tree ha^{-1})	Mean soil respiration (g CO_2 m^{-2} h^{-1})	Total soil respiration (g CO_2 m^{-2} yr^{-1})	Methods	Reference
Larix leptolepis	36	487	0.40	3010	IRGA	This study
L. leptolepis	40	548	0.32	2370	soda-lime	Son and Kim (1996)
L. leptolepis	44	525	0.37	1960	IRGA	Hwang(2004)
Pinus rigida	40	667	0.38	2680	soda-lime	Son and Kim (1996)
P. rigida	40	1100	0.45	2420	IRGA	Hwang (2004)
Quercus mongolica	50	650	0.57	3420	IRGA	Yi (2003)
Q. variabilis	44	1050	0.52	3250	IRGA	Yi (2003)
Q. variabilis	49	825	0.51	3490	IRGA	Yi (2003)
Q. rubra	20	-	0.41	-	soda-lime	Son et al. (1994)

-: no data

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[Received August 14, 2006; accepted December 6, 2006]