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ORIGINAL ARTICLE

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Soil carbon storage, litterfall and CO_2 efflux in fertilized and unfertilized larch (*Larix leptolepis*) plantations

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Abstract This study evaluated the effects of forest fertilization on the forest carbon (C) dynamics in a 36-year-old larch (*Larix leptolepis*) plantation in Korea. Above- and below-ground C storage, litterfall, root decomposition and soil CO_2 efflux rates after fertilization were measured for 2 years. Fertilizers were applied to the forest floor at rates of 112 kg N ha^{-1} $year^{-1}$, 75 kg P ha^{-1} $year^{-1}$ and 37 kg K ha^{-1} $year^{-1}$ for 2 years (May 2002, 2003). There was no significant difference in the above-ground C storage between fertilized (41.20 Mg C ha^{-1}) and unfertilized (42.25 Mg C ha^{-1}) plots, and the C increment was similar between the fertilized (1.65 Mg C ha^{-1} $year^{-1}$) and unfertilized (1.52 Mg C ha^{-1} $year^{-1}$) plots. There was no significant difference in the soil C storage between the fertilized and unfertilized plots at each soil depth (0–15, 15–30 and 30–50 cm). The organic C inputs due to litterfall ranged from 1.57 Mg C ha^{-1} $year^{-1}$ for fertilized to 1.68 Mg C ha^{-1} $year^{-1}$ for unfertilized plots. There was no significant difference in the needle litter decomposition rates between the fertilized and unfertilized plots, while the decomposition of roots with 1–2 mm diameters increased significantly with the fertilization relative to the unfertilized plots. The mean annual soil CO_2 efflux rates for the 2 years were similar between the fertilized (0.38 g CO_2 m^{-2} h^{-1}) and unfertilized (0.40 g CO_2 m^{-2} h^{-1}) plots, which corresponded with the similar fluctuation in the organic carbon (litterfall, needle and root decomposition) and soil environmental parameters (soil temperature and soil water content). These results indicate that little effect on the C dynamics of the larch plantation could be attributed to the 2-year short-term fertilization trials and/or the soil fertility in the mature coniferous plantation used in this study.

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Introduction

Carbon (C) dynamics in forests have recently become a major research focus (Nakane 1995; Davis et al. 2003; Laporte et al. 2003) because forests play an important role in global climate change, as defined in an IPCC report (Watson et al. 2000). However, the role and importance of forests as C sources or sinks are likely to vary according to the type of forest, age of the trees and management practices (Johnson 1992; Nakane 1995; Lee and Jose 2003; Pypker and Fredeen 2003; Jandl et al. 2007). If properly managed, forest plantations are believed to be potential C sinks as they can accumulate carbon in both biomass and soil organic matter pools (Fox 2000; Watson et al. 2000; Janssens et al. 2002).

The quantitative evaluation of C storage and soil carbon dioxide (CO_2) efflux after fertilization is a key process for enhancing C sequestration and storage capacity because C storage and soil CO_2 efflux rates in forests can be affected by the applications of fertilizer (Pangle and Seiler 2002; Lee and Jose 2003; Jandl et al. 2007). Several studies reported a slow increase of soil C storage after fertilization (Johnson 1992; Maier and Kress 2000). This increase was due to organic matter inputs by more root production in fertilized than in unfertilized loblolly pine plantations (Maier and Kress 2000). However, the effect of fertilization on soil CO_2 efflux has received little attention, with conflicting results, in that reports have suggested both an increase (Gallardo and Schlesinger 1994) and a decrease in CO_2 efflux (Haynes and Gower 1995). For example, Gallardo and Schlesinger (1994) found an increase in soil respiration when nitrogen was experimentally added to forest soils in central North Carolina, while Haynes and Gower (1995) reported that soil respiration was significantly lower for fertilized relative to unfertilized plots in red pine plantations in northern Wisconsin. Lee and Jose

(2003) reported that nitrogen fertilization had a significant negative effect on soil respiration in a cottonwood plantation, but no effect was observed in loblolly pine plantations. Since soil respiration results from two main sources, root respiration and the microbial decomposition of organic matter, these conflicting reports could be the result of fertilizer-induced differences in C fixation and allocation patterns among different tree species (Raich and Tufekcioglu 2000; Lee and Jose 2003).

Carbon return via litterfall has been suggested as the primary mechanism by which fixed carbon is transferred to the soil (Berg and Laskowski 2006). Thus, the balance between litterfall and decomposition controls the development of the soil organic layer and the carbon content in the soil (Megonigal et al. 1997; Berg and Laskowski 2006). Many litterfall and decomposition studies have shown the rate of litter decomposition to be closely correlated with the quality of litter and environmental factors (Vitousek 1982; Vogt et al. 1986; Blair 1988; Berg and Laskowski 2006).

Larch (*Larix leptolepis*) plantations in an area of approximately 600,000 ha, planted from 1957 to 1990 (Forest Administration 1994), are the most common type of artificial forest in Korea. This tree has been one of the major species planted for reforestation and managed intensively throughout the country (Lee et al. 2004). Fox (2000) suggested that intensively managed forests are a major atmospheric CO_2 sink. Although fertilizers have been used to increase annual tree growth (Joo et al. 1983) and/or to determine the nutrient dynamics of litter in larch plantations (Lee and Son 2006), few attempts to synthetically and quantitatively examine the importance and behavior of C dynamics after forest fertilization in larch plantations have been undertaken (Son and Kim 1996; Hwang 2004). The objectives of this study were to determine the effects on the forest C dynamics after forest fertilization in a larch plantation. This entailed determining (1) the change in organic C storage (above-ground biomass and a soil depth of 50 cm); (2) the dynamics in organic C inputs (litterfall production) and losses (needle and fine root decomposition); (3) the dynamics in soil CO_2 efflux using closed chamber infrared gas analyzer techniques.

Materials and methods

The study was conducted in the Sambong Exhibition Forests located in Hamyang-gun, Gyeongsangnam-do, and administered by the Western National Forest Office, Korea. The annual average precipitation and temperature in this area are 1,322 mm year^{-1} and 12.8°C, respectively. Experimental plots were located in two adjacent 36-year-old *Larix leptolepis* plantations (35°26′N, 127°37′E, 690 m; 35°27′N, 127°38′E, 630 m) on a moderately productive upland site (site index 15, tree height at 20 years). The mean tree densities of the plantations were slightly lower for the fertilized (456 trees ha^{-1}) than the unfertilized (487 trees ha^{-1}) plots. The mean DBH between the fertilized (23.9 cm) and unfertilized plots (24.1 cm) was similar. The dominant understory tree species were *Viburnum dilatatum, Lindera erythrocarpa, Rubus parvifolius, Quercus serrata, Q. acutissima, Schizandra chinensis, Staphylea bumalda, Zanthoxylum schinifolium, Juglans mandshurica, Styrax japonica, Stephanandra incisa, Cornus controversa* and *Rhus sylvetris*. The soil texture was silt loam, with the chemical properties before the application of fertilizer treatments given in Table 1. The natural fertility of this soil with high organic C content and cation exchange capacity is high compared with other Korean forest soils (Jeong et al. 2003).

The experimental design consisted of a randomized complete block design, with two blocks. Each block was divided into eight 20 × 10-m plots. Four fertilized and four unfertilized plots within each block were randomly assigned with a 5-m buffer zone between each plot. Fertilizers were manually applied to the forest floor surface during the spring for 2 years: 24 May 2002 and 16 May 2003. Urea, fused superphosphate and potassium chloride fertilizers were used as sources of N, P and K, respectively, at rates of 112 kg N ha^{-1} year^{-1}, 75 kg P ha^{-1} year^{-1} and 37 kg K ha^{-1} year^{-1}. These amounts of fertilizers were those generally recommended for a growth increment of mature coniferous forests in Korea (Joo et al. 1983). The C storage of the above-ground tree species was measured using the equations: $Y = 0.9251(\mathrm{DBH}) + 0.3152(\mathrm{DBH})^2$, $R^2 = 0.90$ for estimation of the dry matter of mature larch stands developed from the Korea Forest Research Institute (Kim et al. 1998). The above-ground C storage was calculated by assuming a C concentration of 50% for the dry matter (McPherson and Simpson 1999; Davis et al. 2003).

Soil organic carbon samples were collected from three randomly selected points in each plot during November 2003. At each point, a 100 × 100-cm soil pit was dug for the collection of soil samples at three depths (0–15, 15–30 and 30–50 cm). The soil bulk densities were determined for each depth after drying (105°C) the samples collected in 100-cm^3 stainless steel cans. Five bulk soil samples collected at the three depths were used to measure soil organic carbon content. Soil samples were air-dried and sieved through a 2-mm sieve prior to the analysis of the soil organic C.

To measure the organic C inputs due to litterfall, three circular litter traps with a surface area of 0.25 m^2 were installed 60 cm above the forest floor at each plot. Litter was collected at monthly intervals between May 2002 and April 2004. The litter from each trap was transported to a laboratory and then oven-dried at 65°C for 48 h. All dried samples were separated into needle, bark, cones, branches and miscellaneous components, and each portion was weighed. The litter samples were ground in a Wiley mill to pass through a 40-mesh (0.425 mm) stainless steel sieve. The organic C concentration from a sub-sample of ground litter was determined after heating in a muffle furnace at 375°C for 16 h (Soon and Abboud 1991).

Table 1 Chemical properties of soil before fertilizer treatments in the study site ($n = 16$)

pH (1:5 H_2O)	SOC (%)	TN (%)	Avail. P_2O_5 (mg kg^{-1})	CEC	Exchangeable (cmol*c* kg^{-1})			
					K^+	Na^+	Ca^{2+}	Mg^{2+}
4.9 (0.1)	7.0 (0.5)	0.45 (0.12)	18.5 (2.8)	20.9 (2.9)	0.52 (0.09)	0.15 (0.05)	2.03 (0.31)	0.72 (0.15)

Numbers in parenthesis are standard errors
SOC soil organic carbon, *TN* total nitrogen, *Avail.* available, *CEC* cation exchange capacity

The mass loss rates in the decomposing needle litter were estimated using the litterbag technique. Fresh needle litter from each treatment was collected from the forest floor during late November 2002. After collection, the litter was air-dried at room temperature for 14 days, weighed to the nearest 0.01 g, with approximately 10 g placed in 30 × 30-cm nylon net bag with a mesh size of 0.3 mm. Sub-samples from the litter were also taken to determine the oven-dried masses after heating at 65°C for 48 h. Two litterbags for each treatment plot were randomly placed on the forest floor in December 2002. The litterbags were held fast by 10-cm-long metal pins and collected from each plot after 1 year. After collection, each litterbag sample was oven-dried at 65°C for 48 h, weighed, and the mass loss rates determined.

The fine root decomposition rates were estimated using an in situ buried root decay bag technique, employing 15 × 15-cm nylon bags with a mesh size of 0.3 mm. Fresh fine roots from each treatment were collected during June 2002 from sampling point located at random mineral soil depths. For this study the fine root system was defined as non-woody or woody roots, <1 mm, 1–2 mm and 2–5 mm in diameter, and their associated root tips. After collection, the fine roots were gently rinsed with tap water to remove mineral soils, sorted into size classes, and air dried to constant mass at room temperature for 14 days. Root samples with air-dried masses of 1 g were placed in numbered bags, with sub-samples from each root type also taken to determine their oven-dried masses after heating at 65°C for 48 h. Two root bags, inserted vertically into the mineral soil to a depth of 15 cm using a straight-bladed shovel, were randomly placed on the mineral soils in each treatment plot during December 2002. The bags were collected after incubation of 1 year (December 2003). After collection, each bag sample was oven-dried at 65°C for 48 h, with the mass loss rates then determined.

The soil CO_2 efflux was measured in situ using an infrared gas analyzer system (Model EGM-4, PP systems, Hitchin, UK) equipped with a flow-through closed chamber (Model SRC-2, same manufacturer) each month between August 2002 and July 2004 at three randomly selected locations in each plot, except for during the cold and snow season (January or December). Three measurements from each plot were performed between 10:00 a.m. and 2:00 p.m. The measured CO_2 efflux rates assumed the mean for the month, which were used to calculate monthly soil respiration rates (Haynes and Gower 1995). The soil temperature was measured at a depth of 20 cm adjacent to each chamber using a soil temperature probe (Model STP-1) attached with EGM-4. The volumetric soil water content was measured at a depth of 12 cm using a Hydrosence soil moisture meter (Cambell Scientifics, Inc., Logan, UT).

The effect of fertilization treatment on the carbon dynamics was tested using the general linear model procedure of SAS (SAS Institute 1989) with a Tukey's test used for the mean separation. The soil respiration data collected over the 2-year period were used to test the linear relationships between soil environmental factors (soil temperature, soil water content) and soil CO_2 efflux.

Results

Carbon storage

The estimated above-ground C storage was not significantly different ($P > 0.05$) between the fertilized (41.20 Mg C ha^{-1}) and unfertilized (42.25 Mg C ha^{-1}) plots (Table 2), with similar increment for both the fertilized (1.65 Mg C ha^{-1} $year^{-1}$) and unfertilized (1.52 Mg C ha^{-1} $year^{-1}$) plots. However, the C increment expressed on a per tree basis using the stand density as a denominator was slightly higher for the fertilized (3.62 kg C $tree^{-1}$) than for unfertilized (3.12 kg C $tree^{-1}$) plots. There was no significant difference in the soil organic C content ($P > 0.05$) between the fertilized and unfertilized plots at each soil depth, and a similar trend was shown in the fertilized and unfertilized plots at each soil depth (Table 3).

Litterfall and decomposition rates of needle and roots

There was no significant difference in the organic C inputs on the soil due to needles and total litterfall over the 2-year period ($P > 0.05$) between the fertilized and unfertilized plots (Table 4). The mean organic C inputs due to needles and total litter during both treatments were 1.18 Mg C ha^{-1} $year^{-1}$ and 1.63 Mg C ha^{-1} $year^{-1}$, respectively, over the 2-year period. There was no significant difference in needle litter decomposition rates ($P > 0.05$) between the fertilized and unfertilized plots (Table 5). However, those for fine roots with

Table 2 Above-ground organic carbon storage and increment in fertilized and unfertilized larch (*L. leptolepis*) plantations ($n = 8$)

Treatment	Tree density (trees ha^{-1})	DBH (cm)	Above ground	
			Carbon storage (Mg C ha^{-1})	Carbon increment (Mg C ha^{-1} year^{-1})
Fertilized	456	23.9 (0.80)[a]	41.20 (2.6)[a]	1.65 (0.13)[a]
Unfertilized	487	24.1 (0.97)[a]	42.25 (3.3)[a]	1.52 (0.14)[a]

Means with the same letter do not differ at $P = 0.05$. Numbers in parenthesis indicate standard errors

Table 3 Bulk density, rock content, organic carbon content and carbon storage at different soil depths in fertilized and unfertilized larch (*L. leptolepis*) plantations ($n = 24$)

Depth (cm)	Treatment	Bulk density (g cm^{-3})	Rock (g kg^{-1})	Carbon content (g kg^{-1})	Carbon storage (Mg C ha^{-1})
0–15	Fertilized	0.83 (0.03)[a]	103.0 (16.2)[a]	58.0 (3.5)[a]	69.30 (3.87)[a]
	Unfertilized	0.82 (0.05)[a]	113.3 (16.2)[a]	63.3 (4.4)[a]	73.45 (3.10)[a]
15–30	Fertilized	0.84 (0.06)[a]	150.9 (12.5)[a]	40.8 (3.5)[a]	47.71 (4.40)[a]
	Unfertilized	0.81 (0.06)[a]	122.0 (23.6)[a]	45.5 (3.3)[a]	52.20 (3.10)[a]
30–50	Fertilized	0.91 (0.04)[a]	147.3 (20.8)[a]	39.6 (3.2)[a]	50.11 (3.13)[a]
	Unfertilized	0.93 (0.05)[a]	148.9 (16.7)[a]	40.1 (3.4)[a]	51.47 (3.48)[a]

Means with the same letter do not differ at $P = 0.05$. Numbers in parenthesis are standard errors

Table 4 Organic carbon inputs due to litterfall in fertilized and unfertilized larch (*L. leptolepis*) plantations ($n = 24$)

Treatment	Needle litterfall (Mg C ha^{-1} year^{-1})		Total litterfall (Mg C ha^{-1} year^{-1})	
	May 2002–April 2003	May 2003–April 2004	May 2002–April 2003	May 2003–April 2004
Fertilized	1.112 (0.054)[a]	1.244 (0.061)[a]	1.407 (0.083)[a]	1.734 (0.079)[a]
Unfertilized	1.179 (0.055)[a]	1.183 (0.041)[a]	1.604 (0.109)[a]	1.758 (0.081)[a]

Means with the same letter do not differ at $P = 0.05$. Numbers in parenthesis are standard errors

Table 5 Needle and root decomposition rates in fertilized and unfertilized larch (*L. leptolepis*) plantations ($n = 16$)

Treatment	Needle litter	Root diameter (mm)		
		< 1	1–2	2–5
Fertilized	311 (22.3)[a]	263 (42.1)[a]	303 (17.4)[a]	289 (14.4)[a]
Unfertilized	306 (16.8)[a]	231 (45.7)[a]	256 (12.4)[b]	258 (20.4)[a]

Means with the same letter do not differ at $P = 0.05$. Numbers in parenthesis indicate standard errors. Values are (g kg^{-1} year^{-1})

1–2 mm diameters were significantly increased in the fertilized relative to the unfertilized plots (Table 5).

Soil CO_2 efflux rates

The monthly variations in the soil CO_2 efflux rates were similar between the fertilized and unfertilized plots during the study period, although changes in soil CO_2 efflux rates were observed in June and September 2003 (Fig. 1). The soil CO_2 efflux rates observed during these 2 months were significantly lower ($P < 0.05$) in the fertilized than the unfertilized plots (Fig. 1), and both treatment plots showed clear seasonal variations, where the rates increased during late spring and summer, with maximum values in July and August (Fig. 1). During the fall (September and October), the soil CO_2 efflux declined again, reaching values close to those in spring (April and May). The temporal variation in the soil CO_2 efflux rates in both treatments was closely related to fluctuations in the soil temperature, but was not related to the soil water content (Fig. 1). An exponential regression of each CO_2 efflux against the corresponding soil temperature at a depth of 20 cm (Fig. 2) was highly significant ($R^2 = 0.86$, $P < 0.01$) with both treatments. However, the regression of the soil CO_2 efflux rates against the soil water content was not significant ($P > 0.05$), with the strength of the relationship being quite low ($R^2 = 0.08$).

Discussion

Fertilizer had little effect on any of the parameters related to tree growth, soil C storage, needle litter decomposition and soil CO_2 efflux in this larch plantation over the 2-year period, whereas root decomposition was significantly changed ($P < 0.05$) for those roots with 1–2 mm diameters. The soil C storage with both treatments was not significantly different ($P > 0.05$) at each soil depth, which could be attributed to the similar litterfall (Table 4) and needle and root decompositions (Table 5) with both treatments, as the above-ground

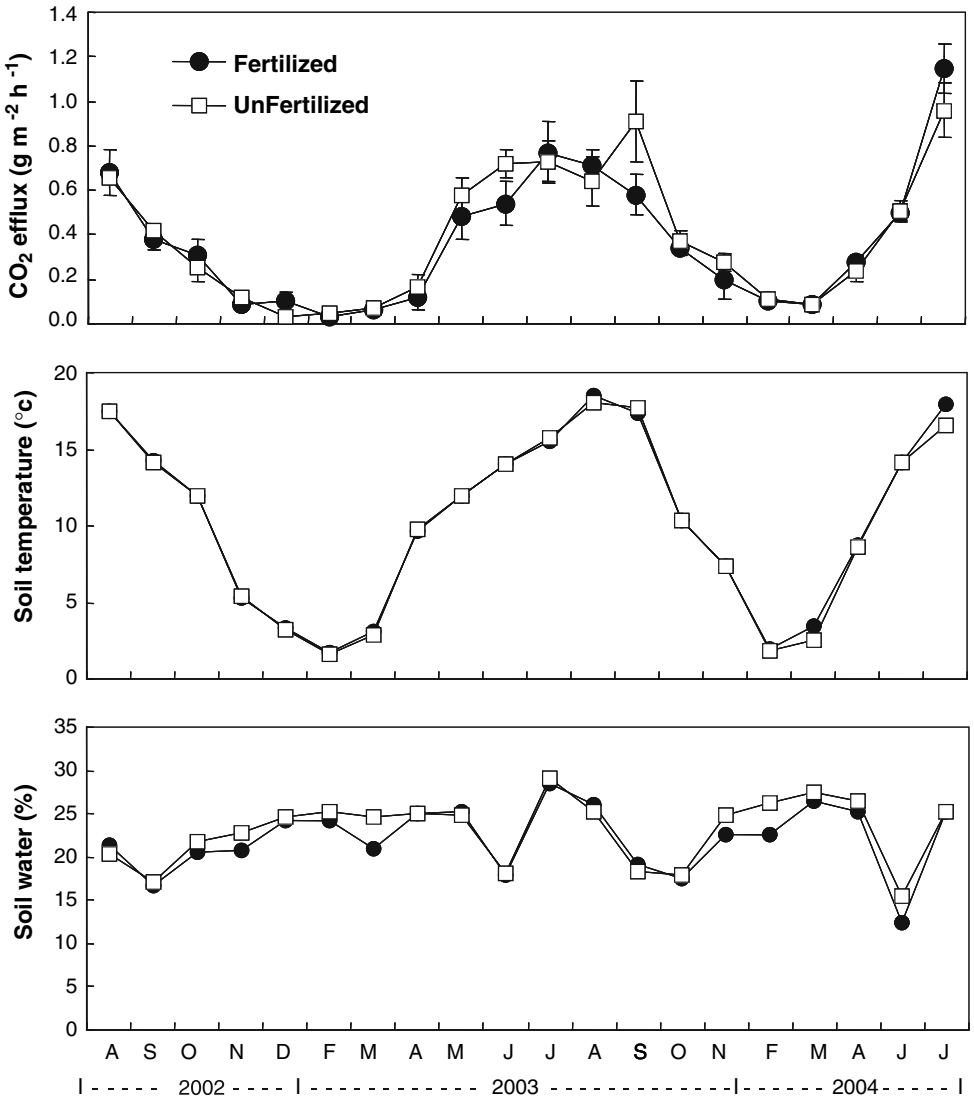

Fig. 1 Monthly variation in the soil CO_2 efflux, soil temperature at a depth of 20 cm, and the volumetric soil water content at a depth of 12 cm in fertilized and unfertilized larch (*L. leptolepis*) plantations ($n = 24$). *Vertical bars* are the standard error of the mean

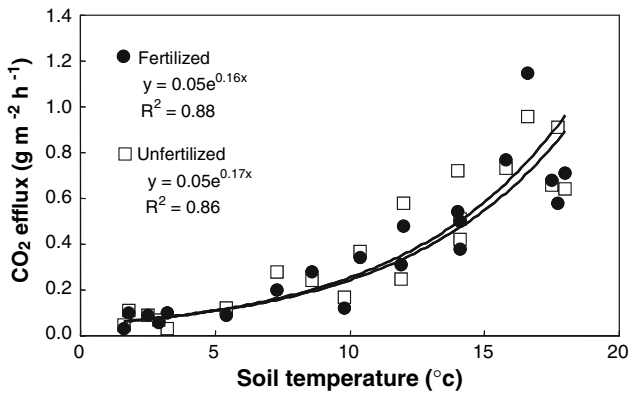

Fig. 2 Relationships between soil CO_2 efflux and soil temperature in fertilized and unfertilized larch (*L. leptolepis*) plantations ($n = 24$)

litterfall and root litter were major sources of C to the soil (Cronan 2003). Although the plantation after fertilization may have different C cycle mechanisms as a result of different litterfall inputs and stand characteristics, fine root production, and microbial biomass, the effects of soil organic C storage in the fertilized plots may have been minimal due to the short-term of this study, i.e., only 2 years. For example, Maier and Kress (2000) observed a significant increase of the soil organic C of top soil (15 cm) due to a 30% increase in root production in the fertilized stands after a 4-year treatment period in an 11-year-old loblolly pine (*Pinus taeda*) plantation, NC, USA.

The organic C inputs due to needle and total litterfall over the 2-year period were not related to the application of fertilizer. Although the C inputs were expected to increase due to litterfall in the fertilized plots in response to fertilization (Haynes and Gower 1995), the similar productions of litterfall between the fertilized and unfertilized plots could have been due to short-term fertilization trials or soil nutrients, which might not be limiting in this plantation. Similarly, Lee and Son (2006) reported that there was no significant difference in the litterfall production in a 41-year-old larch plantation over 2 years

after the application of fertilizer (200 kg N ha^{-1} with 25 kg P ha^{-1}) between control (2.30 Mg C ha^{-1} $year^{-1}$) and fertilizer treated (2.50 Mg C ha^{-1} $year^{-1}$) plots.

The needle litter decomposition rates were not affected by the application of fertilizer, while root decomposition was generally higher in the fertilized than unfertilized plots. Other studies have reported that the addition of fertilizer to coniferous forests did not result in increased rates of needle litter (Theodou and Bowen 1990; Prescott 1995) or root decompositions (King et al. 1997). In addition, King et al. (1997) suggested that root decomposition was seldom affected by fertilization due to the complex ecosystem-level responses to fertilization. Needle or root decompositions can be influenced by abiotic factors, such as temperature, moisture and soil properties, including soil texture and nitrogen availability, and by biotic factors such as nitrogen and lignin concentration and/or the decay organism present in the soil (Joslin and Henderson 1987; Cronan 2003). In this study, both treatments showed that abiotic factors, such as soil temperature and moisture content, which are regarded as the main factors influencing litter decomposition (Vogt et al. 1986; Chen et al. 2000), were not significantly different between the fertilized and unfertilized plots (Fig. 1). The increased decomposition rates in roots with 1–2 mm diameters in fertilized plots may be due to the change of nutrient availability (Hobbie 2005) and the activity of the decomposer on application of fertilizers (King et al. 2002), although the root decomposition response could be affected by the amount of nutrients applied (Ludovici and Kress 2006) and the diameter class of roots (Kern et al. 2004). Kim (2000) suggested that the organic matter decomposition rates under similar climatic and soil conditions could be attributed to the difference of nutrient availability, such as a nitrogen mineralization.

Fertilization had little effect on the monthly variations in the soil CO_2 efflux rates during the study period, whereas those in the fertilized plot decreased significantly during the short time period (June or September 2003) after fertilization (May 2003) (Fig. 1). Many studies have observed decreases in soil CO_2 efflux rates due to reduced microbial biomass (Lee and Jose 2003) and fine root production (Haynes and Gower 1995; Maier and Kress 2000) after fertilization. Although the soil CO_2 efflux rates in this larch plantation were reduced during a short time period after fertilization, they could have also been affected by the increased decomposition of roots. Thus, the decrease in the soil CO_2 efflux in the fertilized plots could be compensated by the increased decomposition of roots after fertilization, as the production of CO_2 in soils was almost entirely from associated microbial biomass activities and root respirations.

Reports on the soil CO_2 efflux rates of forest ecosystem after fertilization have shown conflicting results in that fertilization can decrease (Haynes and Gower 1995), increase (Gallardo and Schlesinger 1994) or have no discernable effect on soil CO_2 efflux (Pangle and Seiler 2002). In addition, the soil respiration rates were significantly lower in fertilized than unfertilized plots in red pine plantations in WI, USA (Haynes and Gower 1995; Maier and Kress 2000), while those with nitrogen application were increased in mineral soils of a warm-temperature forest in central NC, USA (Gallardo and Schlesinger 1994). Lee and Jose (2003) suggested that the soil respiration response to fertilization can vary between conifers and hardwoods; they found significant negative effects on soil respiration in 7-year-old cottonwood stands, while no effect was observed in 7-year-old loblolly pine stands in FL, USA.

The mean annual soil CO_2 efflux rates were 0.38 g m^{-2} h^{-1} for fertilized and 0.40 g m^{-2} h^{-1} for unfertilized plots with no discernable effect after fertilization during the 2-year study period (Fig. 1). In addition, the soil CO_2 efflux rates observed in this study were comparable with those reported for other temperate conifer forests in Korea (Son and Kim 1996; Hwang 2004). The magnitude of the total soil CO_2 efflux rates was 29.65 Mg CO_2 ha^{-1} $year^{-1}$ for fertilized and 30.66 Mg CO_2 ha^{-1} $year^{-1}$ for unfertilized plots. This estimate was higher than the average respirations (23.7–25.5 Mg CO_2 ha^{-1} $year^{-1}$) reported by Raich and Schlesinger (1992) in a review of studies involving temperate coniferous forest sites.

The soil temperature in both treated sites was able to account for the major portion of the variance in soil CO_2 efflux rates via an exponential regression (Fig. 2). The regression in the fertilized plot did not change the fundamental relationships between the soil temperature and soil CO_2 efflux rates, as the soil environmental parameters (soil temperature, soil water content) in this study were not affected by fertilization. Other studies have observed that the soil CO_2 efflux rates were relatively more sensitive to changes in the soil temperature than to those in soil moisture (Bowden et al. 1993; Son and Kim 1996), although the effect of these factors have been shown to vary according to the geographical location and season (Ohashi et al. 1999; Pangle and Seiler 2002; Laporte et al. 2003).

Conclusion

Short-term C dynamics, such as carbon storage, litterfall, decomposition of needles and the mean soil CO_2 efflux rates, were not stimulated by fertilization in this larch plantation. This could be attributed to the fertility of this mature coniferous plantation. In addition, the C dynamics of this productive plantation could not respond to the recommended rates of fertilization. The results indicated that this productive larch plantation should be given low priority when considering fertilization for C sequestration by forests in Korea. Further long-term studies and analyses will be needed to ascertain whether fertilization can induce a change in the C dynamics and to better understand the processes involved in the C dynamics in larch plantations.

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