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Short-term effects of fertilizer application on soil respiration in red pine stands

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Abstract

This study was conducted to evaluate the dynamics of soil respiration (total soil and heterotrophic respiration) following fertilizer application in red pine forests. Fertilizer (N:P:K = 113:150:37 kg/ha), which reflects current practices in Korean forest, was applied in April 2011, and total soil and heterotrophic respiration rates were monitored from April 2011 to March 2012. Monthly variation of total soil and heterotrophic respiration rates were similar between the fertilizer and control treatments, as soil temperature was the dominant factor controlling the both rates. Total soil respiration rates during the study period were not significantly different between the fertilizer (0.504 g CO_2 m^{-2} h^{-1}) and control (0.501 g CO_2 m^{-2} h^{-1}) treatments. However, the proportion of heterotrophic respiration was higher in the fertilizer (78% of total soil respiration rates) than in the control (62% of total soil respiration rates) treatments. These results suggest that current fertilizer practices in Korea forest soil do not substantially affect total soil respiration rates.

Key words: carbon cycle, fertilization, heterotrophic respiration, pine forest, soil CO_2 efflux

INTRODUCTION

The quantitative evaluation of soil respiration following fertilizer application is a key process for understanding carbon dynamics in forest ecosystems, because nitrogen fertilization showed a positive effect on the soil carbon pool among forest management practices (Johnson and Curtis 2001). However, fertilizer application in forest soils has shown to increase, decrease, or to have no effect on soil respiration. Gallardo and Schlesinger (1994) reported an increase in soil respiration when nitrogen was added to forest soils in central North Carolina, while soil respiration was significantly lower for fertilized than for unfertilized plots due to reduced root (Haynes and Gower 1995, Olsson et al. 2005) and microbial respiration (Phillip and Fahey 2007). Also, nitrogen fertilization had a significant negative effect on soil respiration in a hardwood plantation, but no effect was observed in a coniferous plantation (Lee and Jose 2003, Samuelson et al. 2009). Since soil respiration results from two main sources, root respiration (autotrophic respiration) and the microbial decomposition of organic matter (heterotrophic respiration), these conflicting reports could be due to the result of fertilizer-induced differences in carbon fixation and allocation patterns among tree species, or soil-specific differences in the microbial decomposition of organic matter (Raich and Tufekcioglu 2000, Lee and Jose 2003) and mycorrhizal colonization (Phillips and Fahey 2007).

Fertilizer application was found to result in a decrease or an increase in heterotrophic respiration. For example, heterotrophic respiration was reduced after nitrogen applications in pine forests (Franklin et al. 2003), while root

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respiration would be expected to increase along with an increase in forest production after fertilizer application (Bowden et al. 2004). Lee and Jose (2003) suggested that reductions in heterotrophic respirations following fertilizer application could be offset by increases of fine root production. In contrast to this result, fertilization increased heterotrophic respiration, microbial biomass carbon, and microbial activity in a loblolly pine plantation (Samuelson et al. 2009).

Total soil and heterotrophic respiration responded differently to environmental variables such as nutrient availability, soil water content and soil temperature (Raich and Tufekcioglu 2000, Noh et al. 2010, Bond-Lamberty et al. 2011). Although these factors are potentially important regulators of total soil and heterotrophic respiration, experimental data in relation to fertilizer application or soil temperature are limited in Korea forest ecosystems. Red pine (*Pinus densiflora* S. et Z.) forests are the most important type of coniferous tree species and occupy more than 23.5% (1.5 million ha) of Korean forest land (Korea Forest Service 2006). Despite the progress made in quantifying the carbon balance of many coniferous forests in Korea (Kim 2008, Lee et al. 2010, Noh et al. 2010), little is known about the underlying relationships of total soil and heterotrophic respiration rates, which might change in response to fertilizer application. The objective of this study was to determine the effects of fertilizer application on total soil and heterotrophic respiration in red pine stands.

MATERIALS AND METHODS

This study was conducted in approximately 40-year-old natural red pine stands in the Wola National Experimental Forest, which is administered by the Southern Forest Research Center, Korea Forest Research Institute. The average annual precipitation and temperature in this area are 1,490 mm/y and 13.1°C, respectively. The soil is a slightly dry, dark-brown forest soil (mostly Inceptisol, United States Soil Classification System) originating from sandstone or shale with a silt loam texture. The site index of dominant pine trees indicates low forest productivity (site index, 8-10 at 20-year-old base age) suggesting poor soil fertility. The treatment plots were established on the same facing slopes and aspects under similar environmental conditions to minimize spatial variation in soil properties. The experimental design consisted of a completely randomized block design with 2 blocks (35°12′32″ N, 128°10′23″ E, 180 m; 35°12′26″ N, 128°10′25″ E, 195 m) involving 12 plots (plot size = 10 × 10 m): 2 treatments [fertilized, control] × 2 blocks × 3 replicated plots) in mature red pine stands, which were identified based on homogeneity between the sites. Fertilizer application (N:P:K = 113:150:37 kg/ha) was based on the guidelines of forest fertilization in Korea (Joo et al. 1983). Urea, fused superphosphate, and potassium chloride fertilizers were used as sources of N, P, and K, respectively, and were applied manually in 21 April 2011. Tree densities were similar between the fertilizer and the control treatments (Table 1). The mean diameter at breast height was 15.80 cm in the fertilizer and 15.51 cm in the control treatments, whereas the stand basal area was slightly higher in the control (22.35 m^2/ha) than in the fertilizer (20.62 m^2/ha) treatment (Table 1). The understory tree species in each stand were *Lespedeza* spp., *Quercus variabilis*, *Q. serrata*, *Smilax china*, and *Lindera glauca*. The soil properties before fertilizer application is given in Table 2.

Table 1. General stand characteristics of the study plots (*N* = 6)

Treatments	Stand density (trees/ha)	DBH (cm)	Basal area (m^2/ha)
Control	1,200 (141)	15.51 (0.81)	22.35 (1.96)
Fertilization	1,150 (193)	15.80 (1.11)	20.62 (2.38)

Values in parenthesis represent one standard error.
DBH, diameter at breast height.

A root exclusion collar with a trenching was used to separate heterotrophic respiration (Vogel and Valentine 2005, Bond-Lamberty et al. 2011) from total soil respiration. Trenching was performed by excavating the outside edges of a columnar soil of 50 cm diameter and 30 cm deep about one month (24 March 2011) prior to fertilizer application. The soil depth to 30 cm involved the bottom of B horizon and the top of C horizon in a shallow soil of

Table 2. Soil property before fertilizer application in study plots (*N* = 6)

Treatment	Sand (%)	Silt (%)	Clay (%)	C (%)	N (%)	K^+	Ca^{2+}	Mg^{2+}
							($cmol_c$/kg)	
Control	45 (3.5)	43 (3.0)	12 (1.0)	2.40 (0.28)	0.07 (0.01)	0.09 (0.01)	1.35 (0.19)	0.43 (0.05)
Fertilization	42 (2.9)	44 (1.8)	14 (1.0)	2.82 (0.21)	0.09 (0.01)	0.09 (0.01)	1.77 (0.17)	0.54 (0.04)

Values in parenthesis represent one standard error (*N* = 6).

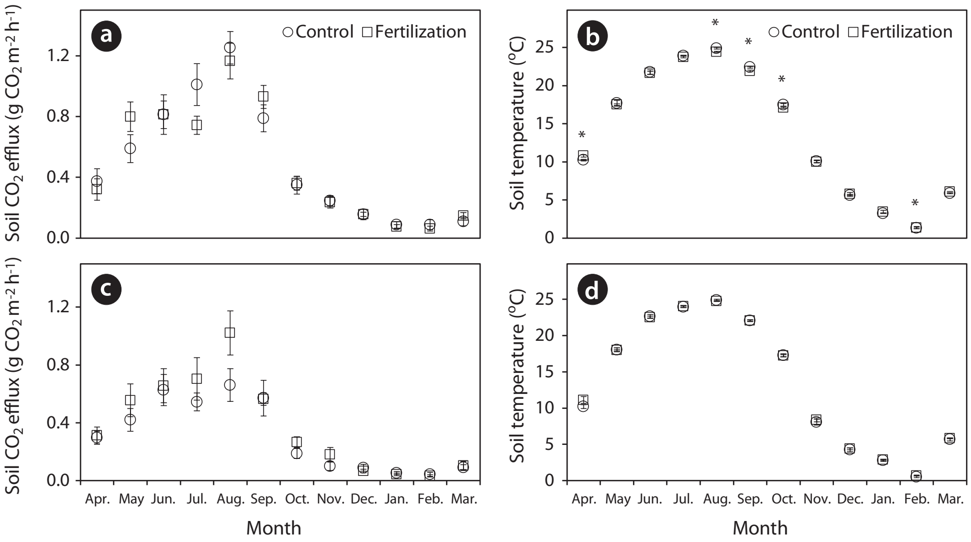

Fig. 1. Monthly variations of total soil (a, b) and heterotrophic (c, d) respiration rates, and the corresponding soil temperature at a depth of 8 cm between fertilizer and control treatments in red pine stands. Bars represent one standard error ($N = 12$) and asterisks indicate a significant difference between fertilizer and control treatments at $P = 0.05$.

the study site. In addition, the trenching depth cut down most live roots. Polyvinyl chloride (PVC) collars (50 cm inner diameter, 30 cm high, 4 mm thick) were inserted into the columnar soil (total 12 plots:6 plots in control and 6 plots in fertilizer treatments) and were backfilled with excavated soil . Seedlings and herbaceous vegetation inside the collars were manually removed, while litter fall was retained within the collars during the study period.

In this study, we assumed that total soil respiration was regarded as soil CO_2 efflux omitted from outside of the trenched location, while heterotrophic respiration was regarded as soil CO_2 efflux omitted inside of the PVC collars in each plot (Lee et al. 2010). Four replicate measurements (2 inside PVC collars and 2 outside the trenched locations) of each plot were performed monthly between 1000 and 1230 h during the study period by using an infrared gas analyzer system (Model EGM-4 environmental gas monitor systems; PP Systems, Hitchin, UK) equipped with a flow-through closed soil respiration chamber (Model SRC-2; PP Systems). Soil temperature from each plot was measured at 8 cm depth adjacent to the soil respiration chamber, using a digital soil temperature probe (Summit SDT 200; Summit, Incheon, Korea).

Data were analyzed by two-way analysis of variance (ANOVA) to determine the significance of main effects (fertilizer treatments [F], trenching treatments [T]) and their interactions (F × T) at a significance level of $P = 0.05$ using the General Linear Models procedure in SAS (SAS Institute Inc. 2003). Soil respiration data collected for a one-year period were used to test exponential functions between soil CO_2 efflux rates and soil temperature:

$$\text{Soil } CO_2 \text{ efflux rates} = B_0 e^{B1ST}$$

, where B_0 and B_1 are coefficients estimated through regression analysis, and ST is soil temperature. The Q_{10} values were calculated by the B_1 coefficient, which is used in the multiplier for soil CO_2 efflux rates given an increase of 10°C in soil temperature ($Q_{10} = e^{10*B1}$).

RESULTS AND DISCUSSION

Monthly rates of total soil and heterotrophic respiration were not significantly affected ($P > 0.05$) by fertilizer application, with no significance of the two factor interaction. Heterotrophic respiration rates during some months were generally higher in the fertilizer treatments than in the control treatments (Fig. 1). There was a significant main effect on trenching treatment during growing seasons, with no significant two-factor interaction observed during the study period. Total soil and heterotrophic respiration in both treatments showed a clear seasonal variation, in which the rates increased during spring and summer, and reached maximum values (Fig. 1) in July and September. During autumn (October and November), total soil and heterotrophic respiration declined again, reaching values close to those in spring (April and May). In addition, temporal variation in total soil and heterotrophic respiration rates had a similar seasonal pattern to soil temperature regardless of fertilizer application (Fig. 1).

Annual mean total soil respiration rates in this study were similar between the fertilizer treatments (0.504 g CO_2 m^{-2} h^{-1}) and control treatments (0.501 g CO_2 m^{-2} h^{-1}) (Fig. 2). Many studies have observed decreases in soil respiration rates due to reduced microbial biomass (Lee and Jose 2003) and fine root production (Haynes and Gower 1995, Olsson et al. 2005, Phillips and Fahey 2007) because soil environmental changes in response to fertilizer application are closely related to microbial activity and nutrient availability (Lee and Jose 2003, Kim 2008). However, the decrease in the soil CO_2 efflux following fertilizer application could be compensated for by the increased decomposition of organic matter with the change of carbon and nitrogen ratio in forest floor and mineral soil layers (Bolan et al. 1996, Kim et al. 2002, Kim 2008). In addition, heterotrophic respiration rates in the fertilizer (0.393 g CO_2 m^{-2} h^{-1}) represented 78% of total soil respiration rates, and 62% in the control (0.312 g CO_2 m^{-2} h^{-1}) treatments. Lower root respiration in fertilizer (0.111 g CO_2 m^{-2} h^{-1}) compared with the control (0.189 g CO_2 m^{-2} h^{-1}) treatments could be due to the decreased allocation of carbon to roots in response to increased nutrient availability (Haynes and Gower 1995, Phillips and Fahey 2007). Similarly, Samuelson et al. (2009) reported that fertilizer application increased heterotrophic respiration, microbial biomass, and carbon and microbial activities, with reduced fine root biomass. The proportion of heterotrophic respiration rates in the control treatments of this study was comparable to about 66% of total soil respiration in temperate coniferous forests in Korea (Lee et al. 2010).

An exponential regression has been widely used to describe the relationship between soil respiration and temperature following fertilizer application (Bowden et al. 2004, Kim 2008). In this study, the exponential relationships between total soil or heterotrophic respiration rates and the corresponding soil temperature at a depth of 8 cm (Fig. 3) were highly significant (total soil respiration: r^2, 0.937 to 0.947; $P < 0.01$; heterotrophic respiration: r^2, 0.914 to 0.928; $P < 0.01$) in the fertilizer and control treatments. Soil temperature explained the major portion of the variance in total soil and heterotrophic respiration rates in the fertilizer and control plots.

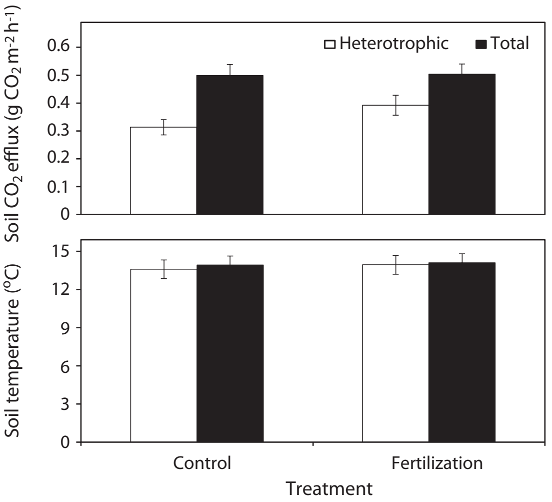

Fig. 2. Annual mean total soil (black) and heterotrophic (white) respiration rates with soil temperature between fertilizer and control treatments in red pine stands. Bars represent one standard error ($N = 12$).

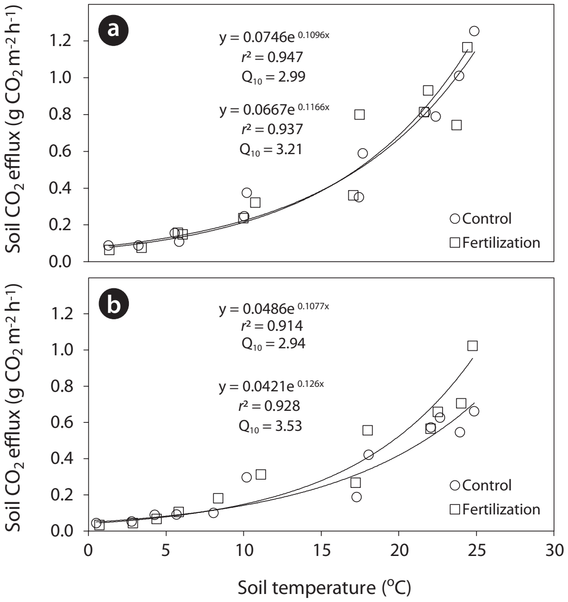

Fig. 3. Exponential regressions of total soil (a) and heterotrophic (b) respiration rates against the corresponding soil temperature between fertilizer and control treatments in red pine stands.

Sensitivity of soil respiration to soil temperature following trenching was commonly expressed by the coefficient Q_{10} (Bond-Lamberty et al. 2011). Q_{10} values in total soil respiration were 3.21 in the fertilizer and 2.99 in the control treatments. Q_{10} values in heterotrophic respiration were also higher in the fertilizer (3.53) than in the control (2.94) treatments. The high Q_{10} value in total soil and heterotrophic respiration might indicate higher sensitivity to soil temperature in systems with fertilizer application compared to control treatments. This result could be attributed to the change (e.g., carbon and nitrogen ratio) of carbon and nutrient availability for microbial decay following fertilizer application. For example, fine roots in larch plantations were more rapidly decomposed in fertilized than in unfertilized treatments (Kim 2008). Q_{10} values of total soil respiration rates in this study were comparable to those of other red pine forests in Korea, which are 3.45-3.77 at 12 cm soil depth (Noh et al. 2010).

CONCLUSION

Fertilizer application induced changes in heterotrophic respiration, while total soil respiration rates were little affected in red pine stands. Both total soil and heterotrophic respiration rates in fertilizer and control treatment showed high sensitivity by soil temperature. Further long-term studies are needed to examine the controlling factors, such as root and microbial activities, related to total soil and heterotrophic respiration following fertilizer application.

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