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Soil CO_2 Efflux and Leaf-Litter Decomposition of *Quercus variabilis* and *Pinus densiflora* Stands in the Southern Region of Korean Peninsular

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Abstract : It is necessary to determine the amount of carbon dioxide (CO_2) absorbed by plants and released from forest floor into atmosphere, to gain a better understanding how forests participate in the global carbon cycle. Soil CO_2 efflux, litter production, and decomposition were investigated in *Q. variabilis* and *P. densiflora* stands in the vicinity of Gwangju, Chonnam province. Soil CO_2 efflux was measured using Infrared Gas Analyzer (IRGA) at midday of the 10th day at every month over 12-month period, to quantify seasonal and annual budgets of soil CO_2 efflux. Soil temperature and soil moisture were measured at the same time. Seasonal soil CO_2 efflux in *Q. variabilis* and *P. densiflora* were the highest in summer season. In August, maximum soil CO_2 efflux in *Q. variabilis* and *P. densiflora* was 7.49, 4.61 CO_2 $\mu mol \cdot m^{-2} \cdot s^{-1}$, respectively. Annual CO_2 efflux in each stand was 1.77, 1.67 CO_2 $kg \cdot m^{-2}$ respectively. Soil CO_2 efflux increased exponentially with soil temperature and related strongly in *Q. variabilis* (r^2=0.96), and in *P. densiflora* (r^2=0.91). Litter production continued throughout the year, but showed a peak on November and December. Annual litter production in the *Q. variabilis* and *P. densiflora* stands were 613.7 g $dw \cdot m^{-2} \cdot yr^{-1}$ and 550.5 g $dw \cdot m^{-2} \cdot yr^{-1}$, respectively. After 1 year, % remaining mass of *Q. variabilis* and *P. densiflora* litter was 48.2, 57.1%, respectively. The soil CO_2 efflux rates in this study showed clear seasonal variations. In addition, the temporal variation in the CO_2 efflux rates was closely related to the soil temperature fluctuation rather than to variations in the soil moisture content. The range of fluctuation of soil CO_2 efflux and litter decomposition rate showed similar seasonal changes. The range of fluctuation of soil CO_2 efflux and litter decomposition rate was higher during summer and autumn than spring and winter.

Key words **:** *Litter decomposition, Litterfall,* P. densiflora, Q. variabilis, *Soil CO_2 efflux*

Introduction

Forests have been considered as potential C 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). However, the role and the importance of forests as C sources or sinks are likely to be quite variable with region, type of forest, age of trees and forest management activities (Lee and Jose 2003; Pypker and Fredeen 2003). In addition, Photosynthesis by plant and respiration processes changes in forest ecosystems is a key factor in understanding the C cycling, because both processes are an important process in the C flow in forest ecosystems (Bowden *et al.*, 1993; Raich, 1998; Kim, 2004).

Soil CO_2 efflux represents a major component of the soil C cycle (Raich and Schlesinger 1992) and is an indicator of C storage, soil biological activity and overall soil quality (Ewel *et al.,* 1987; Tufekcioglu *et al.*, 2001). In general, soil CO_2 efflux depends on the respiration of plant roots and soil microorganisms. Environmental factors such as soil temperature and soil moisture are major two factors influencing the seasonal dynamics of soil CO_2 efflux (Lloyd and Taylor 1994). Soil physical and chemical properties such as texture, organic matter content, root density, and microbial biomass may also affect the magnitude of soil CO_2 efflux (Haynes and Gower 1995; Kelting *et al.* 1998; Raich and Tufekcioglu 2000).

The influence of climate and substrate quality on fresh litter decomposition has been well documented (Aber *et al.*, 1990; Aert 1997; Berg *et al.*, 1993; Couteaux *et al.*,

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1995; Meentemeyer 1978; Melillo *et al.,* 1982; Taylor *et al.,* 1991). However, the findings to date are limited by the range of ecological sites and length of study. The latter limitation is particularly important as understanding the factors controlling later stages of decomposition are needed to determine the potential fate of the organic matter stores with climate change. In particular, the role of temperature on the decomposition rates of well-decayed organic matter has been the subject of some debate (Grace and Rayment 2000). In an analysis of literature, Giardina and Ryan (2000) concluded that decomposition rates of well-decayed soil organic matter are not strongly controlled by temperature and that increased temperature alone would not stimulate decomposition of forest-derived C in mineral soil.

The objectives of this study were 1) to measure differences in soil CO_2 efflux under two different stands (*Q. variabilis* and P. *densiflora*) and to examine the relationships among soil CO_2 efflux, soil temperature, soil moisture content, 2) to measure litterfall and decomposition rates in *Q. variabilis* and *P. densiflora* litter.

Materials and Methods

1. Study site

The study was conducted in Mountain Mudeung (35° 07' N, 126° 31' E) located in Gwangju, Korea. The annual precipitation in the area was 1,070.3 mm·yr^{-1} and the annual average temperature was 14.7°C during the study year at Gwangju meterological administration. Experimental plots were located in two adjacent *Q. variabilis* and *P. densiflora* stands. The study included a completely randomized design with three plots (10×10 m) for each species. Species found in *Q. variabilis* stand were *Prunus sargentii*, *Viburnum dilatatum*, *Cornus controcersa*, *Weigela subsessilis Fraxinus sieboldiana*, *Rhododendron mucronulatum* etc. Species found in *P. densiflora* stand were *Rhus sylvestris*, *Styrax japonica*, *Quercus serrata*, *Stephanandra incisa*, *Lindera erythrocarpa* etc. The soil texture of *Q. variabilis* stand was SiL with pH 4.40. The mean stand density of the stand was 750 trees·ha^{-1}. The mean tree diameter and height were approximately 18 cm and 21 m, respectively. The soil texture of *P. densiflora* stand was L with pH 4.74. The mean stand density of the stand was 900 trees ha^{-1}. The mean tree diameter and height were approximately 22 cm and 23 m, respectively.

2. Soil CO_2 efflux

Soil CO_2 efflux was measured by using an infrared gas analyzer (IRGA) (Licor 6400 portable photosynthesis system, Li-Cor Inc., Lincoln, NE) equipped with a soil chamber. At the time of measurement, the forest floor was removed to insert chamber and the chamber was inserted 2 cm into the soil. Intervals between samplings were long enough to get reliable estimates of CO_2 efflux with the equipment used. Measurements were performed between 10:00 a.m. and 14:00 p.m. for 12 months (from September 2006 to August 2007) in the study sites. During the measurement, soil temperature and moisture were measured with (T&D Thermo Recorder and Fieldscout TDR 100) at 15 cm depth adjacent to each chamber at the same time.

3. Litterfall

Litterfall was collected in littertraps using 1.5 mm nylon net. The collecting area was 1 m^2. Eighteen traps in three plots (10×10 m) in *Q. variabilis* and *P. densiflora* stands were installed on the ground. Litter was collected at approximately monthly intervals from September 2006 to August 2007. Litter collected from each trap was transported to the laboratory and oven-dried at 65°C for 48 hours. All dried samples were separated into leaf, branch, reproductive organ, bark, other, and each portion was weighed.

4. Litter decomposition

Mass loss rates in decomposing litter were estimated using the litterbag technique. Fresh litter from each plot was collected on the forest floor. After collection, the litter was air-dried at room temperature for 14 days. And approximately 10 g was placed in 18 cm×25 cm nylon net bags each with a 1.0mm size mesh. Sub-samples from the litter were also taken to determine oven-dried mass at 65°C for 48 hours. Litterbags within each plot were randomly placed on the forestry in September 2006. The litterbags were collected from each plot at 2 month intervals from Nov 2006 to Nov 2007. After collection, each litterbag sample was oven-dried at 65°C for 48 hours, weighed, and mass loss rates were determined.

5. Lignin and holocellulose

Air-dried litter of 40~60 mesh was extracted with benzene:alchol (2:1, v/v) for 8 hrs in a Sohxlet apparatus and again air-dried. Holocellulose was prepared by delignification of extractive-free litter with acidified sodium chlorite at 75°C for 4 hrs. Lignin content was determined as the insoluble residue after hydrolysis of the litter with 72% sulfuric acid by the Klason lignin method(Effland 1977).

Results

1. Soil CO_2 efflux

Soil CO_2 efflux rates showed a clear seasonal variations. The rates increased during spring and summer, and

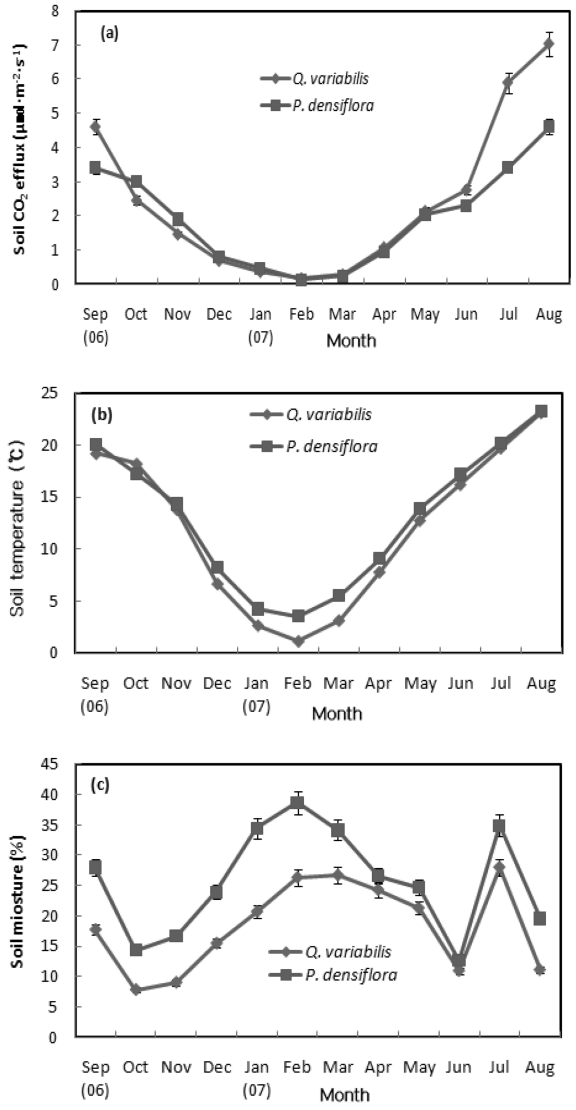

Figure 1. Monthly variation of soil CO_2 efflux(a), soil temperature(b) at 15cm depth, soil moisture content(c) at 15cm in the study stands.

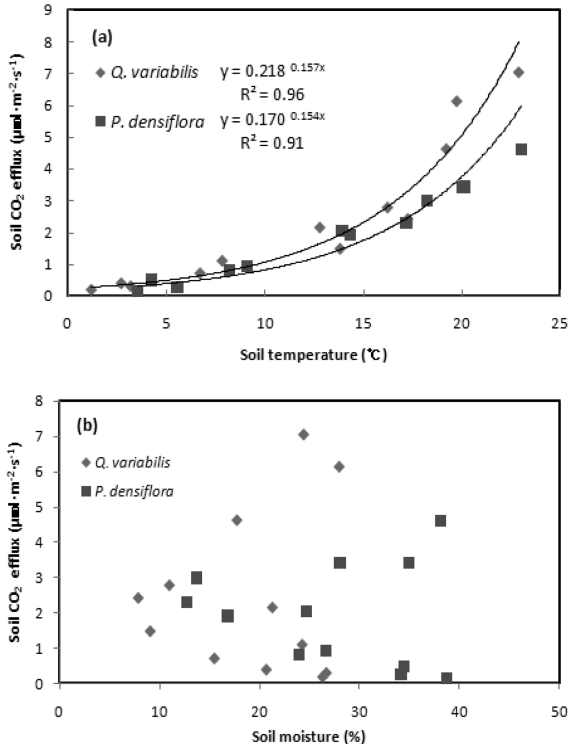

Figure 2. The relationships between soil CO_2 efflux rate and soil temperature(a), soil moisture(b) in study stands.

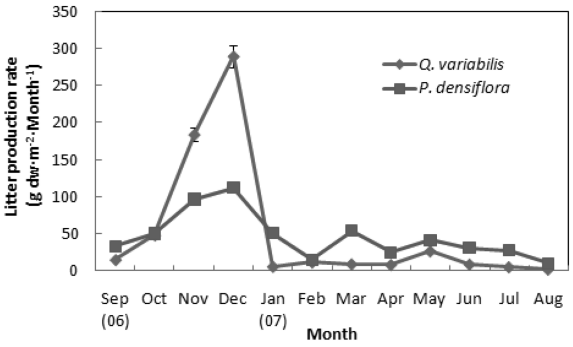

Figure 3. Monthly change of leaf litter inputs in the study stands.

reached maximum values in August (Figure 1). Soil CO_2 efflux rates began to decline during the fall, reaching values close to those in spring. A correlation coefficient between soil CO_2 efflux and soil temperature at 15cm depth (Figure 2) was highly significant. Soil temperature was related strongly to soil CO_2 efflux in *Q. variabilis* (r^2=0.96) *P. densiflora* (r^2=0.91). However, the regression between the soil CO_2 efflux rates and soil moisture content was not significant (Figure 3). Annual mean CO_2 efflux during the study period of one year in *Q. variabilis* and *P. densiflora*were were 0.46 g $CO_2 \cdot m^{-2} \cdot h^{-1}$, 0.37 g $CO_2 \cdot m^{-2} \cdot h^{-1}$ respectively.

2. Litterfall

The annual litterfall in *Q. variabilis* and *P. densiflora* stands was 613.7, 550.5 g $dw \cdot m^{-2} \cdot yr^{-1}$, respectively. Leaf litter was major component of total litterfall in the stands. leaf litter in *Q. variabilis* stand accounted for 66.5% of total annual litterfall, followed by other (21.2%) > branch (6.9%) > reproductive organ (4.9%) > bark (0.5%). leaf litter in *P. densiflora* stand accounted for 51.3% of total annual litterfall, followed by other (21.1%) > reproductive organ (13.6%) > bark (7.3%) > branch (6.7%). In seasonal variation, the heavy litterfall month in the stands was November and December (Figure 3). Litterfall production in *Q. variabilis* and *P. densiflora* stands during this period involved 77.1%, 38.0% of the annual litterfall.

3. Litter decomposition

Mass loss rates for one year from decomposing litter were faster in *Q. variabilis* than in *P. densiflora* ($P<0.05$)

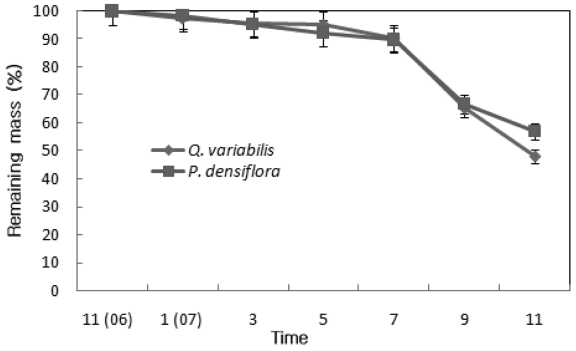

Figure 4. Remaining mass of leaf litter for one years in study stands.

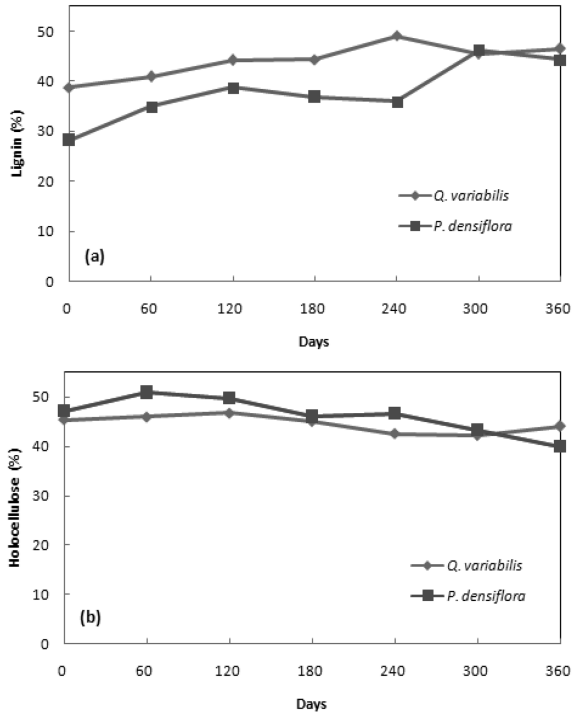

Figure 5. Lignin(a) and holocellulose(b) concentration changes of decomposing leaf litter.

(Figure 4). Decomposing litter declined steadily in weight during the experiment. The mass loss change was similar between the *Q. variabilis* and *P. densiflora* for one year. About 52% of the original mass in the *Q. variabilis* litter disappeared, while about 43% in *P. densiflora* disappeared. The rates of litter decomposition was not significantly different between the *Q. variabilis* and *P. densiflora* stands.

4. Lignin and holocellulose

The original concentrations of lignin in *Q. variabilis* and *P. densiflora* were 38.8%, 28.2% respectively. The lignin change in decomposing litter was similar between the *Q. variabilis* and *P. densiflora*. The origin concentrations of holocellulose in *Q. variabilis* and *P. densiflora* were 45.4%, 47.2% respectively.

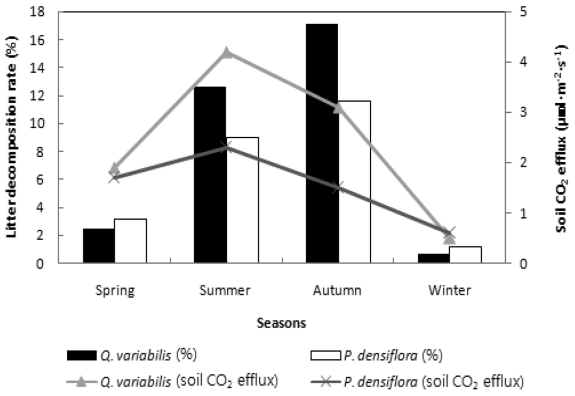

Figure 6. Change phases on the range of fluctuation of soil CO_2 efflux and litter decomposition rate of intra-season. Spring (Mar.~May), Summer (Jun.~Aug.), Autumn (Sep.~Nov.), Winter (Dec.~Feb.)

Discussion

The range of fluctuation, reducing minimum value from maximum value of the soil CO_2 efflux and the litter decomposition rate of intra-season, was graphed to elucidate relationship between them (Figure 6). The range of fluctuation of soil CO_2 efflux and litter decomposition rate showed similar seasonal changes. The range of fluctuation of soil CO_2 efflux and litter decomposition rate was higher during summer and autumn than spring and winter.

Soil CO_2 efflux rates showed a clear seasonal variations. In addition, temporal variation in the rates was closely related to soil temperature fluctuation rather than the variation of soil moisture content (Figure 1). Many studies reported that soil CO_2 efflux in temperate forests is typically higher in summer and lower in winter, corresponding to changes in ambient temperature because root and soil organism contribute to soil CO_2 efflux through respiration (Son and Kim 1996, Ohashi *et al.*, 1999, Wiseman and Seiler 2004), the effect of these factors varied according to the geographical location and season (Ohashi *et al.*, 1999). In addition, an exponential increase in soil CO_2 efflux with respect to soil temperature was observed in this study. Previous investigator report similar results that soil CO_2 efflux was correlated strongly with soil temperature (Son and Kim 1996, Ohashi *et al.*, 1999, Laporte *et al.*, 2003, Lee and Jose 2003).

Annual mean soil CO_2 efflux during the study period of one year in *Q. variabilis* and *P. densiflora* were 0.46 g $CO_2 \cdot m^{-2} \cdot h^{-1}$, 0.37 g $CO_2 \cdot m^{-2} \cdot h^{-1}$ respectively. These values were similar to other stands in Korea (Table 1). Total soil respiration rates in *Q. variabilis* and *P. densiflora in this study* were 4029 g $CO_2 \cdot m^{-2} \cdot yr^{-1}$, 3241 g $CO_2 \cdot m^{-2} \cdot yr^{-1}$ respectively. Son and Kim (1996) observed that the annual soil respiration in a 40-year-old larch

Table 1. Mean soil CO_2 efflux of *Quercus* spp. and *Pinus* spp. forest stands in Korean peninsular.

Stand	Stand age (yr)	Stand density (tree·ha^{-1})	Mean soil CO_2 efflux (g CO_2·m^{-2}·h^{-1})	Method	Reference
P. densiflora	45	850	0.43	KOH	Mun (2004)
P. rigida	40	667	0.38	soda-lime	Son and Kim (1996)
P. rigida	40	1,100	0.45	IRGA	Hwang (2004)
Q. mongolica	50	650	0.57	IRGA	Yi (2003)
Q. variabilis	44	1,050	0.52	IRGA	Yi (2003)
Q. variabilis	49	825	0.51	IRGA	Yi (2003)
Q. variabilis	36	525	0.80	KOH	Mun (2004)
P. densiflora	45	750	0.37	IRGA	This study (2007)
Q. variabilis	40	900	0.46	IRGA	This study (2007)

stand ranged from 2370 to 2680 g CO_2·m^{-2}·yr^{-1} in Yangpyoung in central Korea.

Annual litter production in the *Q. variabilis* and *P. densiflora* stands were 613.7 g dw·m^{-2}·yr^{-1} and 550.5 g dw·m^{-2}·yr^{-1}, respectively (Figure 3). Yi *et al.* (2005) reported that litter production of *Q. mongolica* natural forests ranged from 314.3to 554.9 g dw·m^{-2}·yr^{-1}(average 428.5 g dw·m^{-2}·yr^{-1}). Litter production of oak forests in Korea ranged from 248.0 to 876.1 g dw·m^{-2}·yr^{-1} (Mun and Joo1994, Son *et al.,* 2004). Litter production of oak forests in this fell within those ranges. Mun and Kim (1992) reported that litter production in *P. densiflora* forests was 453.5 g dw·m^{-2}·yr^{-1}, respectively, Kim (2006) also reported that litter production in *P. densiflora* forest was g dw·m^{-2}·yr^{-1}. Litter production of pine foerst in this study was much higher than that of above results. This difference might be related to tree density, age and canopy cover among them. Leaf litter was the major component of total litterfall in the stands.

Litter decomposition rates during 12 months were more rapid in *Q. variabilis* than *P. densiflora*. About 52% of the original mass in the *Q. variabilis* litter disappeared, while about 43% in disappeared (Figure 4). These differences in decomposition rates are probably due to in differences substrate quality. Weight loss in summer season was greater than that in winter season. This may be due to the greater activities of decomposer in summer season and water soluble fractions in litter leached out more in wet summer season (Jensen 1974, Millar 1974, Swift 1979).

Acknowledgment

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