Short Communication
pISSN: 2288-9744, eISSN:2288-9752
Journal of Forest and Environmental Science
Vol.34, No.3, pp.253-257, June, 2018
https://doi.org/10.7747/JFES.2018.34.3.253

JFES
Journal of Forest and
Environmental Science

Effects of Experimental Drought on Soil CO_2 Efflux in a *Larix Kaempferi* Stand

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Abstract

Climate models forecast more frequent and a longer period of drought events which may impact forest soil carbon dynamics, thereby altering the soil respiration (SR) rate. We examine the simulated drought effects on soil CO_2 effluxes from soil surface partitioning heterotrophic and autotrophic soil respiration sources. Three replicates of drought plots (6 x 6 m) were constructed with the same size of three control plots. We examined the relation between CO_2 and soil temperature and soil moisture, each being measured at a soil depth of 15 cm. We also compared which factor affected CO_2 efflux more under drought conditions. Total SR, autotrophic respiration (AR) and heterotrophic respiration (HR) were positively correlated with soil temperature ($p < 0.05$), and the relationships were stronger in roof plots than in control plots. Total SR, AR, and HR were negatively correlated only in roof plots, and the only HR showed a significant correlation ($p < 0.05$, $r = -0.59$). Soil respiration rates were more influenced by soil temperature than by soil moisture, and this relationship was more evident under drought conditions.

Key Words: climate change, experimental drought, soil CO_2 efflux, soil respiration, throughfall exclusion

Introduction

Cumulative emissions of greenhouse gas CO_2 are one of the main drivers of future climate events such as drought (IPCC 2014). This climate change evidently impacts the forest soil carbon dynamics (Cox et al. 2000; Davidson et al. 2006; Lal 2004; Schindlbacher et al. 2012), thereby altering soil respiration. Soil respiration is CO_2 emission from soils driven by roots and soil microorganisms (Raich and Schlesinger 1992). Heterotrophic and autotrophic soil respirations, which are major carbon fluxes from the terrestrial biosphere into the atmosphere, are affected by soil temperature and soil moisture (Broken et al. 2006; Pang et al. 2013; Yuste et al. 2007). Except gross photosynthesis, all other carbon exchanges between terrestrial and atmospheric biospheres are surpassed by soil respiration, and it was reported that almost 10 % of the atmospheric CO_2 passes through soils annually (Raich and Schlesinger 1992; Raich and Potter 1995). In addition, temperature and precipitation are major limiting factors which considerably alter future forest conditions (Borken et al. 1999; Borken et al. 2006). Thus, it is important to examine correlations among climate factors and soil respiration under drought conditions. The objective of this study was to examine the responses of soil CO_2 efflux under the simulated drought.

Received: January 31, 2018. Revised: June 11, 2018. Accepted: June 12, 2018.

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Materials and Methods

Site description

The experiment was conducted from July 15th 2016 to October 20th 2017. Measurements were carried out in *Larix kaempferi* stand located at the experiment forest area of Kangwon National University (37˚47'30"N, 127˚49'49"E) at an elevation of 569 m elevation, in Gangwon province, Korea. The stand is dominated by 53-year-old Japanese larch (*Larix kaempferi*), 8-year-old Korean pine (*Pinus koraiensis*), *Zanthoxylum schinifolium*, *Aralia elata*, *Lindera obtusiloba*, and *Cornus alba*. The ground vegetation, consisting mainly of *Dryopteris crassirhizoma* and *Rubus crataegifolius* covers about 80% of the soil surface during growing season. The soil is classified as B2 (Korea Forest Service) with loam, and its depth ranges between 30 and 60 cm. Recent 30-year climate records indicated mean annual precipitation of 1,450 mm $year^{-1}$ and mean annual temperature of 11.5 °C, with a mean August maximum of 30°C and a mean January minimum of -9°C.

Experimental design

Six 6 x 6 m plots were randomly distributed and half of the plots were subjected to experimental drought treatment with three translucent roofs constructed 1.5 m above the forest floor in July 2016, with other ones being control plots. Also, a ditch at a depth of 0.4 m was dug along the perimeter of each exclusion plot to avoid percolation of surface and subsurface drainage. All measurements were conducted in the core zone of each plot surrounded by a 1 m wide buffer zone to prevent edge effect.

Measurements of soil CO_2 efflux, soil temperature, and soil moisture

Soil moisture and soil temperature were measured hourly from data logging system (1000A, IStech, Korea; GL840, ALTHEN, Germany) installed at a soil depth of 10 cm and 30 cm in each plot. Data collection was temporarily ceased during the winter season from December to February in 2016 due to snowfall which made it difficult to exchange batteries for electric power supply.

Soil respiration was measured by partitioning (1) autotrophic respiration and (2) heterotrophic (microbial) respiration. Soil CO_2 efflux was measured in two randomly selected measurement points consisting of a soil pit (40 x 40 x 40 cm) in order to measure soil heterotrophic respiration and control for measuring total soil respiration, in the center area of each plot. Soil CO_2 effluxes from the soil surface were measured biweekly during daylight hours, totaling 14 sampling days during the growing season (April – October) in 2017 using a carbon dioxide probe (GMP 343, Vaisala CARBOCAP®, Finland) equipped into a PVC chamber (16 cm tall and 13 cm diameter). The chamber was planted 1.4 cm into the soil surface when soil respiration was measured. Linear regressions were performed to calculate the soil CO_2 efflux rates in 5s intervals for a duration of 5 minutes. Soil moisture and soil temperature were simultaneously measured at a soil depth of 15 cm adjacent to the chamber while soil respiration was measured using handheld digital thermometer (TP3001, KKmoon, China) and soil moisture meter (FieldScout TDR 300, Spectrum Technologies, Inc., USA) in order to examine the correlations among soil respirations, soil temperature, and soil moisture.

Data analysis

Soil respiration rates, soil temperature, and soil moisture were calculated as the averages of the three replicated control and roof plots. Kruskal Wallis H test and Non-parametric multiple comparison test were used to examine soil temperature and soil moisture through treatment. The mean differences of soil respirations between control and roof plots were analyzed by utilizing Student's t-test. In addition, Pearson correlation test and linear regression analyses were used to estimate the relationships between soil respiration, soil temperature and soil moisture. All statistical analyses were performed using R version 3.4.2, and in all cases, significance was accepted at p levels < 0.05.

Results and Discussion

Seasonal variation in soil moisture and soil temperature

The simulated drought caused a rapid and gradual decrease of soil moisture. Under the drought simulation, soil moistures by depths (10 cm and 30 cm) were significantly lower compared to controls ($p < 0.05$). The soil moisture at a soil depth of 10 cm drastically decreased, and the soil

Table 1. Correlation coefficients (r) between soil CO_2 efflux, soil moisture and soil temperature* and** indicate significance at p < 0.05 and $p < 0.01$, respectively

Treatment	Respiration sources	Soil moisture	Soil temperature
Control	Total	0.63*	0.77**
	Heterotrophic	0.38	0.81**
	Autotrophic	0.70**	0.50
Roof	Total	-0.27	0.91**
	Heterotrophic	-0.59*	0.86**
	Autotrophic	-0.26	0.80**

moisture dropped up to 2.6% in Nov 2016. In addition, the soil moisture at 10 cm soil depth in roof plots was significantly lower than any other soil depth and treatments ($p < 0.05$). These results indicate that experimental drought effect was successful especially at a shallower soil depth.

Impacts of simulated drought on the relationship between soil CO_2 efflux, soil temperature, and soil moisture

Soil CO_2 efflux increased including the maximum efflux in both control and treatment plots during the warm season. Total soil respiration was the highest on 14 July 2017 in both control and roof plots (1319.75±133.1 mg $\mathrm{Cm}^{2\text{-}1}\mathrm{hr}^{-1}$, 559.83±28.46 mg $\mathrm{Cm}^{2\text{-}1}\mathrm{hr}^{-1}$, respectively). Total, heterotrophic, and autotrophic respiration were significantly higher in control plots than in roof plots ($p < 0.05$). Total and heterotrophic soil respirations were more than two times higher in control plots compared to in the exclusion plots. Also, autotrophic respiration was 34% restrained under the simulated drought. These results indicate that soil respirations were suppressed by drought conditions, and especially severe drought stress was more influenced by heterotrophic soil respiration.

Correlations between soil respiration, soil moisture, and soil temperature were described in **Table 1.** Soil moisture showed positive correlation with soil respiration in control plots whereas it was negatively correlated in roof plots. Soil respiration showed relatively high correlations with soil temperature compared to with soil moisture, especially in roof plots. On the other hand, only heterotrophic soil respiration was significantly correlated with soil moisture in roof plots.

The linear relationships were found between soil moisture and soil respirations. The predicting equations of total soil respiration (Eq. [1], $R^2= 0.3968$), autotrophic soil respiration (Eq. [2], $R^2= 4853$), both of which belong to control plots, and heterotrophic soil respiration (Eq. [3], $R^2= 0.3441$) in roof plots from the linear regression analysis were,

$$CO_2(mgCm^{2\text{-}1}hr^{-1}) = -34.55 + 53.52M \ [1]$$
$$CO_2(mgCm^{2\text{-}1}hr^{-1}) = -113.657 + 27.11M \ [2]$$
$$CO_2(mgCm^{2\text{-}1}hr^{-1}) = 380.24 - 35.79M \ [3]$$

where M indicates the soil moisture. Also, the linear relationships between soil temperature and soil respiration were found. The predicting equations for total soil respiration (Eq. [4]), heterotrophic soil respiration (Eq. [5]) both

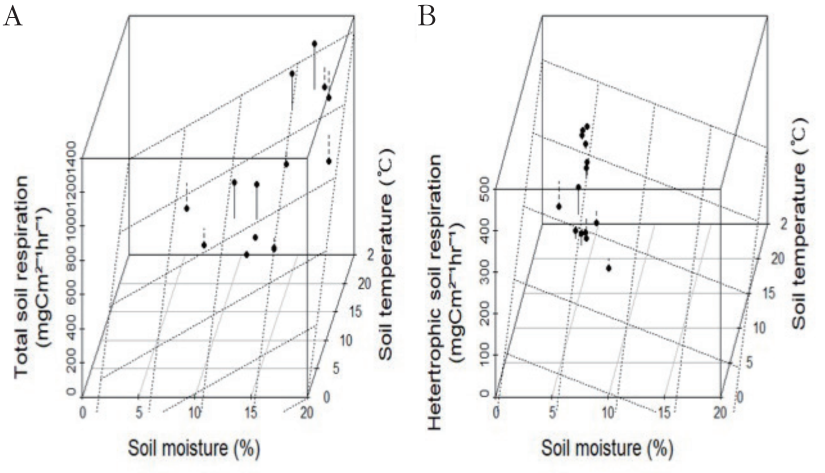

Fig. 1. Mean total soil respiration of the control plots (A) and mean heterotrophic soil respiration of the roof plots (B) as a function of soil temperature and soil moisture (n=3). Dotted plane correspond to the multiple linear regression model ($R^2= 0.7696$, $p < 0.01$ for control plots; and $R^2= 0.7694$, $p < 0.01$ for roof plots.

of which belong to control plots, and total soil respiration (Eq. [6]), heterotrophic soil respiration (Eq. [7]), and autotrophic soil respiration (Eq. [8]) in roof plots were,

$CO_2(mgCm^{2\text{-}1}hr^{-1}) = -428.41 + 63.34T$ [4]
$CO_2(mgCm^{2\text{-}1}hr^{-1}) = -358.95 + 50.47T$ [5]
$CO_2(mgCm^{2\text{-}1}hr^{-1}) = -387.22 + 41.06T$ [6]
$CO_2(mgCm^{2\text{-}1}hr^{-1}) = -162.892 + 20.83T$ [7]
$CO_2(mgCm^{2\text{-}1}hr^{-1}) = -295.27 + 28.25T$ [8]

where T indicates the soil temperature. In addition, prediction of soil respirations was improved by combining soil temperature and soil moisture factors in both control and roof plots. The model for total soil respiration in control plots explained about 77% of the variance (R^2= 0.7696) in

total soil respiration (Eq. [9], Fig. 1a),
$CO_2(mgCm^{2\text{-}1}hr^{-1}) = -755.19 + 37.45M + 52.61T$ [9]

where M and T indicate soil moisture and soil temperature, respectively. In roof plots, the multiple regression model for heterotrophic soil respiration in exclusion plots explained about 77% of the variance (R^2= 0.7694) in heterotrophic soil respiration (Eq. [10], Fig. 1b),

$CO_2(mgCm^{2\text{-}1}hr^{-1}) = -71.32 - 10.53M + 18.6T$

where M and T indicate soil moisture and soil temperature, respectively.

These results implied that it is apparent that the simulated drought considerably altered soil respiration sources, especially related to heterotrophic soil respiration. In addition, soil respirations were highly altered under the drought so that the correlations were negative only in roof plots. Also, these results indicated that soil temperature was a more influential driving factor which affects soil respiration than does soil moisture.

Acknowledgement

This work was supported by the National Research Foundation of Korea (NRF) grant funded by the Korea government (MSIP) (No. 2015R1C1A1A01052341). Also, this study was supported by 2015 Research Grant from Kangwon National University.

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