学位論文内容の要旨

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学位論文題名

Variations in soil fluxes of methane and carbon dioxide in an immature deciduous forest

未成熟な落葉樹林におけるメタンと二酸化炭素の土壌フラックスの変動特性

Soil carbon flux is the primary pathway of carbon cycles between the atmosphere and terrestrial ecosystems, determining the changing rate of soil carbon stock. In terrestrial ecosystems, almost half of the total organic carbon is stored in forest soils, indicating the importance of forest soils in regulating the global climate system. A better understanding of relationship between soil carbon dynamics and environmental factors has become an urgent need especially in the context of global warming.

In this study, an automated chamber system was applied to measure soil methane (CH_4) and carbon dioxide (CO_2) fluxes in a regenerating deciduous forest during the growing seasons in 2021 and 2022. Ten chambers were evenly divided into two treatments: Root (with roots and without aboveground plants) chambers for soil respiration (RS) and Trench (without roots and aboveground plants) chambers for heterotrophic respiration (RH). Based on explanatory environmental variables, flux prediction models were developed using machine learning algorithms to investigate the spatiotemporal variations and controlling factors of soil carbon dynamics. In addition, RS was separated into RH and root respiration (RR) by an empirical equation (RR = RS – RH), in which RH was calculated by a conventional method as the mean RH of Trench chambers and by a Random Forest (RF) approach. Furthermore, relationship between RR and gross primary production (GPP), which was measured by the eddy covariance method, was analyzed using the wavelet cross power analysis, and time lag between GPP and RR was determined.

1. Soil carbon dynamics and controlling factors

The forest soil functioned as a net CH_4 sink and CO_2 source in two years. Mean daily soil CH_4 and CO_2 fluxes are -2.35 ± 0.47 nmol m^{-2} s^{-1} and 2.14 ± 1.49 μmol m^{-2} s^{-1} ($\pm$ 1 standard deviation), respectively, in Trench chambers and -2.56 ± 0.61 nmol m^{-2} s^{-1} and

2.67±1.69 μmol m^{-2} s^{-1}, respectively, in Root chambers. Both CH_4 sink and CO_2 source intensities were significantly higher ($P < 0.001$) in Root chambers probably because of the existence of fine roots and better soil aeration. RF models showed a high performance in predicting CH_4 and CO_2 fluxes. Soil moisture had the highest relative importance in CH_4 models, whereas soil temperature was the most important factor in CO_2 models, indicating soil carbon dynamics were regulated by soil temperature and moisture in our study site.

2. Separation of soil respiration

Mean daily RR separated by a conventional method (RR_C) was 0.53 ± 0.39 μmol m^{-2} s^{-1}, which was significantly smaller ($P < 0.05$) than RR separated by the RF method (RR_RF) (0.61 ± 0.50 μmol m^{-2} s^{-1}). Significant spatial variation of RR emerged among different chambers from both methods. The exponential relationship with soil temperature was more significant for RR_RF than RR_C. In addition, RR_RF was correlated to fine root dynamics more significantly than RR_C was. Thus, the RF approach would be a more reliable method to estimate RR.

3. Time lag between gross primary production and root respiration

Photosynthate translocated from leaves is the main substrate of RR. Thus, RR links to GPP with some delay. Following the diurnal variation of GPP, RR_RF showed a more reasonable variation than RR_C did. Results of the wavelet cross power analysis showed a significant ($P < 0.05$) common one-day period between GPP and RR, indicating RR changed synchronously with GPP. Mean lag between GPP and RR_RF was 5.07 ± 4.97 hours.