

Determination of appropriate measurement timing of soil CO₂ emission in dry dipterocarp forest, western Thailand

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Abstract:

Emission of CO₂ from soil surface varies in time and space, depending on various environmental factors. This study aims to determine the appropriate timing that reflects the daily average value of soil CO₂ emission in dry dipterocarp forest. Soil CO₂ emission was measured by sensors that allow high time resolution (every 15 seconds) of gas sampling and concentration determination. It was found that mean of daily soil CO₂ efflux rates were $1.63 \pm 0.02 \mu\text{mol m}^{-2} \text{s}^{-1}$. Measurement timing between 11.30 and 13.30 (Thailand Time) is recommended as best time to reflect this daily mean value. The measurements in this period had 0.75% deviation from the mean value ($n=480$). With this high resolution data, it was also revealed that precipitation events differently affect the amount of measured soil CO₂ fluxes between closed chamber and sensor methods. During rain events, lower CO₂ emission was detected by sensor method when compared to that of the closed chamber method.

Keywords: Soil CO₂ Efflux; Soil Respiration; Soil CO₂ Sensor; CO₂ Gradient Method; Diurnal Variation.

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1. Introduction

Soil respiration or surface soil CO₂ efflux is a key ecosystem process which plays the important roles in regulating atmospheric CO₂ concentrations and climate dynamics. Forestry is the largest source of carbon sequestration in the world. This carbon is mainly accumulated in trees and soil. It is reported that the amount of carbon in the trees and the soil are 3.5 times more than in the atmosphere. In forests, the carbon in the form of CO₂ is exchanged between the atmosphere and the soil. Quantifying the amount of this CO₂ exchange is important to understand the response of forest to climate change and to estimate sink/source capacity of forest. The exchange process is controlled by photosynthesis and respiration, and their interactions with the environmental factors so varies in time and space. Emission of CO₂ from soil surface can be done by using various techniques. A limitation of a traditional method such as chamber method is its inability to measure continuously and frequently (Tang et al., 2003). Because of fast-response of soil CO₂ efflux to environmental changes, lacks of the continuous and frequent data in diurnal scales could be the causes of errors associated with CO₂ emission quantification. The diurnal data can be a source of more errors of estimating annual soil CO₂ emission when is not accounted for appropriately (Savage et al., 2014; Yiqi and Xuhui, 2006). Therefore, in this study we measured soil CO₂ by the newly established method as a sensor method using CO₂ profile gradient. Buried CO₂ probes within the soil can measure continuously and frequently (every 15 seconds) in dry dipterocarp forest. The objectives were to estimate soil CO₂ efflux rates by newly established method and to determine appropriate measurement timing of soil CO₂ emission in dry dipterocarp forest. The appropriate measurement timing in diurnal variation can guide for other methods of the soil CO₂ measurement in order to reduce the errors and fine quality data.

2. Material and methods

2.1 Site description

The study site was located in dry dipterocarp forest at Ratchaburi (DFR), King Mongkut's University of Technology Thonburi (KMUTT), Ratchaburi Campus, western Thailand (Latitude: 13° 35' 13.3" N, Longitude: 99° 30' 3.9" E). The DFR site was situated at 118 m elevation. The

vegetation type was dry dipterocarp forest and the dominant species were *Dipterocarpus intricata*, *D. obtusifolius*, *D. tuberculatus*, *Shorea obtuse* and *S. siamensis*. The canopy was about 5-7 m height and diameter at breast height of stem was about 8 cm (measurement in 2009) Total area is around 240 ha (1,500 rai). Soil texture was loamy sand (Sanwangsri et al., 2011).

2.2 Soil CO₂ measurement by sensor method

Soil CO₂ concentrations were continuously measured by the soil CO₂ sensors (GMP343, Vaisala Inc., Finland), which were horizontally buried along soil profiles at depths of 5 cm and 20 cm. The sensors scanned for concentration determination for every a second and recorded every 15 seconds. These sensors were connected with a transmitter, a datalogger and a computer for data records. In this study, three replications were made. The measurements were commenced on the 1st to the 120th day of the year in 2011.

2.3 Assessing the soil CO₂ efflux rates

The steps of the calculations were suggested by the manufacturer (Tang et al., 2003). The soil CO₂ effluxes (F , $\mu\text{mol m}^{-2} \text{s}^{-1}$) were determined by Fick's first law of diffusion which was a main equation as follow Eq. (1).

$$F = -D_s \frac{\partial C}{\partial z} \quad (1)$$

where F is soil CO₂ efflux ($\mu\text{mol m}^{-2} \text{s}^{-1}$), D_s is CO₂ diffusion coefficient ($\text{m}^2 \text{s}^{-1}$), dC/dz is the vertical soil CO₂ gradient, C is CO₂ concentration ($\mu\text{mol m}^{-3}$) and z is depth (m).

2.4 Data analysis

T-test (a significance level of 0.05) and Mean Absolute Percentage Error (MAPE) were applied to compare the results and determine the appropriate measurement timing of the soil CO₂ emissions.

3. Results and discussion

3.1 Soil CO₂ Concentration and their efflux rates

CO₂ emissions were compared against those from the closed chamber method. There was no statically difference between both methods (Bulsathaporn et al., 2012). In the DFR site, soil CO₂ concentrations were measured continuously and frequently and recorded data every 15 seconds for 120 days ($n = 627,327$). The daily average CO₂ concentration at the depths of 5cm was $1,286.65 \pm 834.27 \mu\text{mol mol}^{-1}$ and at the depths of 20 cm was $2,091.70 \pm 1,148.60 \mu\text{mol mol}^{-1}$. Mean soil CO₂ efflux rate across study period was equal to $1.63 \pm 0.02 \mu\text{mol m}^{-2} \text{s}^{-1}$. For diurnal time scale (fluctuations that occur during each day as 24 hours), CO₂ flux peak as $1.57 \mu\text{mol m}^{-2} \text{s}^{-1}$ was observed at 8:30 and $1.70 \mu\text{mol m}^{-2} \text{s}^{-1}$ at 16:30 (local time) as minimum (Min) and maximum rates (Max), respectively (Fig. 1).

3.2 The appropriate measurement timing of daily soil CO₂ emission

Diurnal patterns of soil CO₂ efflux in the DFR site were coincident across study period and coincident with patterns of soil temperature (Bulsathaporn et al., 2012). Larionova et al. (1989) and Davidson et al. (1998) recommended that the midmorning effluxes closely approximate the daily mean of soil CO₂ effluxes. Xu and Qi (2001) recommended the appropriate time between 9:00-11:00 which found a sampling error of 0.9 to 1.5%. In our study, we found that it was at 12:30 as shown in Fig. 1. We recommend that the measurements should be carried out between 11.30 and 13.30 with a sampling error of 0.75% ($n=480$). This better represents the daily mean soil CO₂ emission than other times. We found that measurement time during 9:00-11:00 as recommended in other studies could cause an error of 2.02% in this forest. Our high time-resolution also enabled us to see the interactions between precipitation events and CO₂ emission. Four precipitation events on

days 75, 82, 96 and 109 (Fig. 2) resulted in increased emissions when measured by closed chamber method but decreased emission when measured by the sensor technique. Generally, precipitation event, soil CO₂ would be replaced by water as soil degassing and resulted in CO₂ pulses as observed by chamber method. This reason results in decreased emission when calculated based on the CO₂ gradient profile as the case for sensor technique. However, soil CO₂ emission calculated based on sensor technique is increased as water could percolate down the profile and replace CO₂ in the lower soil layers while that of the chamber decreased. Eventually if there is no rainfall event, CO₂ along the soil profile returns to equilibrium again and the emissions from chamber and sensor technique become comparable. Such phenomenon could not be seen and explained unless high-resolution measurements are implemented.

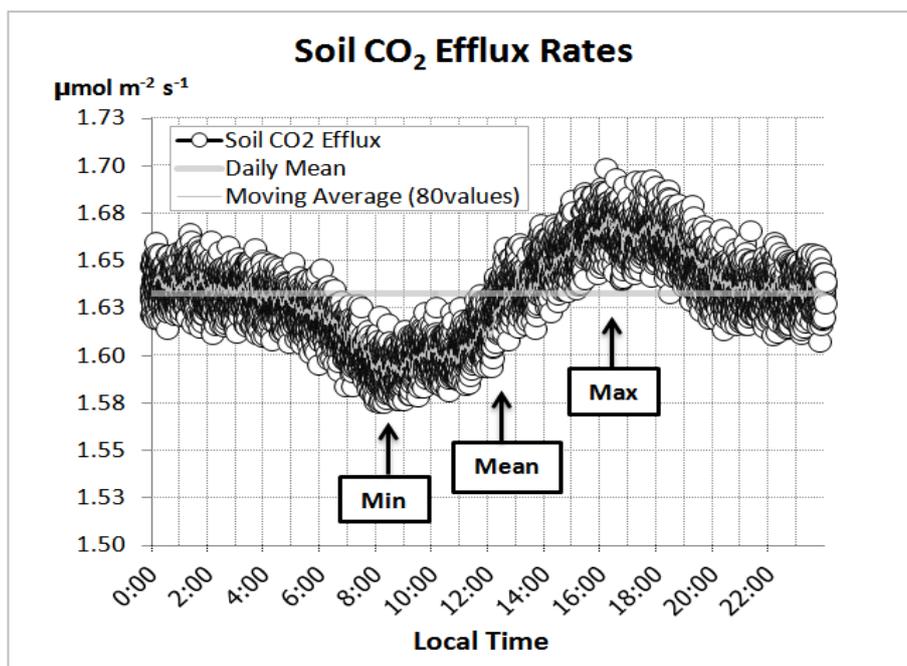


Fig. 1 Diurnal variation of soil CO₂ efflux rates measured by the sensor method for 120 days in 2011 (n = 5,760).

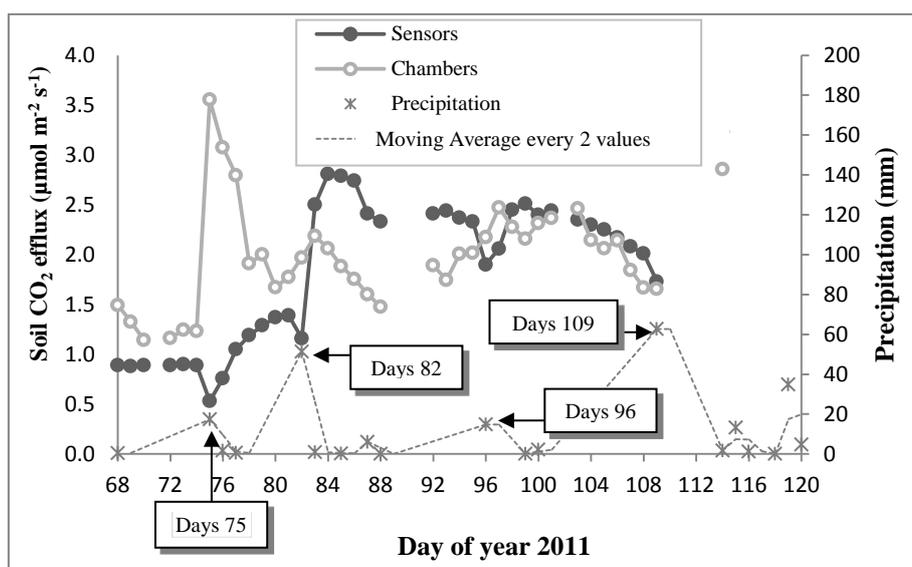


Fig. 2 Daily average of soil respiration rates and precipitation between days 68 to days 120.

4. Conclusion

Using high time-resolution measurements of soil CO₂ emissions by sensor technique we found that an appropriate time of daily soil CO₂ measurements in dry dipterocarp forest is between 11.30 and 13.30. We also found that sensor technique has the advantage that the effects of rapid change in controlling factors such as precipitation on soil emission could be also investigated.

5. Acknowledgment

This research was financially supported by Center of Excellent for The Joint Graduate School of Energy and Environment (JGSEE), Center of Excellence on Energy Technology and Environment (PERDO) and the *National Research University Project* (NRU) of Thailand's Office of the Higher Education Commission.

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