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Soil organic matter derived CO_2; comparison of partition methods from an Acric Umbrisol in a subtropical forest

Louis-Pierre Comeau[*1], *Derrick Y. F. Lai*[1], *Jane Jinglan Cui*[1]

[*]comeau_louis@hotmail.com
[1]Department of Geography and Resource Management, Chinese University of Hong Kong, Shatin, Hong Kong.

Abstract

Without accurate data on soil heterotrophic respiration (Rh), assessments of soil carbon (C) sequestration rate (or C balance) are challenging to produce. Accordingly, it is essential to determine the contribution of the different sources of the total soil CO_2 flux (Rs), but to date no single, fully satisfactory partitioning procedure exists. We partitioned soil carbon dioxide (CO_2) flux into Rs and Rh component in a subtropical secondary forest in Hong Kong. We combined automated chamber measurements of Rs with five different partitioning methods: (1) regression between root mass and root derived CO_2; (2) root exclusion bags with intact soil blocks; (3) root exclusion bags with hand-sorted roots; (4) lab incubations with minimally disturbed soil microcosm cores; and (5) $\delta^{13}C$ natural abundance (experiment in progress). Excised roots and litter decomposition rates were also assessed with decomposition bags to further segregate microbial respiration of dead plant material from soil organic matter (SOM) derived CO_2. Preliminary results showed large variance of Rh fluxes and Rh/Rs ratio between the different methods analyzed. The lowest Rh/Rs ratio was produced by the lab incubations (22.5% Rh) and the largest by the intact root exclusion bags (61.3% Rh). Both root exclusion bags techniques produced very similar Rh flux and these fluxes were slightly larger than the one produced by the root regression method but notably larger than the lab incubation with soil cores.

Keywords: soil organic matter derived CO_2 fluxes; partitioning methods for heterotrophic respiration assessment.

Introduction

Last year during the COP21 (United Nations Climate Change Conference), a goal of increasing the global soil organic carbon (SOC) stocks by 0.4 percent per year, to mitigate global anthropogenic greenhouse gas emissions, was set (Budiman et al., 2017). This ambitious aim was made with the notion that the SOC in the top soil layer is sensitive and responsive to management changes and this might offers opportunities to slowdown the current increase rate in atmospheric CO_2 concentration (Kuzyakov, 2006).

It is known that carbon (C) enters into ecosystems via photosynthesis then a fraction of this C is directly respired by the roots and above ground plant parts (autotrophic respiration) to produce energy (i.e. adenosine-5'-triphosphate) and the other fraction is synthesized into organic molecules. Some of these C-containing compounds are harvested and the remainder is added to the soil as plant residues (Janzen et al., 1998). Subsequently, a portion of these fresh organic compounds is respired by organisms (heterotrophic respiration) and another portion is converted into SOC by the processes of soil organic matter (SOM) genesis (Janzen, 2006; Lal, 2005). In sum, when the amount of new organic residues added to the soil is greater than the C lost by SOC decomposition, SOC content increases (Ellert and Bettany, 1995). However, SOM structure and genesis are not yet fully understood and there are still many uncertainties about the rates of SOC accumulation and decomposition in many ecosystems (Schmidt et al. 2011). These uncertainties are due in large part to the fact that total CO_2 flux (Rs) from soil do not provide the necessary information to

assess whether the soil is a net source or net sink for atmospheric CO_2 (Kuzyakov 2005). Specifically, the autotrophic (Ra) part of the Rs does not cause net C losses to the atmosphere because this C is simply cycling around inside the ecosystem. Conversely, microbial respiration (i.e. heterotrophic; Rh) represent net C losses. For the reason that, the boundary between Ra and Rh is nor sharp (i.e. the rhizo-microbial respiration is linked to both) realistic Rh assessments are difficult to produce (Braig and Tupek, 2010). In turn, it is then problematic to assess soil C sequestration (or C balance) rate without accurate Rh data. As a result, many years (up to decades) are currently needed to assess SOC stock changes in order to evaluate which management practices are beneficial for SOC sequestration (Harmon et al., 2011; Wood et al., 2012).

The goal of our study was to compare five different partitioning methods to separate CO_2 flux into its Rs and Rh component in a subtropical secondary forest in Hong Kong. In addition, excised roots decomposition and litter-fall/decomposition rate were determined to further segregate microbial respiration of dead plant material from SOM derived CO_2.

Methodology

This study was made in a subtropical secondary forest of Hong Kong (Tai Po Kau Nature Reserve; 22° 27´N, 114° 11´E, 250 m.a.s.l.). The mean annual temperature was 23.3°C and annual precipitation 2400 mm with a hot-humid season (April–September) and a cool-dry season (October–March) (Hong Kong Observatory). The soil was classified as Acric Umbrisol (Nechic).

The regression between root mass and root derived CO_2 was made following Farmer (2013) with 22 sampling spots. The experiment was made in October 2016. Each spot was a square of 20 x 20 cm randomly distributed in a one ha area. In each spot, Rs was determined per triplicate using a portable IRGA EGM-4 (Environmental Gas Monitor, PP Systems, UK) attached to a soil respiration chamber (SRC-1, PP Systems, UK). Concurrently with CO_2 flux measurements, air and soil (10 cm depth) temperatures and soil moisture were measured at each sampling spot. Immediately after the Rs measurement, the 20x20 cm square were excavated 25 cm depth. All the visible roots (diameter larger than 0.1 cm) from the excavated soil were collected. In the lab, the roots were washed and then oven dried at 60°C until a steady dry weight was attained, which was then recorded. Linear random effects modelling was performed using the R statistical package (R Development Core Team 2008).

To measure Rh in root exclusion bags with hand-sorted/removed roots Fenn et al. (2010) method was followed with seven root exclusion pits (20 × 20 cm, depth: 25 cm) using mesh bags. Briefly for each root exclusion hole, soil was excavated in 10 cm layers and visible roots were removed from each layer. Then a micromesh bag was placed inside each hole. Subsequently, soil was repacked in respective 10 cm layers (5cm for the 20-25 cm depth) and each repacked. For the Rh with root exclusion bags with intact soils blocks, seven soil block (20 × 20 cm, depth: 25 cm) were removed from the soil. Then they were put into the above mentioned micromesh bags and inserted back into their original pit. Each intact root exclusion block was paired (i.e. 150 cm distance) with a hand-sorted root exclusion bags.

For the lab incubations, undisturbed soil cores of volume 98 cm^3 (inner diameter 5 cm, height 5 cm) were collected using a stainless steel core soil sampler from the upper part of the soil profile (0–5 cm). Four groups of four soil cores were collected then pooled per group and brought to the lab. Subsequently all visible roots were removed but with special care to not destroy the small aggregates. The soil was then repacked to original bulk density in minimally disturbed soil microcosm cores of 45 cm^3 (inner diameter 3.5 cm, height 5 cm). The soil cores were separated in four groups of different volumetric moisture content (i.e. 15, 25, 35 and 45 %; equivalent to % of maximum water holding capacity of 30, 48, 66 and 84). These moisture levels corresponded to the natural annual fluctuation in the field (i.e. from dry to moist season). After moisturizing the samples, each individual soil core was placed into a hermetically sealed 2.9 dm^3 plastic container. The experiment lasted four weeks and had four different incubation temperature levels

(one per week; 14°C, 20°C, 26°C and 32°C) corresponding to the minimum, intermediate maximum soil temperature values in the field based on preliminary studies (Cui, 2017). At the beginning of each week, the soil cores were pre-incubated in their incubation box to their corresponding weekly temperature (i.e week #1 14°C … week #4 32°C) for 3 days and then opened and vented for one minute. From all the boxes gas samples were collected (20 ml) with an air-tight syringe (t= 0, 24, 72 hour) after box closure. The CO_2 concentrations were analyzed within 48 hours with a gas chromatograph (GC system7890A, Agilent Technologies). The GC system was equipped with a flame ionization detector and an electron capture detector to quantify and CO_2. Between each measurement session, the boxes opened to vent and the moisture of the soil cores was readjusted if needed.

The $\delta^{13}C$ of Rs/Rh respiration will be determined following Lin et al. (1999) and Millard et al. (2010). The isotopic partitioning experiment will assess values of the $\delta^{13}C$ of the Rs, Ra and Rh. The sampling will take place in February 2017. Briefly, in ten closed chambers (10 cm diameter, 10 cm high) will be randomly positioned in the study area at least 24 hours prior to sampling. The $\delta^{13}C$ of the Rs will exclude any atmospheric CO_2. Then the root will be incubated in CO_2 free air in a Tedlar bag. For the $\delta^{13}C$ Rh respiration, root free, soil samples will be collected from up to 25 cm below the chambers, placed in CO_2 free air in Tedlar bags. The $\delta^{13}C$ ratios, all expressed relative to VPDB, will be calculated with respect to CO_2 reference gases injected with every sample and traceable to International Atomic Energy Agency reference material NBS 19 TS-Limestone.

Litterfall was collected each month from 7 traps randomly distributed in the one ha study area. Root and litter decomposition rate were assessed with mesh bags following Steward and Davies (1989).

Results

Regression of the CO_2 fluxes against root density of the 22 quadrants yielded a statistically significant slope correlation of 0.08 g CO_2 m^{-2} s^{-1} (P=0.03), and set the intercept at 25 g CO_2 m^{-2} s^{-1} (P=0.02) which was assumed to be the basal flux in absence of root representing the Rh (Fig. 1 and Table 1).

Regarding the other methods to assess Rh, our preliminary results are showing large variance of fluxes and Rh/Rs ratio between the different techniques analyzed. Specifically, our preliminary data have revealed that both root exclusion bags techniques produced very similar Rh flux values and these fluxes were slightly larger than the one produced by the root regression method but notably larger than the lab incubation with soil cores (Table 2).

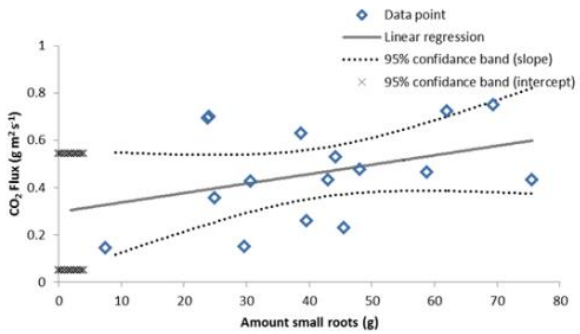

Fig. 1. Linear regression between root quantity and CO_2 flux

Table 1. Linear regression report between root quantity[a] and CO_2 flux[b]

Parameter	Value (mg cm^3)	SE[c]	t value	P value
Intercept[b]	0.25	0.10	2.50	0.02
Slope[b]	0.08	0.04	2.31	0.03

Overall r^2 of the linear regression: 0.21.

[a] root quantity in unit of milligram, small (radius between 0.1-0.5 cm) dried roots (60°C) per cm^3 of soil.

[b] CO_2 flux in unit of gram per m^2 per second.

[c] SE, standard error.

Table 2. Preliminary results of the comparison of heterotrophic respiration assessment methods

Method	Rh flux[a] (g CO_2 m^3 h^{-1})	SE[b]	Rh to total soil CO_2 flux (%)
Soil cores incubation	0.11	0.01	22.5
Root regression	0.25	0.10	51.1
Hand-sorted root exclusion bags	0.29	0.04	59.2
Intact root exclusion bags $\delta^{13}C$-CO_2	0.30	0.06	61.3

[a] Rh, heterotrophic respiration.

[b] SE, standard error.

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