B-1.7.1 Study on carbon flow caused by microbial community in the soils of temperate zone.

Contact Person Mikiya Hiroki
senior researcher
Environmental Microbiology Section, Environmental Biology Division,
National Institute for Environmental Studies
Environmental Agency
Onogawa 16 - 2, Tsukuba, Ibaraki, 305 Japan
Tel: +81-298-50-2513, Fax: +81-298-51-4732
E-mail: hiroki-m@nies.go.jp

Abstract   To reveal biological and chemical properties of soils which affect the CO_2 evolution from soil, a measuring system for determination of the CO_2 evolution from soil was developed, and CO_2 fluxes from soil surface, litter decomposition, biological and chemical properties of the soils were measured in a deciduous broad-leaved forest in Japan.

The CO_2 evolution measuring system examined by flow-through chamber method had the advantage that CO_2 efflux was able to be determined easily in a short time at any field site without an electric power supply or other special equipment. *In situ*, there was a negative correlation between the CO_2 fluxes and the water content of soil in summer season. 31% of litter in litter bags was decomposed from June to November. The decomposition rate of the litter decreased in processing of degradation. In laboratory experiment, CO_2 evolution rates from incubated litter were ranged from 51 - 83 mgC kg^{-1}h^{-1}. CO_2 evolution rates from incubated soils collected from 0-5 cm depth layer were ranged 1.2-2.0 mgC kg^{-1}h^{-1}, while those of the deeper layer were lower than 0.2 mgC kg^{-1}h^{-1}. These results suggest that the CO_2 evolution is carried out at litter and surface layers down to 10 cm depth. CO_2 evolution rates from incubated soils were significantly correlated to the microbial biomass in the soils, which correlated more significantly to nitrogen contents than to the carbon contents in the soils.

Key Words   Biomass, CO_2, Organic matter, Microorganisms, Soil respiration

1. Introduction

Since a rise in atmospheric carbon dioxide (CO_2) concentration is expected to lead to global warming, it is important to quantify global carbon circulation. Most of organic carbon photosynthesized from atmospheric CO_2 to the plant body is finally decomposed to CO_2 by soil microorganisms.   Since number and activity of the microorganisms are affected by physical and chemical properties of soil, the decomposition rate of soil organic matters vary by site and site. Generally, the decomposition rate of soil organic matter has been determined by CO_2 evolution rate from soil, and a flow-through chamber method seems to be suitable for measuring the CO_2 evolution rate, because the rate is determined under nearly natural conditions. However, this method has a disadvantage, because the apparatus is composed of an infra-red CO_2 analyzer, air pumps, mass flow meters, a recorder, and other items, which are too large, heavy and complex to use in the field.   Hence, the flow-through chamber method has been used only at sites where electric power supply and other equipment were available.

The objective of the present research were 1) to establish a flow-through chamber method using a portable CO_2 analyzer system , for determination of CO_2 evolution from soil without an electric power supply or other special equipment, 2) to reveal biological and chemical properties of soils which affect the CO_2 evolution from soil surface in a deciduous broad-leaved forest.

2. Determination of CO_2 evolution from soil using a portable photosynthesis meter[1]
2.1 Method

When a fixed flow rate of air is pumped through a cylindrical open chamber placed on the soil surface, the change of CO_2 concentration in the chamber is described by Eq. 1:

$$C - Co = k_1 + k_2 \exp(k_3 t') \qquad (1)$$
$$(k_1 = aV/F_1 \; ; \; k_2 = Ci - Co - aV/F_1 \; ; \; k_3 = -F_1/ah)$$

where a is area of the soil surface covered with the chamber (cm^2), V is CO_2 efflux from soil (μgC cm^{-2} min^{-1}), C and Co are CO_2 concentrations in the chamber and in the ambient air pumped through the chamber (μgC cm^{-3}), F_1 is flow rate of air pumped through the chamber (cm^3 min^{-1}), h is height of the chamber (cm), t is time (min), and Ci is CO_2 concentration in the chamber (μgC cm^{-3}) at $t = 0$.

In the present method, a portable system for photosynthesis measurement (Shimadzu SPBH-3) consisting of an infra-red absorption CO_2 analyzer, mass-flow meters, pumps, and a datalogger was used with a cylindrical chamber of polyvinyl chloride (inner diameter, 10.7 cm; height, 5 cm) through which two polyvinyl tubes were inserted. The chamber was placed on the soil surface without insertion into the soil, because disturbance of the soil may affect the diffusion coefficient of the soil. Ambient air collected from an air sampler of 2.7 m height was stored in a reservoir, and pumped to the chamber at rate F_1 (0.2-0.4 L min^{-1}). The ambient and inner airs of the chamber were pumped alternately to the infra-red CO2 analyzer at rate F_2 (0.1 L min^{-1}) for measurement of CO_2 concentration (Co and C μmol mol^{-1}) every 30 seconds during minutes 1 to 5 after the chamber had been placed on the soil surface. The measured CO_2 concentrations were approximated to Eq. 1 by the least squared method, and the CO_2 efflux was calculated from the k_1 value ($V = k_1F_1/a$). In order to obtain the approximation, Kaleida-Graph (Abelbeck Software) was used on a personal computer.

2.2 Experiment 1

Variance among the effluxes determined in the present method was examined at a red-pine (*Pinus densiflora* Sieb. et Zucc.) forest floor in Tsukuba City, Japan. The chamber was placed on soil surface without a litter layer, and CO_2 effluxes were determined as described. The flow rate of air through the chamber was fixed to 0.2 L min^{-1}. The measurement was made in duplicate at 5 sites, all more than 2 m from each other.

CO2 efflux calculated from the k_1 value showed a mean value of 256 mgC m^{-2}h^{-1} with a S.D. of 35 mgC m^{-2}h^{-1}. The difference in effluxes between the duplicate measurements at the same site ranged from 0.3 to 26 mgC m^{-2}h^{-1}, which was less than the variance among the sites.

2.3 Experiment 2

The effect of the flow rate on the determined CO_2 efflux was examined at a site in the red-pine forest on 2 June and 8 July 1994. The flow rate were fixed to 0.2 and 0.4 L min^{-1} on each day. The air temperatures were 24.1-24.2 (2 June) and 28.7-29.1 °C (8 July), and the temperatures of the soil were 19.7 (2 June) and 24.2 °C (8 July).

CO_2 efflux on 8 July (291.7 and 257.5 mgC m^{-2}h^{-1} at the flow rates of 0.2 and 0.4 L min-1) was about 3 times higher than that on 2 June (87.1 and 79.7 mg C m^{-2}h^{-1}, at the same flow rates), because of the higher temperature on 8 July. On both days, the measurements at a flow rate of 200 ml min-1 were about 9-13% larger than those at a flow rate of 400 ml min^{-1}.

The chamber was placed on the soil surface without insertion; however, a slight mass flow from the chamber into the soil might cause a decrease in CO_2 efflux with increasing flow rate pumped into the chamber. If the mass flow rate increased proportionally with the difference between the flow rate pumped into and from the chamber, the CO_2 efflux without mass flow would be 4% (2 June) or 6% (8 July) higher than that at the flow rate of 200 ml min^{-1}. In conclusion, although the flow rate pumped into the chamber had a slight effect on the measurement, the present flow-through chamber method has the advantage that CO_2 efflux is able to be determined easily in a short time at any field site.

3. CO2 evolution from a deciduous broad-leaved forest soil and microbial community in the soil

3.1 Study site and method

To reveal biological and chemical properties of soils which affect on the CO_2 evolution, CO_2 fluxes from soil surface were measured in a deciduous broad-leaved forest in Fukushima

Prefecture, Japan. Four study sites (S1 - S4) were located at west side of Mt. Denjo (1000 m), at 770-840 m above sea level. 5 study sites (M1 - M5) were located near Miyatoko mire which was less than 400 m away from the S1 - S4.

At S1 - S4, CO_2 fluxes from soil surface were determined, and soil samples were collected from three different depth layers at each site (0 - 5 or 8 cm, 5 - 12 or 20 cm, 12 - 34 or 45 cm) on 18 August 1994. The samples were incubated at 22 °C to measure CO_2 evolution rates, carbon and nitrogen contents and microbial biomass[2]. At S1 and S2, the carbon contents of the soils were more than 15% of dry weight in the first layers and less than 10% in the second and the third layers, while in the third layer at S3 and in the second layer at S4, those were more than 15%. In the third layer at S3 and S4, nitrogen content was not high, where the C/N ratios were more than 25, while those of the other sites and layers ranged between 19.2 - 23.0.

At M1 - M5, CO_2 fluxes from soil surface, litter fall and decomposition rate of litter bag were measured in June, September, October, and November 1995. Water content of the soils were high in June and November (1.25 and 1.37; mean values of the 5 sites), and low in September (0.98). The water content of the soil at M2 was higher than those at the other four sites at every sampling time. The litter fall at M1 - M5 were 485 g/m2/yr. 50% of the litter was *Quercus serrata* Thunb. and 27% of those was *Quercus crispula* Blume. Litter and soil samples were collected and incubated at 22 °C to measure CO_2 evolution rates, carbon and nitrogen contents and microbial biomass.

3.2 Result and discussion

CO_2 fluxes from soil surface *in situ* varied extremely among sites and seasons. At S1 - 4, the CO_2 fluxes from soil surface were ranged 70 - 240 mgC m^{-2}h^{-1}. At M1 - M5, the CO_2 fluxes were ranged from 33 to 220 mgC m^{-2}h^{-1}, and those at the M2 site were higher than those at the other four sites. There was a negative correlation between the CO_2 fluxes and the water content of soil in June and September (Fig. 1).
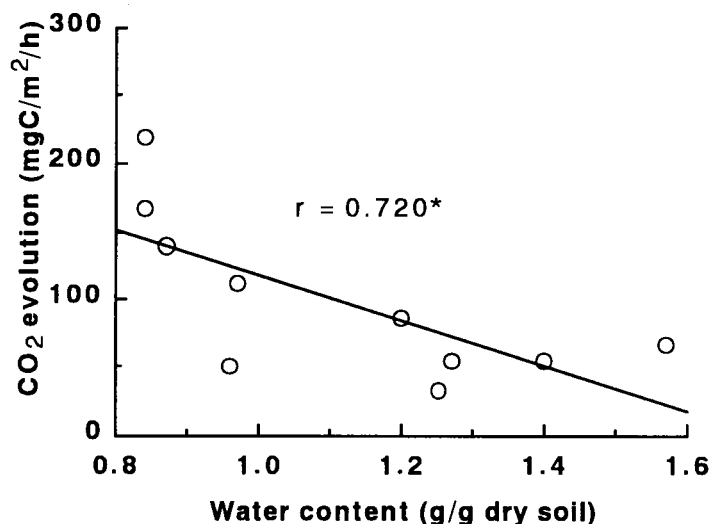

Fig. 1 Relationship between water content of soils and CO2 evolution rate in June and September.

There were not significant differences between June and September in air temperatures (19.3 °C and 16.2 °C), however, soil respiration rate was higher in September than in June, since water content of soil was higher and air permeability was lower in June than in September.

Bacterial numbers in the soils positively responded to the seasonal fluctuation of water content of the soils, while there was a negative correlation between bacterial number and the

water content of the soil among sites (Fig. 2). There was not any significant correlation between the microbial biomass and CO_2 fluxes from soil surface.
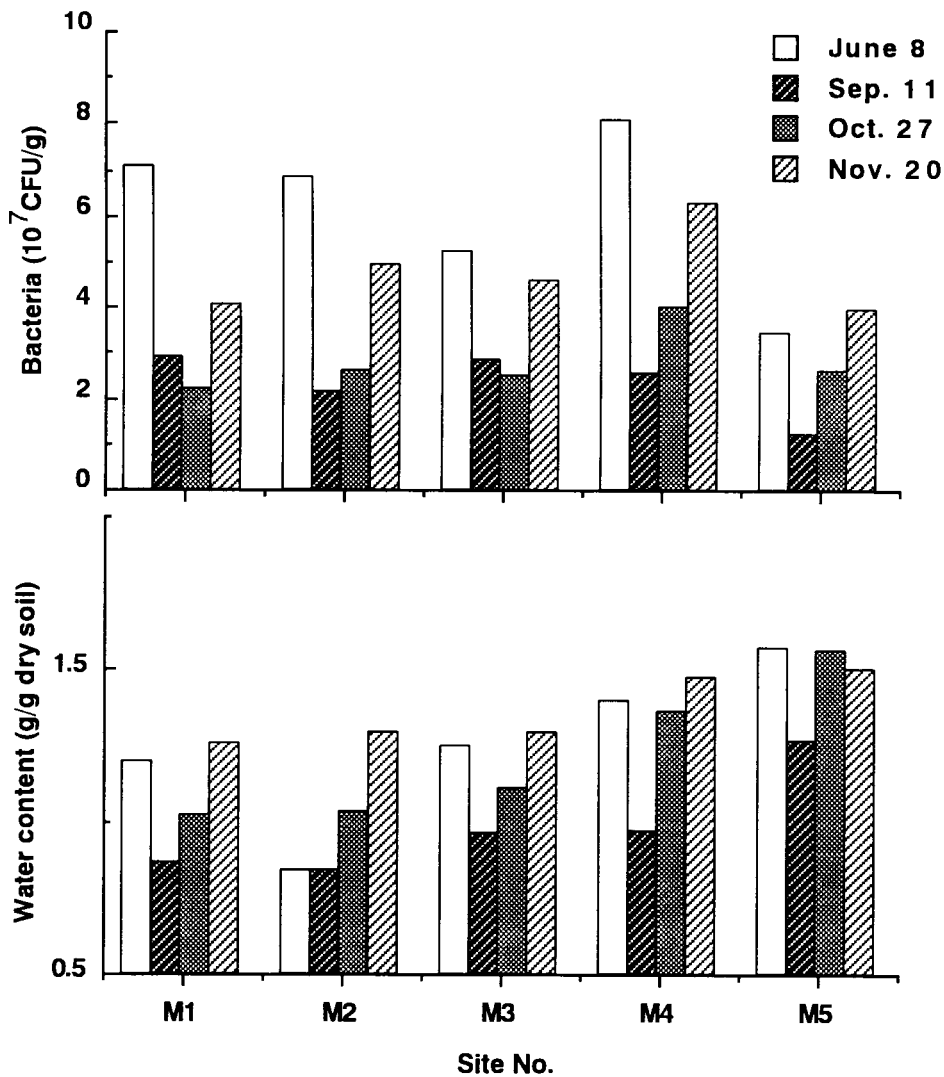

Fig. 2 Bacterial number and water content at M1 - M5.

In laboratory experiment, CO_2 evolution rates from incubated soils collected from 0-5 cm depth layer at S1-3 were ranged 1.2-2.0 mgC $kg^{-1}h^{-1}$, while those of the deeper layer were lower than 0.2 mgC $kg^{-1}h^{-1}$. Although the CO_2 evolution rate from the incubated soil of 5-20 cm depth layer at S4 was 2.1 mgC $kg^{-1}h^{-1}$, this value seemed to be higher than that in the field condition (160 to 360 $mgCm^{-2}h^{-1}$). CO_2 evolution rates from incubated litter and soils of M1 - M5 were ranged from 51 - 83 mgC $kg^{-1}h^{-1}$ (litter) and 3.1 - 4.4 mgC $kg^{-1}h^{-1}$ (soil). These results suggest that the CO_2 evolution is carried out at litter and surface layers down to 10 cm depth.

At S1 - S4, CO_2 evolution rates from incubated soils were significantly correlated to the microbial biomass in the soils, which correlated more significantly to nitrogen contents than to the carbon contents in the soils (Fig. 3, 4). At M1 - M5, 31% of litter in litter bags was decomposed in situ from June to November. The decomposition of the litter was approximated by Eq. 2.

$$D = 37.4 \times (1 - \exp(-0.0115t)) \tag{2}$$

where D is decrease of litter weight (%), t is time (days).

The decomposition rate decreased in processing of degradation. In laboratory experiment, the respiration rate of microbial biomass was higher in litter (6.8 mgC $gC^{-1}h^{-1}$) than in soil (1.1 mgC $gC^{-1}h^{-1}$). These result suggest that the microbial community changed and the activity decrease in processing of degradation.
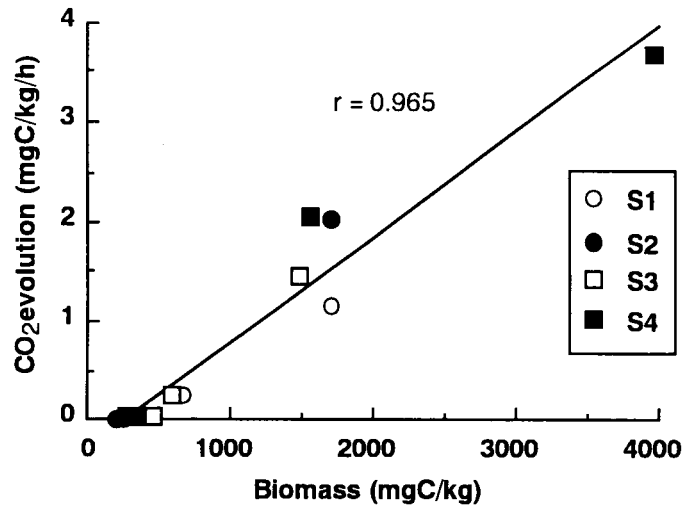

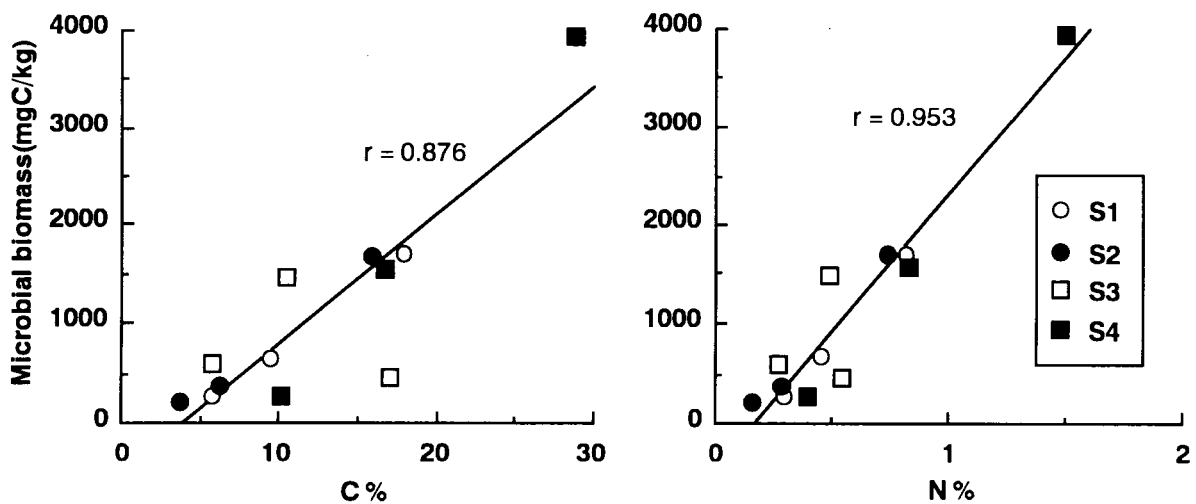Fig. 3 Relationship between microbial biomass in soil and CO_2 evolution

Fig. 4 Relationship between carbon and nitrogen content and microbial biomass in soil.

Reference
1) Hiroki, M. and Watanabe, M.M., Field measurement of carbon dioxide evolution from soil in flow-through chamber method using a portable photosynthesis meter., Soil Sci. Plant Nutr., (in press).
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