Phyton (Austria) Special issue: "APGC 2004"	**Vol. 45**	Fasc. 4	(109)-(115)	1.10.2005

Measurement of Wood CO_2 Efflux Using a Multichannel Automated Chamber System

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K e y w o r d s : Automated chamber, carbon budget, larch, stem respiration, temperature.

S u m m a r y

LIANG N., FUJINUMA Y. & INOUE G. 2005. Measurement of wood CO_2 efflux using a multichannel automated chamber system. - Phyton (Horn, Austria) 45 (4): (109)-(115).

CO_2 efflux from the aboveground woody tissue, the most biomass of forest ecosystem, was continuous measured in a 50-year-old Japanese larch (*Larix kaempferi* Sarg.) plantation by utilizing a multichannel automated chamber system. We developed a fast-response system with 16 chambers that connected in parallel to a single CO_2 analyzer equipped with a 16-channel gas sampler to sequentially measure CO_2 efflux from wood tissue. The cylinder design chamber can completely envelop a segment of stem or branch. Between measurements the chamber is opened to allow the ambient air passing through the chamber and prevent temperature increase and condensation inside the chamber. During the measurement, the chamber is closed and the increase in CO_2 concentration inside the chamber is measured. The sampling period for each chamber is set to 225 s, and running a measurement cycle through 16 chambers takes just 1 h.

During the mid-summer between August 28 and September 15 in 2002, mean CO_2 efflux at stem height of 2.9 m was about 0.7 μmol m^{-2} s^{-1}. CO_2 efflux increased with stem height, and the highest rate of 1.3 μmol m^{-2} s^{-1} was shown at the branch level. Wood CO_2 efflux had daily as well as seasonal pattern, and it showed significant exponential correlation with wood temperature. The Q_{10} quotient of wood CO_2 efflux was 4.1, 2.8 and 2.4 at stem height of 2.9, 9.1 and 12 m (branch). Annual CO_2 efflux of total aboveground wood tissue was estimated to be about 775 to 795 kg-C ha^{-1}. Wood CO_2 efflux contributed 5% of ecosystem respiration during the non-growing season. For the whole year, however, 7% of ecosystem respiration could be contributed by the aboveground wood CO_2 efflux.

I n t r o d u c t i o n

Forests worldwide contain about 45% of the global stock of carbon, thus playing an important role in the global carbon balance. However, the relationship

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between gross primary production (GPP) and net primary production (NPP) for forest ecosystems is not fully understood. One of the uncertainties relevant to this issue is the magnitude of CO_2 efflux from woody tissue because it is relatively under-studied (MEIR & GRACE 2002).

Aboveground woody tissue contains most biomass of forest ecosystem, on average of 80%, and it varies no significantly among stands (reviewed by CAIRNS & al. 1997). However, contribution of wood CO_2 efflux to GPP changes significantly among tree species (MEIR & GRACE 2002), stands (RYAN & al. 1997), and with temperature (RYAN 1990). Early measurements of wood CO_2 efflux were made on excised sections of woody tissue (YODA 1967), which could have yielded inflated efflux through the effects of wound respiration (MEIR & GRACE 2002). More recently studies (e.g. RYAN 1990, BOLSTAD & al. 2004) have emphasized the utility of in situ chamber measurements and scale wood CO_2 efflux to stand level with both sapwood volume (RYAN 1990) and surface area (LEVY & JARVIS 1998). However, most of the chamber measurements were sampled at lower stem height (e.g. generally lower than 2 m) which might underestimate wood CO_2 efflux, due to efflux from upper stem bole is often greater than lower stem because of higher growth rates at the upper positions relative to lower positions (M. G. RYAN, person. commun.). In addition, previous chamber measurements were conducted periodically or continuously for only a short term (e.g. up to a week), which might induce biases during up scaling, because wood CO_2 efflux change seasonally and with tree phenology.

Our objectives were (1) quantify the relative amounts of CO_2 efflux from aboveground woody tissue of a forest ecosystem, (2) evaluate the effect of temperature on wood CO_2 efflux, and (3) estimate the contribution of wood CO_2 efflux to total ecosystem respiration.

Material and Methods

Study site

The experiment was carried from August 28 (day 240) and throughout the end of 2002 at the Tomakomai Flux Research Site (lat 42°44'N, long 141°31'E), Hokkaido, Japan. The forest is a 50-year-old Japanese larch (*Larix kaempferi* Sarg.) monoculture plantation with canopy height of about 15 m. In 2001, the stand density of trees with trunk diameter at breast height (DBH, 1.3 m high) larger than 5 cm was 1087 trunks ha^{-1}, with DBH ranging from 6 to 48 cm (18 cm average). The total basal area was 23.2 m^2 ha^{-1}, and the trunk volume and branch volume was 151 and 24.5 m^3 ha^{-1}, respectively.

The site is characterized by a humid continental climate with cold winters and cool summers but without apparent wet or dry seasons. Mean annual precipitation is approximately 1250 mm; and mean annual temperature is 7.3 °C, with the mean monthly temperature ranging from 19.1 °C in August to –3.2 °C in January. The soil is homogeneous, well-drained, arenaceous, and developed from volcaniclastic sediment. Further information of the study site has been described in details by LIANG & al. 2004.

Chamber system description

We developed multichannel automated chamber systems for continuous measurements of ecophysiological processes contributing to net ecosystem production (NEP), including soil CO_2

efflux, heterotrophic respiration, understorey photosynthesis (LIANG & al. 2003, 2004, 2005c), canopy photosynthesis/respiration (LIANG 2002, LIANG & al. 2005a,b), and aboveground wood CO_2 efflux. The wood CO_2 efflux measurement system has a flow-through, non-steady-state design, comprising 16 automated chambers and a control unit. The control unit is designed as similar as used in soil CO_2 efflux system (LIANG & al. 2003, 2004, 2005c). In brief, the aluminium control unit (70 × 50 × 35 cm, L × W × H) includes a 16-channel gas sampler, an infrared gas analyzer (IRGA; LI-820, LI-COR, Lincoln, NE, USA), a datalogger (CR10X, Campbell Scientific, Logan, UT, USA) and a compressor system.

The cylinder design chamber is made of 0.1 mm thick transparent polyester film, and completely envelops a segment of the tree stem or branch by pasting to two permanently neoprene flexible–rings which are sealed against the stem with fast curing silicone caulk (LIANG 2002). Between the measurements, two small window, one in each end-side of the chamber, are opened by two micro actuators, and the chamber air is exchanged with the ambient air by a micro fan to prevent temperature, humidity and CO_2 concentration increases inside the chamber. During the measurement, the two windows are closed and the chamber air is mixed by another micro fan. The chamber air is circulated through the IRGA by a micro pump, and the increase in CO_2 concentration is measured.

Field application

In the middle of August 2002, we selected five individuals for continuous measurement of wood CO_2 efflux. 15 chambers were set at stem heights of 2.9 m (5 chambers), 9.1 m (5 chambers) where just beneath the crown, and 12 m of branches at upper-middle of the tree crown (5 chambers). Another one chamber was used as a control chamber by seting the chamber to the stem that covered with polyester film. Therefore, the effluxed CO_2 from the stem could not diffuse into the chamber and the measurement system could be calibrated by injecting the standard gases into this control chamber. A thermocouple was inserted at 1-2 cm depth into the wood inside each chamber for monitoring stem temperature. We set the sampling period for each chamber to 225 s, and running a measurement cycle through 16 chambers took just 1 h.

Data analysis

We made a simple upscaling as following procedures based on the high-frequency data. (1) 5 chambers at the same stem height were averaged on both surface area basis and wood volume basis; (2) Mean annual CO_2 efflux was calculated for each of the three chamber locations (heights) on wood volume basis; (3) Mean annual CO_2 efflux for each of the chamber locations was multiplied by the amount of wood volume represented by that component. For instance, CO_2 efflux at 2.9 m height would represent wood CO_2 efflux from 0 to 6 m height, CO_2 efflux at 9.1 m height would represent wood CO_2 efflux from 6 m to the top of trunks, and CO_2 efflux at 12 m height would represent CO_2 efflux for the branch biomass. (4) Annual total wood CO_2 efflux was estimated by summing the tree components in (3).

Results and Discussion

Daily and seasonal changes in wood CO_2 efflux

Hourly averaged wood CO_2 efflux showed significant diurnal pattern, reaching lowest efflux rate in the early morning (just before sunrise) and highest efflux rate in the early afternoon (data not shown). The diurnal change of CO_2 efflux associated with daily temperature pattern. CO_2 efflux also showed significant seasonal pattern, with highest value in the mid-summer and gradually decreased from late sumer to the lowest value in the non-growing (winter) season at all three measurement heights (Fig. 1).

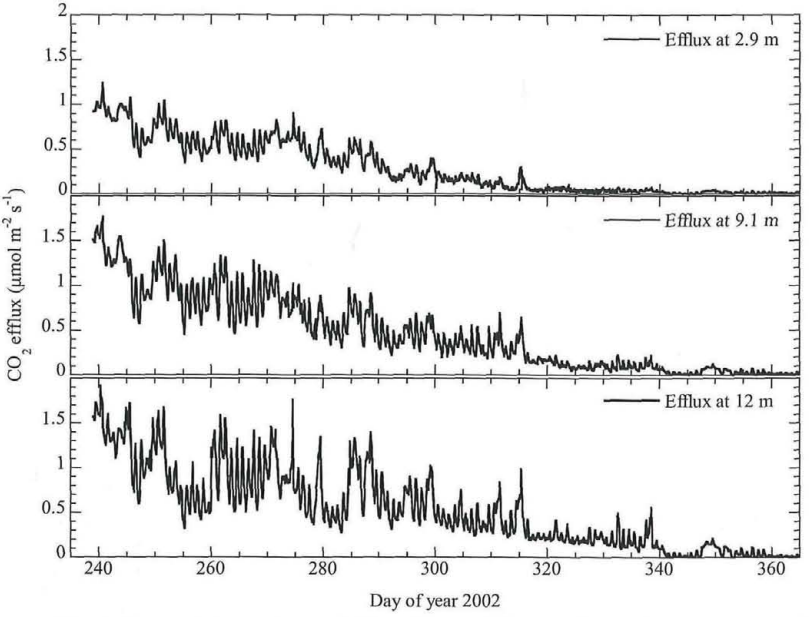

Fig. 1. Seasonal change in wood CO_2 efflux at different heights of stem on unit surface area basis.

Wood CO_2 efflux versus stem height

During the hottest mid-summer between August 28 (day 240) and September 15 (day 258), mean CO_2 efflux at stem height of 2.9 m was about 0.7 μmol m^{-2} s^{-1}, similar to those reported for other temperate deciduous species (RYAN & al. 1997, BOLSTAD & al. 2004). However, efflux rate increased significantly ($p < 0.001$) at stem height of 9.1 m that was 1.1 μmol m^{-2} s^{-1}. Efflux rate for branches at 12 m high showed the highest value of 1.3 μmol m^{-2} s^{-1} (Fig.1). This vertical pattern is more significant when efflux rate was presented on wood volume basis (data not shown). Generally, wood CO_2 efflux can be partitioned into maintenance and growth (construction) components. Previous measurements were usually carried out at lower stem positions (lower than 2 m), where growth costs for wood biomass were calculated to be 20 to 50% of total wood efflux (RYAN & al. 1997, MEIR & GRACE 2002). Therefore, higher efflux rate at upper stem position and branch level is probably because of higher growth rate for the upper stem and branch (M. G RYAN, person. comm.).

Temperature response of wood CO_2 efflux

We found strong wood temperature dependence of CO_2 efflux at all of the three measurement heights ($r^2 > 0.75$; Fig. 2). Throughout the whole measurement period, the efflux Q_{10} quotient was average to 4.1 for wood efflux at 2.9 m high.

However, Q_{10} decreased to 2.8 and 2.4 at stem height of 9.1 and 12 m, respectively. The relative higher Q_{10}s in the current study are unusual compared with previous studies, where reported that wood Q_{10}s approach around 2.0 (e.g. RYAN & al. 1997, MEIR & GRACE 2002), but Q_{10}s between 4.5 and 7.6 have been recorded for Douglas-fir (PRUYN & al. 2002).

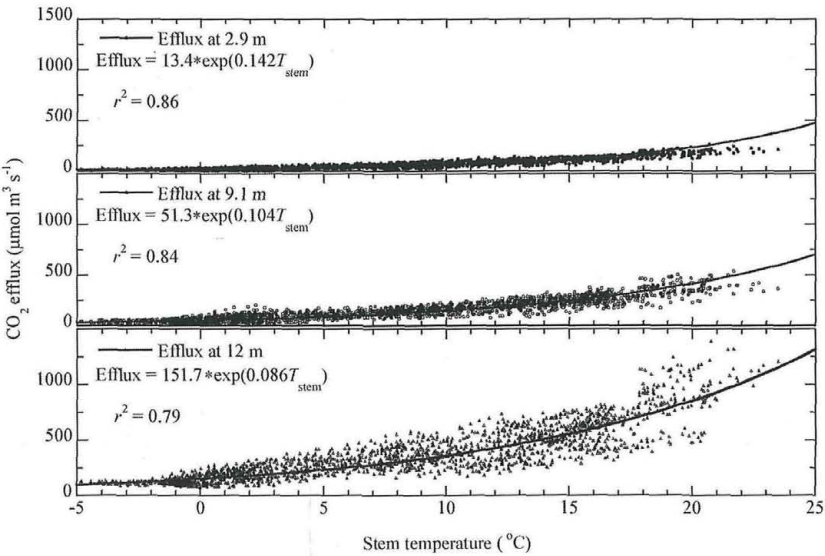

Fig. 2. Temperature response function of wood CO_2 efflux.

Wood CO_2 efflux versus phenology

For short term from a day up to a week, we found strong correlation between wood CO_2 efflux and air temperature within the forest canopy (Fig. 3). Though stem temperature could good evaluate wood CO_2 efflux (Fig. 2) and most of previous studies used Q_{10} and periodical measurements to estimate stand level annual wood CO_2 efflux, wood CO_2 efflux did not match temperature in some season. In this study, efflux rate decreased rapidly from September 15 (day 253), while temperature maintained stil high. This phenomena might be at least partially explained by tree phenology because photosynthesis supplies carbon substrate for stem metabolism and growth, and a decrease in substrate supply can decrease stem efflux within days. Additionally, we also observed significant decrease in GPP at the same time by the eddy covariance measurement (LIANG & al., unpublished data).

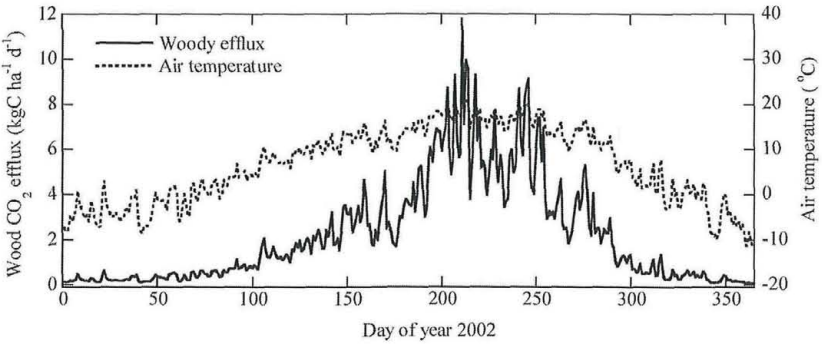

Fig. 3. Relationship between wood CO_2 efflux and air temperature.

Conclusion

Wood CO_2 efflux on sapwood volume basis has proved to be a better index than on area basis for scaling from chamber data to whole tree or stand level, probably because sapwood volume is proportional to the amount of living parenchyma cells therein (e.g. RYAN 1990) as well as the whole tree or stand level of sapwood volume is relative easy to be estimated. Previous studies scaled wood CO_2 efflux to stand by sapwood volume from measurements at only one location (generally at stem height lower than 2 m) because it was difficult for access and they assumed uniform respiration rates among all the stem parenchyma cells. This assumption is unlikely to be valid because sapwood is not uniform in age and maturity (PRUYN & al. 2002). In the current study, stand level annual wood CO_2 efflux was estimated to be 414, 730 and 1650 kg-C ha^{-1} based on efflux rate on a unit sapwood volume at the measurement height of 2.9, 9.1 and 12 m, respectively. If we calculated wood CO_2 efflux separately for different measurement heights and summed them as stand level wood CO_2 efflux, then the stand level annual wood CO_2 efflux could be 775 kg-C ha^{-1}, suggesting that scaling chamber based respiration to stand level by measurement at only one location likely be under- or overestimate of wood CO_2 efflux. Interestingly, stand level annual wood CO_2 efflux was estimated to be 795 kg-C ha^{-1}, equally well with former scaling method, when the scaling was based on wood volume following the procedure described in Data analysis section. Based on data of wood CO_2 efflux in this study, soil CO_2 efflux (LIANG & al. 2004, 2005c) and canopy respiration (LIANG & al. 2005a, b), wood CO_2 efflux contributed 5% of ecosystem respiration during the non-growing season. For the whole year, however, 7% of ecosystem respiration could be contributed by the aboveground wood CO_2 efflux.

Acknowledgements

This work has been supported in part by the Global Environment Research Program of the Ministry of the Environment of Japan. We thank Dr. D. BALDOCCHI (University of California, Berkeley), Dr. J. GRACE (University of Edinburgh) and Dr. M. G. RYAN (USDA Forest Service RMRS) for their suggestions on data analysis. We also thank Mr. K. INUKAI and Mr. Y. KITAMORI (Econixe, Hokkaido) for their maintenance of the study site.

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