P1.11

USING CONTINUOUS STABLE ISOTOPE MEASUREMENTS TO PARTITION NET ECOSYSTEM CO_2 EXCHANGE INTO PHOTOSYNTHESIS AND RESPIRATION OF A CORN-SOYBEAN ROTATION ECOSYSTEM

Jianmin Zhang[1*], Timothy J. Griffis[1] and John M. Baker[1,2]
[1]Department of Soil, Water, and Climate, University of Minnesota, St. Paul, Minnesota, USA
[2]USDA-ARS & Department of Soil, Water, and Climate, University of Minnesota, St. Paul, Minnesota, USA

1. INTRODUCTION

Studies of the stable carbon isotope variation and exchange between ecosystems and the atmosphere can provide new insight of biological and physical controls on carbon cycling. One subject of particular interest is to use the isotopic techniques to partition net ecosystem CO_2 exchange (NEE) into photosynthesis and respiration.

The objectives of this study were to: 1) partition the NEE of a C_3-C_4 rotation agricultural ecosystem by combining continuous stable isotope measurements and micrometeorological observations; 2) examine the temporal variation of the critical isotope characteristics of the ecosystem, and 3) explore the sensitivities of the partitioning methodology.

2. METHOD

2.1 Experiment

The experiment was conducted in a 17 ha corn (*Zea mays* L.,*C_4* pathway) field from May 21 to Oct.14 at the Rosemount Research and Outreach Center of the University of Minnesota, which is located 24 km south of St. Paul (44˚ 44′ N, 93˚ 05′ W). The site was planted with soybean (C_3 pathway) in the year 2002.

The mixing ratios of $^{12}CO_2$ and $^{13}CO_2$ (*μ*mol CO_2/mol dry air) were measured using the tunable diode laser (TDL) technique (TGA100, Campbell Scientific Inc., USA). The fluxes of sensible heat, latent heat, and CO_2 were measured with a 3-D sonic anemometer (CSAT3, Campbell Scientific Inc., USA) and an open-path infrared gas analyzer (LI-7500, LI-COR Inc., USA), which were mounted on the same tower as the TGA sample air inlets. Other micrometeorological measurements included: incoming and outgoing solar and long-wave radiation, soil heat flux, soil water content, and precipitation. Leaf area index (LAI) was measured every week. The analysis of isotope ratios of plants was performed on a Fisons Optima continuous flow model mass spectrometer.

2.2 Flux partitioning

The partitioning of NEE was based on the principle of mass conservation, which was expressed as,

$$P + R = NEE \tag{1}$$

$$\delta^{13}C_p \cdot P + \delta^{13}C_r \cdot R = \delta^{13}C_b \cdot NEE \tag{2}$$

$$\delta^{13}C_p = \delta^{13}C_a - a - b' - \frac{b'P}{g_c C_a} \tag{3}$$

where P and R are ecosystem photosynthesis and respiration, respectively. $\delta^{13}C_r$, $\delta^{13}C_p$, $\delta^{13}C_b$, and $\delta^{13}C_a$ are isotope ratios of ecosystem respiration, assimilated CO_2, net ecosystem exchange of CO_2, and ambient air above the canopy, respectively. C_a is the mixing ratio of CO_2 of ambient air. Parameter *a* is the diffusion discrimination against $^{13}CO_2$. Parameter $b' = b_4 + b_3 f - a$, where b_3 is the fractionation caused by RuP_2 carboxylation, b_4 is the fractionation caused by PEP carboxylase, and *f* is the fraction of CO_2 leaking out of the bundle sheath cells and refixed by Rubisco. The values of *a*, b_3, b_4, and *f* were obtained from Evans et al. (1986) and Farquhar et al. (1989). Parameters $\delta^{13}C_r$ and $\delta^{13}C_b$ were computed from TDL measurements (Griffis et al, 2004). g_c is the bulk canopy conductance, which was inverted from the Penman-Monteith equation. The unknowns, P, R, and $\delta^{13}C_p$ were solved for using equations (1) ~ (3).

2.3 Respiration predicted from nighttime regression

For comparison, the ecosystem respiration was also simulated using a regression method as,

$$R_e = A \exp(B_1 T + B_2 LAI) \cdot F(\theta) \tag{4}$$

where R_e is the modeled ecosystem respiration. Empirical parameters A, B_1, and B_2 were determined using an optimization method (Optimization toolbox, MATLAB 6.5.0, Math Works Inc., USA). F(*θ*) is a function of soil water content (*θ*) measured at a depth of 10 cm. T is the soil temperature measured at a depth of 2.5 cm.

3. RESULTS AND DISCUSSION

3.1 Partitioning NEE into P and R

NEE was partitioned into P and R for each half-hour using both the isotope approach and the regression methodology. The ensemble daily variation of partitioned photosynthesis and respiration of selected periods with similar weather conditions is shown in Fig. 1. In general, the isotopic partitioning method agreed well with the regression method in magnitude during the full canopy stage (Fig.1 (b) and (c)), but differed significantly during early and late growth stages (Fig.1 (a) and (d)). The diurnal pattern of R was different from that of R_e, with the peak of R_e skewing toward afternoon (i.e. when maximum soil temperature occurred) while R generally peaking around noon when photosynthesis was large. The seasonal P ranged from -10 μmol m^{-2} s^{-1} to -35 μmol m^{-2} s^{-1}, reaching a maximum in July and mid August. The seasonal R varied from 4 to 15 μmol m^{-2} s^{-1}, reaching a maximum at the full canopy stage from early July to early August.

---

[*] *Corresponding author address*: Jianmin Zhang, 439 Borlaug Hall, 1991 Upper Buford Circle, St. Paul, Minnesota, 55108, USA. e-mail: jzhang@umn.edu.

3.2 Isotope ratios of the assimilated CO$_2$ ($\delta^{13}C_p$), NEE ($\delta^{13}C_b$) and C_i/C_a

Fluctuations in daily $\delta^{13}C_b$ were relatively large (Fig. 2). For the majority of the daytime, the value of $\delta^{13}C_b$ was between $\delta^{13}C_a$ and $\delta^{13}C_p$, varying from -6‰ to -12‰. $\delta^{13}C_p$ remained relatively constant for the whole season, with values varying around -11‰. Some fluctuations of $\delta^{13}C_p$ lower than -15‰ were observed.

The ratio of intercellular CO$_2$ mixing ratio, C_i over C_a, was calculated at the canopy scale from $-P = g_c (C_a - C_i)$ (Fig. 3). The average C_i/C_a was slightly larger in the earlier growth stages than during the full canopy stage. The typical daily C_i/C_a was around 0.5~0.6, which was higher than the common leaf scale value of about 0.3.

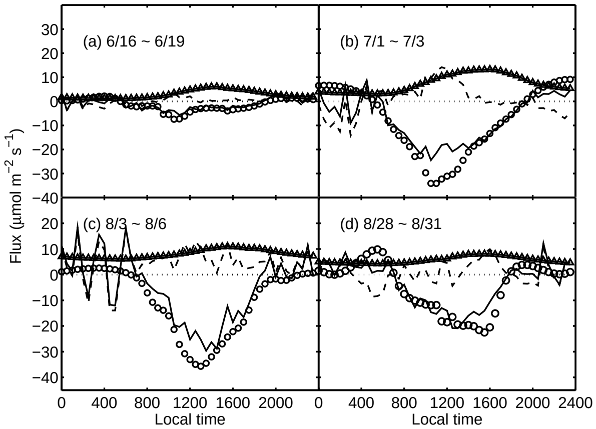

Fig.1. Photosynthesis and respiration from the isotope partitioning method and the regression model in typical growth stages. The circles are photosynthesis P from isotope partitioning, solid line is NEE, dashed line is isotopic partitioned respiration R, and the solid line with triangles is the regression modeled respiration R_e.

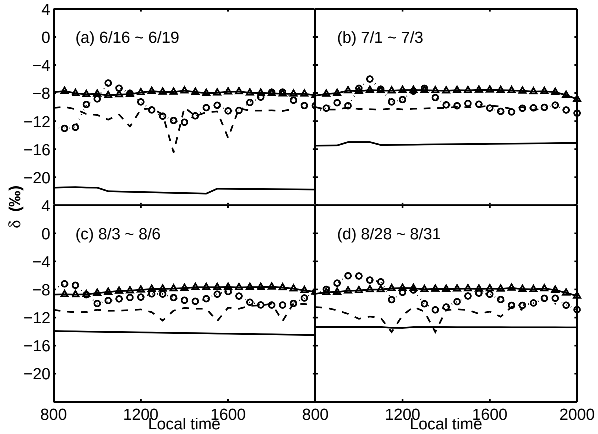

Fig. 2. Ensemble daily variations of $\delta^{13}C_r$, $\delta^{13}C_b$, $\delta^{13}C_p$, and $\delta^{13}C_a$. The solid line is $\delta^{13}C_r$, dashed line with circles is $\delta^{13}C_b$, dashed line is $\delta^{13}C_p$, and solid line with triangles is $\delta^{13}C_a$.

3.3 Sensitivity analysis

We performed a sensitivity analysis to examine the variation of partitioning with respect to changes in the critical parameters. The sensitivity test showed that the partitioning was most sensitive to $\delta^{13}C_b$. The partitioning also showed high sensitivity to variations in parameters b_3 and b_4, which implies that the difference between leaf scale and canopy scale parameters could cause significantly different results.

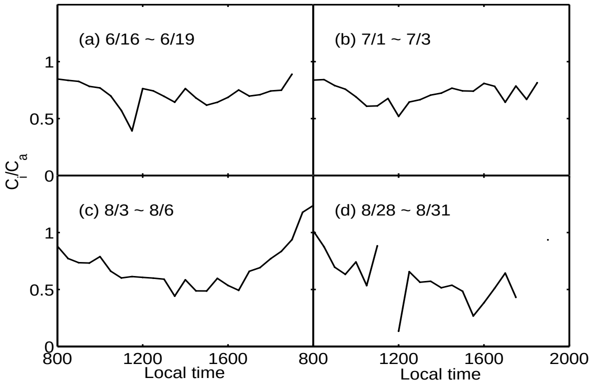

Fig. 3. Ensemble daily variation of C_i/C_a.

4. CONCLUSIONS

In this study, the isotopic measurements combined with the micrometeorological observations were used to partition the NEE of a C$_3$-C$_4$ rotation agricultural ecosystem into photosynthesis and respiration. The isotopic method provides real-time partitioning of NEE, and should lead to better understanding of the short-term ecophysiological processes than the regression method. The results showed that the partitioned photosynthesis and respiration were in accordance with the temperature regression method in magnitude during the full canopy stage; however, we observed a different diurnal pattern. The partitioning was most sensitive to $\delta^{13}C_b$. The replacement of term $\delta^{13}C_b$NEE on the right-hand-side of eqn.(2) with direct measurements of ^{13}NEE using the eddy covariance technique could improve our partitioning results.

ACKNOWLEDGEMENTS

This study was funded by the Office of Science (BER), U.S. Department of Energy, grant No. DE-FG02-03ER63684, and the University of Minnesota, Grant-in-Aid-of-Research, Artistry and Scholarship Program (TJG).

REFERENCES

Farquhar, G.D., Ehleringer, J.R. and Hubicck, K.T., 1989. Carbon isotope discrimination and photosynthesis. *Annual Review of Plant Physiology and Plant Molecular Biology*, 40: 503-537.

Evans, J.R., Sharkey, T.D., Berry, J.A. and Farquhar, G.D., 1986. Carbon isotope discrimination measured concurrently with gas exchange to investigate CO$_2$ diffusion in leaves of higher plants. *Australian Journal of Plant Physiology*, 13: 281-292.

Griffis, T.J, Baker, J.M., Sargent, S.D., Tanner, B.D. and Zhang, J., 2004. Measuring field-scale isotopic CO$_2$ fluxes with tunable diode laser absorption spectroscopy and micrometeorological techniques. *Agricultural and Forest Meteorology,* 124(1-2):15-29.