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CO_2 LOSSES DURING THE COLD PERIOD ABOVE SAGEBRUSH-STEPPE ECOSYSTEMS IN IDAHO AND OREGON

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1. INTRODUCTION

Since the mid-1990s, continuous measurements of CO_2 exchange during the growing season have been made in various types of rangelands of the United States using both Bowen ratio-energy balance (Dugas et al., 1999; Frank and Dugas, 2001; Sims and Bradford, 2001) and eddy covariance systems (Ham and Knapp, 1998; Meyers, 2001). These measurements provide important information on CO_2 flux magnitudes and their relationships to environmental factors, but are not sufficient for complete characterization of carbon cycling and balance. Understanding of the CO_2 dynamics during the non-growing season is necessary to close the annual carbon budget. This is especially true for some temperate rangelands in northern latitudes where the cold period represents almost half of the year.

Only a limited number of winter flux measurements have been made in northern latitude rangelands, most involving short-term, periodic determinations rather than continuous records (Fahnestock et al., 1999; Frank et al., 2000). The USDA-ARS Rangeland Carbon Flux Network (Svejcar et al., 1997) is undertaking an effort to document CO_2 fluxes during the winter for several important rangeland ecosystems. Our study is a part of this effort and documents winter flux measurements in sagebrush-steppe ecosystems in Idaho and Oregon.

2. MATERIALS AND METHODS

Continuous measurements of CO_2 exchange were obtained during the winter at two shrub-steppe locations: 1) the Dubois site in central Idaho (U.S. Sheep Experiment Station, 44°16' N, 112°08' W) with data collection at the beginning and the end of the year 2000, and (2) the Burns site in eastern Oregon (Northern Great Basin Experimental Range, 43°29' N, 119°43' W) with data collection during the winter of 2000-2001.

Measurements were made with Bowen ratio/energy balance (BREB) CO_2 flux systems (Model 023/ CO_2 Bowen ratio, Campbell Scientific, Logan, Utah, USA) with the control box insulated for winter conditions. The theory and operation of BREB systems were described in detail by Dugas et al. (1999). The BREB system provides continuous records of net ecosystem CO_2 exchange rate, $\boldsymbol{F}$ (mg CO_2 m^{-2} s^{-1}), which is equal to the difference between the rates of gross primary production and ecosystem respiration. To identify possible relationships between daily flux and environmental characteristics, 24-hour flux integrals, $\boldsymbol{F(j)}$, representing net CO_2 exchange for the calendar day, $\boldsymbol{j}$, were calculated. Simultaneously, average daily characteristics of soil temperature (5 cm depth), $\boldsymbol{T_s(j)}$, wind speed, $\boldsymbol{U(j)}$, and snow depth, $\boldsymbol{S_d(j)}$, were obtained. Corresponding datasets contained 113 records for the Dubois site and 77 records for the Burns site. They were used to identify the multivariate nonlinear model:

$$F = a_1\, Exp(a_2 T_s + a_3 U + a_4 S_d) + \varepsilon \qquad (1)$$

where flux from the ecosystem to the atmosphere is positive, $\{a_i\}$ are nonlinear regression parameters, and ε is the random error. Estimates of parameters $\{a_i\}$ were obtained using nonlinear regression modules of Mathematica® (Wolfram Research, 2001) and Statistica™ (StatSoft, 2001) software packages.

3. RESULTS AND DISCUSSION

For the Dubois site, relationships of daily flux $\boldsymbol{F}$ (g CO_2 m^{-2} d^{-1}) to $\boldsymbol{T_s}$, $\boldsymbol{U}$, and $\boldsymbol{S_d}$ can be represented by the equation:

$$F = 0.648\, Exp(0.453\, T_s + 0.154\, U + 0.015\, S_d) \qquad (2)$$

which explains 67% of the variability in daily flux and has a standard error of 0.24 g CO_2 m^{-2} d^{-1} (Fig. 1).

At the Burns site, where the availability and amount of snow during the measurement period were substantially lower than at Dubois (Fig. 2), snow depth was not a significant factor (parameter a_4 in equation (1)). Nevertheless model (3) described the effect of snow as a categorical factor:

$$F = \begin{cases} 0.280\, Exp(0.507\, T_s + 0.244\, U), & S_d = 0 \\ 0.465\, Exp(0.130\, T_s + 0.198\, U), & S_d > 0 \end{cases} \qquad (3)$$

which resulted in an R^2 of 63% and standard error of 0.27 g CO_2 m^{-2} d^{-1}.

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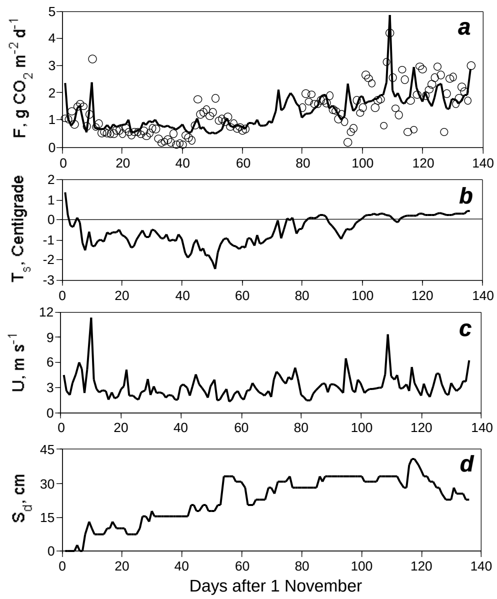

Fig. 1. Net daily CO_2 exchange in the sagebrush-steppe ecosystem at the Dubois site and its controlling factors during the winter period (Nov. 1 - March 15): a) net daily CO_2 flux, ***F*** (dots - BREB measurements, curve - model (2)); b) soil temperature, $\boldsymbol{T_s}$; c) wind speed, ***U***; and d) snow depth, $\boldsymbol{S_d}$.

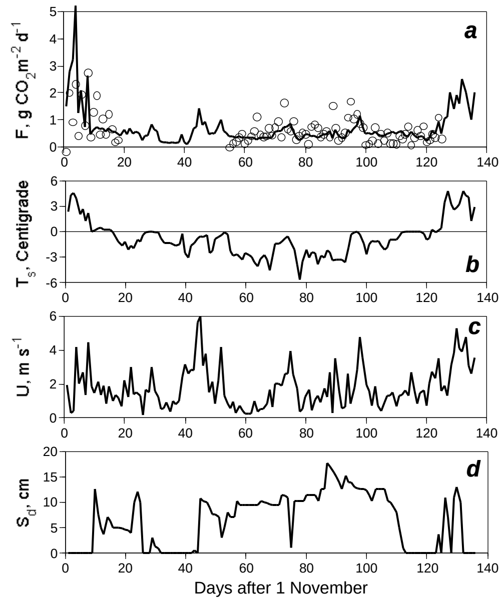

Fig. 2. Net daily CO_2 exchange in the sagebrush-steppe ecosystem at the Burns site and its controlling factors during the winter period (Nov. 1 - March 15): a) net daily CO_2 flux, ***F*** (dots - BREB measurements, curve - model (3)); b) soil temperature, $\boldsymbol{T_s}$; c) wind speed, ***U***; and d) snow depth, $\boldsymbol{S_d}$.

For the whole winter season (Nov. 1 to March 15), integrated flux at Dubois was estimated to be $\Sigma(\boldsymbol{F_{win}})$ = 117 g CO_2 m^{-2} with average daily rate $\boldsymbol{F_{win}}$ = 1.30 $\pm$ 0.80 g CO_2 m^{-2} d^{-1}. At the Burns site, corresponding estimates were $\Sigma(\boldsymbol{F_{win}})$ = 92 g CO_2 m^{-2} and $\boldsymbol{F_{win}}$ = 0.68 $\pm$ 0.56 g CO_2 m^{-2} d^{-1}. Compared to CO_2 gain in these ecosystems during the active part of the growing season (May - Sept.), which was estimated as ~550 g CO_2 m^{-2} for Dubois (mean for 1996-2000) and ~300 g CO_2 m^{-2} for Burns (mean for 1995-2000), wintertime losses in sagebrush-steppe ecosystems accounted for about one third of the CO_2 accumulation during the growing season. This implies that the spring and fall periods likely represent periods of high respiratory activity when moist soil conditions are combined with favorable temperatures to promote microbial decomposition.

4. CONCLUSIONS

Measurements of net ecosystem CO_2 exchange at sagebrush-steppe sites in Idaho and Oregon during the winter demonstrated that CO_2 efflux averaged 1.30$\pm$0.80 g CO_2 m^{-2} d^{-1} for the Dubois site and 0.68 $\pm$ 0.56 g CO_2 m^{-2} d^{-1} for the Burns site. These values agree with estimates of winter respiration from other northern latitude ecosystems. Multivariate analysis showed that winter CO_2 efflux was most closely associated with soil temperature, wind speed and snow depth, explaining 67 and 63% of variability in efflux rates at Dubois and Burns, respectively.

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