Seasonal CO_2-exchange variations of temperate semi-desert grassland in Hungary

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Abstract

CO_2 exchange components of a temperate semi-desert sand grassland ecosystem in Hungary were measured 21 times in 2000–2001 using a closed IRGA system. Stand CO_2 uptake and release, soil respiration rate (R_s), and micrometeorological values were determined with two types of closed system chambers to investigate the daily courses of gas exchange. The maximum CO_2 uptake and release were –3.240 and 1.903 μmol m^{-2} s^{-1}, respectively, indicating a relatively low carbon sequestration potential. The maximum and the minimum R_s were 1.470 and 0.226 μmol(CO_2) m^{-2} s^{-1}, respectively. Water shortage was probably more effective in decreasing photosynthetic rates than R_s, indicating water supply as the primary driving variable for the sink-source relations in this ecosystem type.

Additional key words: chamber technique; net ecosystem CO_2 exchange; soil respiration; soil water content.

Introduction

Long-term measurements of CO_2 and water vapour exchange allow better understanding of the role of the grassland in the global carbon cycle. Most of these studies are based on meteorological methods (Saigusa *et al.* 1998, Frank and Dugas 2001, Sims and Bradford 2001, Suyker *et al.* 2003, Kato *et al.* 2004), but several chamber techniques are also in use (Angell and Svejcar 1999, Oechel *et al.* 2000, Steduto *et al.* 2002) providing information on the spatial physiological heterogeneity of vegetation. Micrometeorological methods are also used to measure soil respiration rate, R_s (Verma 1990). Limited changes in precipitation could have a greater ecological impact on arid ecosystems than on wet ones (Chapin *et al.* 2002). To estimate the effects of the global changes on natural ecosystems needs measuring and modelling gas exchange. Although semi-desert temperate grassland ecosystems are substantial and integrated elements of the temperate grassland zone, we are not aware of any long-term carbon-balance measurements for this type of vegetation.

The main objective of this work was to study by chamber technique the CO_2 exchange variations (stand photosynthesis, stand respiration, and R_s) during the year in a semi-desert temperate sand grassland ecosystem.

Materials and methods

The measurements were carried out in a semi-desert sand grassland near Vácrátót, Hungary (latitude 47°42'N, longitude 19°15'E, 140 m a.s.l.). The climate of the site is of temperate continental type. Total annual precipitation is about 500 mm, the mean annual air temperature (T_a) is 10.5 °C. The temperature of the sand surface regularly reaches 60 °C at noon in summer. The vegetation is an open semi-arid grassland (*Festucetum vaginatae danubiale*), which is distributed in the Carpathian Basin, evolved on sandy soils and has semi-desert characteristics due to

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Abbreviations: F_{CO2} – CO_2 flux; NEE – net ecosystem CO_2 exchange; PAR – photosynthetically active radiation; R_s – soil respiration; RH – relative humidity; SWC – soil water content; T_a – air temperature.
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edaphic causes (Fekete *et al.* 1988). This community is dominated by *Festuca vaginata* W. *et* K. and *Stipa capillata* Klokov. The average cover by vascular plants is 30–40 % and mosses [mainly *Tortula ruralis* (Hedw). Gaertn.] contribute 18–20 % to the total cover.

Gas exchange field measurements were carried out from November 2000 to November 2001. CO_2-exchange (net ecosystem exchange, NEE and R_s), evapotranspiration, T_a, relative humidity (RH), and vapour pressure were measured at intervals of 1.5–2.0 h during the day by a portable closed-loop IRGA (*LI-COR 6200*; *Li-Cor*, Lincoln, NE, USA). This instrument samples the air in a cylinder-chamber of 60 cm diameter and 70 cm high (Czóbel *et al.* 2002) with a narrow metallic frame on the bottom, but without collar in the soil. The air within the chamber was mixed by an outer fan. The chamber was placed over the plots for a short time (about 1 min), because of the increasing temperature. Gas exchange measurements were carried out in three replicates on five permanent plots.

R_s was measured in three replicates on three plots between the tussocks by using the same IRGA with a plexi hemisphere chamber of 20 cm diameter. The metabolically active vegetation was excluded from the plots. The soil respiration chamber was very similar to the non-steady-state through-flow chamber (Pumpanen *et al.* 2004) equipped with fans. No collars were used with this chamber.

Soil water content was measured by a TDR reflectometer (*ML2*, *Delta-T Devices Co.*, Cambridge, UK) in three replications at 5, 10, and 20 cm soil depths. Photosynthetically active radiation (PAR) was recorded using sunfleck ceptometers (*Decagon Devices*, Pullman, WA, USA). Leaf area index (LAI) was calculated from the sunfleck/PAR-transmittance values, using software written in an *Excel* (*VisualBasic*) macro based on algorithms by Campbell (1986).

Results and discussion

Stand CO_2-exchange: The measured net CO_2 flux (F_{CO2}) was highly variable within and across seasons. In winter the highest F_{CO2} values were monitored only on frost-free days. They were close to zero or slightly negative at noon (Fig. 1). In spring, F_{CO2} increased and reached the maximum value in May (–3.24 µmol m^{-2} s^{-1} on 9 May 2001) (Fig. 2). During the study period the daily maximum F_{CO2} values were foundd before noon. In summer they were lower than in spring because of the low water availability.

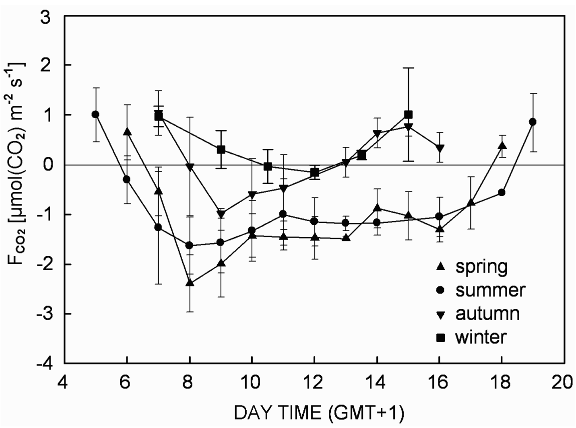

Fig. 1. The daily courses of net ecosystem CO_2 exchange, F_{CO2} (winter averages are only for the frost-free days) in the temperate semi-desert grassland. Negative values indicate carbon uptake.

There was considerable variability in F_{CO2} during summer due to uneven temporal distribution of precipitation. In the same vegetation season and under very similar meteorological conditions (except for water supply), net ecosystem CO_2 exchange (NEE) was considerably lower because of the water shortage (Table 1). The variability of F_{CO2} in autumn was due to cloud cover. Our results showed a lower photosynthetic capacity than the ones (semiarid prairie grasslands) found by Frank and Dugas (2001) or Sims and Bradford (2001).

Fig. 2 shows the correlation between F_{CO2} and PAR. On the frost free winter days at mean PAR of 500 µmol m^{-2} s^{-1} the maximum F_{CO2} was 0.421 µmol m^{-2} s^{-1} (14 December 2000). The summer F_{CO2} values show that the water supply could influence the CO_2 uptake/emission transition at high PAR, which is coupled also with high T_a.

In spite of the decreasing R_s in autumn and winter, F_{CO2} at zero PAR (including dark respiration and soil respiration) values were also high [about 1 µmol(CO_2) m^{-2} s^{-1}], probably because of the dark respiration of mosses, which are metabolically active in this period of the year.

R_s was indicative of root and soil microbial respiration and depended on soil temperature and water content. This ecosystem type was characterized by a low nutrient content, but great root biomass (400 g m^{-2} of above- and 745 g m^{-2} of below-ground biomass, in late spring; unpublished data), therefore the role of root respiration might be more significant as to the whole process of respiration than the microbiological one.

The correlation between R_s and T_a was exponential (Fig. 3). R_s showed a seasonal dynamism (Norman *et al.* 1992, Chen *et al.* 2003); it reached a peak in summer and declined through autumn and winter. The maximum R_s [1.47 µmol(CO_2) m^{-2} s^{-1}] was observed on 27 July 2001 (0.054 m^3 m^{-3} soil water content and Ta of 33 °C). The lowest value [0.142 µmol(CO_2) m^{-2} s^{-1}] was found on 16 January 2001 (0.01 m^3 m^{-3} water content, T_a of 1.8 °C).

Table 1. Net ecosystem CO_2 exchange (NEE) and soil respiration rates (R_s) on two summer days (June 2001) under very similar conditions but under different water supply in the temperate semi-desert grassland.

Date	NEE [µmol m^{-2} s^{-1}]	R_s [µmol m^{-2} s^{-1}]	PAR [µmol m^{-2} s^{-1}]	T_{air} [°C]	RH [%]	SWC [m^3 m^{-3}]
1 June	-0.108	0.98	1 137	29.49	36.21	0.031
26 June	-1.421	1.08	1 079	28.78	37.00	0.064

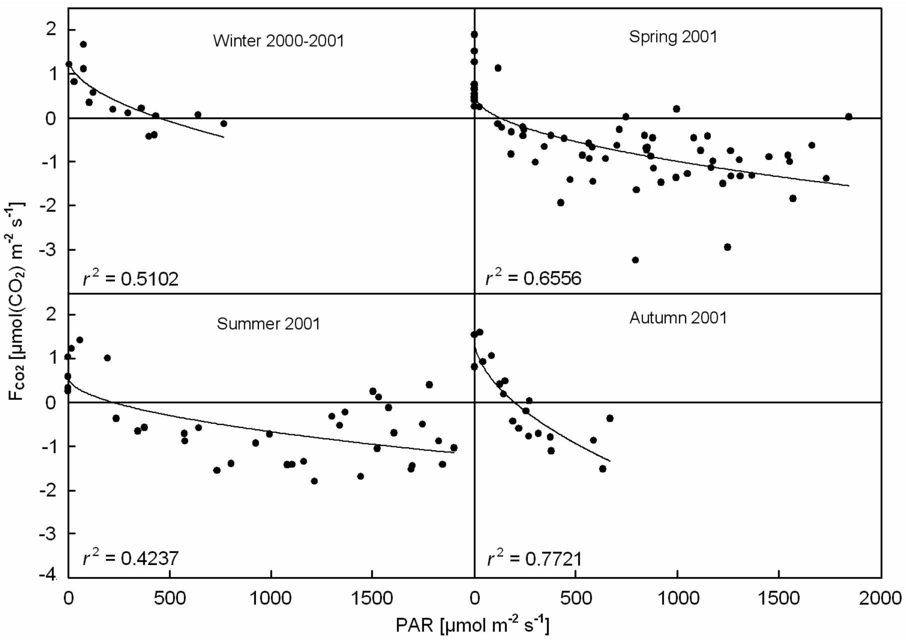

Fig. 2. CO_2 fluxes, F_{CO2} as a function of the photosynthetically active radiation (PAR) in the investigated temperate semi-desert grassland. Every dot represents the average of 15 measurements.

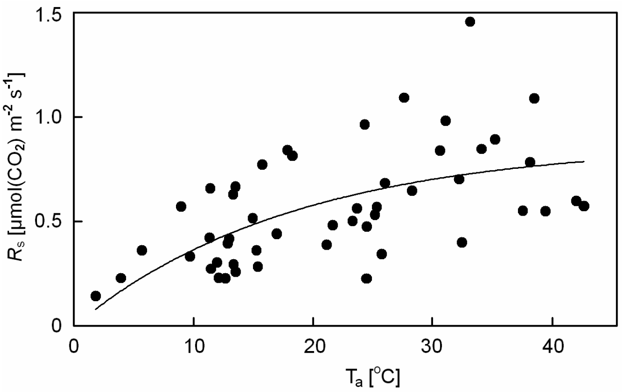

Fig. 3. Temperature dependence of the soil respiration of the temperate semi-desert sand grassland (r^2 = 0.3332, p<0.001). Every dot represents the average of 9 measurements (3 measurements over 3 plots). Data are pooled from measurements over the year.

The CO_2 flux from soil was probably more sensitive to soil moisture than to photosynthesis (Table 1). This result was in accordance to Lloyd and Taylor (1994) for Australian savannah.

The carbon balance in semi-arid grassland ecosystems is usually close to the equilibrium (Frank and Dugas 2001). Our results, on the whole, showed a relatively low carbon sequestration potential of the considered ecosystem. The occurrence of droughts seemed to be a major factor influencing the carbon budget of the community; water shortage being more effective in decreasing F_{CO2} than R_s. The *Festucetum vaginatae danubiale* was affected by variation of water distribution, because of soil sandy texture. Consequently, increasing droughts could have serious consequences on the structure and productivity capacity of this vegetation type. Moreover, the results suggested that this type of vegetation was a weak sink for CO_2 and that its sink-characteristics depend strongly on the precipitation pattern.

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