Experimental study on soil CO_2 emission in the alpine grassland ecosystem on Tibetan Plateau

ZHANG Xianzhou, SHI Peili, LIU Yunfen & OUYANG Hua

Institute of Geographic Sciences and Natural Resources Research, Chinese Academy of Sciences, Beijing 100101, China
Correspondence should be addressed to Zhang Xianzhou (email: zhangxz@igsnrr.ac.cn)

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Abstract The Tibetan Plateau, the Roof of the World, is the highest plateau with a mean elevation of 4000 m. It is characterized by high levels of solar radiation, low air temperature and low air pressure compared to other regions around the world. The alpine grassland, a typical ecosystem in the Tibetan Plateau, is distributed across regions over the elevation of 4500 m. Few studies for carbon flux in alpine grassland on the Tibetan Plateau were conducted due to rigorous natural conditions. A study of soil respiration under alpine grassland ecosystem on the Tibetan Plateau from October 1999 to October 2001 was conducted at Pangkog County, Tibetan Plateau (31.23°N, 90.01°E, elevation 4800 m). The measurements were taken using a static closed chamber technique, usually every two weeks during the summer and at other times at monthly intervals. The obvious diurnal variation of CO_2 emissions from soil with higher emission during daytime and lower emission during nighttime was discovered. Diurnal CO_2 flux fluctuated from minimum at 05:00 to maximum at 14:00 in local time. Seasonal CO_2 fluxes increased in summer and decreased in winter, representing a great variation of seasonal soil respiration. The mean soil CO_2 fluxes in the alpine grassland ecosystem were 21.39 $mgCO_2 \cdot m^{-2} \cdot h^{-1}$, with an average annual amount of soil respiration of 187.46 $gCO_2 \cdot m^{-2} \cdot a^{-1}$. Net ecosystem productivity is also estimated, which indicated that the alpine grassland ecosystem is a carbon sink.

Keywords: soil CO_2 emission, alpine grassland ecosystem, Tibetan Plateau.

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Human beings gave their attention to soil respiration and the activities of soil microorganisms early in the 19th century[1], and scientists began to study the soil respiration during the late 19th and early 20th centuries. However, studies of soil respiration were poorly reported in the following decades[2]. After the 1960s, with the development of instruments and the improvement of measurements, there has been an increasing interest in the studies of soil respiration. Especially in the recent ten years, with the global climate change as one of the focuses of the science and the carbon dioxide as an important greenhouse gas, accurate measurements of the carbon dioxide flux from soil have caused worldwide concern.

Since the IBP (International Biological Program) was carried out in the 1960s, studies on biomass productivity of the global ecosystems have been conducted and much information about the carbon balance of the typical terrestrial ecosystems has been reported[3]. As a main partition of the global carbon budgets, soils are the largest carbon pool in terrestrial ecosystem, containing about 1500 PgC, two times of atmosphere[4]. The CO_2 emissions from soil to atmosphere are a major part of the C cycle in ecosystem and the annual CO_2 emissions are estimated to be 68—75 PgC at global scales[5,6].

In China, we have only a history of over ten years in the studies about carbon cycle. Many studies have been widely conducted in ecosystems of forest[7,8] and grassland[9—13]. However, very little information is available about soil CO_2 efflux in the hinterland of the Tibetan Plateau[14,15], except the forest and grassland ecosystems in Mt. Gongga[16], Haibei[9,17] and Wudaoliang[18,19].

The Tibetan Plateau is characterized by high elevation, high radiation, low air pressure and its CO_2 concentration is only two thirds that of the plain. Under the cool or cold weather, the decomposition rate of plant litter is very low, especially in the regions with an elevation above 4000 m. Tibetan Plateau has a very large carbon pool in soils and its CO_2 emissions are more sensitive to the global climate change, compared with other regions. Is the Tibetan Plateau eventually a carbon source or a sink? How big is it? These questions will be the focus of the researches about the global change. The solutions to these questions will help us to study the global climate change and provide us a new explanation for some uncertain questions in the global carbon balance.

The main objectives of this study are to: (1) quantificationally describe how soil CO_2 emission varies diurnally and seasonally in the alpine grassland ecosystem; and (2) evaluate the annual carbon balance of the alpine grassland ecosystem.

1 Experiments and measurements

1.1 Site description

The experimental site was located in Pangkog County, Tibetan Plateau (31.23° N, 90.01° E, elevation 4800 m). In this area, there are low pressure, low air temperature, low air humidity and great wind. The climate belongs to subfrigid zone. Annual mean air temperature is about −1.2℃, annual relative humidity is 48%—51%, annual rainfall is about 380 mm, annual sunshine hours range from 2852.6 h to 2881.7 h and total radiation is over 8360 MJ • m^{-2} • a^{-1} . There is no absolutely frost-free period here. The ecosystem is classified as bunchgrass or rhizanthous Carex L alpine grassland, dominated by *Stipa purpurea* Griseb, associated with *Carex moocroftii* Falx. Ex Boott. The soil is classified as plateau grassland soil, with pH value of 8.2, organic matter of 1.1% and total N of 0.067%.

1.2 Field measurement

Soil respiration was measured by a static closed chamber technique. The chamber was made from opaque PVC board with a 0.25 m^2 (50 cm×50 cm) base area, and 30 cm height. The chamber was fixed with an air mixture fan, a temperature sensor, a 3-way sampling stopcock and a syringe for sampling gas. Twenty-four hours before the measurement, three steel frames with 50 cm×50 cm surface area were randomly inserted into soil of sampling plot 5 cm deep, which means that each measurement has three replicates, and the plants in the frames were cut on the ground level. And the chamber was mounted on the frame by water seal. During the measurement, 1 L gas was extracted each time using syringe (100 mL) at 0, 10, 20 and 30 min after lid was covered. Air samples were collected in polyethylene-coated aluminum bags. LI-COR6252 was used to measure the CO_2 concentration of the air samples. The CO_2 flux was measured over the period from October 1999 to July 2001. The measurements were carried out twice a month in growing season, and once in non-growing season. In the day of measurement, air samples were extracted once respectively during 07:00—09:00 a.m. and 15:00—17:00 p.m. But in measurements for diurnal variations, samples were extracted from 19:00 at intervals of 3 h a day. In total, 22 times were measured in the two whole years, of which 6 times were measured for diurnal variations. In addition, soil temperature was measured with the temperature sensor at different soil layers of 0, 5, 10, 15, 20 cm at the nearby site while soil respiration was measured. The daily meteorological data, e.g. soil temperature, were taken from the weather station of Pangkog County 2 km away.

The samples of biomass harvest were collected from 3 replicate treatments that were determined randomly within the experimental plot. Each replicate treatment size of 50 cm × 50 cm was determined for all above-ground biomass harvest. The biomass samples were taken to laboratory in order to get their drying weight. At the same time, root biomass was also measured, and roots associated with the soils were put into bags and taken to laboratory. Then the roots were filtered out from soil and washed. After air-drying, the matter was dried to invariable weight by oven (65℃). To evaluate the annual biomass productivity, biomass was measured on January 7 and August 27 in 2000, once respectively.

1.3 Flux calculation

The CO_2 flux can be given from the following formula:

$$F = \frac{\Delta m}{\Delta t} \cdot D\frac{V}{A} = hD\frac{\Delta m}{\Delta t},$$

where F is the soil CO_2 flux ($mg \cdot m^{-2} \cdot h^{-1}$), V is the volume of the chamber, A is the area of the chamber's bottom, D ($mol \cdot m^{-3}$) is air density within the chamber ($D=n/v=P/RT$, P is air pressure in the chamber, T is the temperature in the chamber, R is air constant), $\Delta m/\Delta t$ is the linear slope that air concentration changes with time during the observation; h is the height of the chamber.

2 Results and discussions

2.1 Diurnal variations of CO_2 fluxes

During the whole period, 6 measurements of diurnal variation were conducted mainly in spring, summer and autumn. Because of the rigorous natural conditions of Pangkog in winter, it was very difficult to measure soil CO_2 emission for the diurnal variation. From fig. 1, it can be seen that the diurnal variation of the soil respiration displayed a single-peaked curve obviously; CO_2 flux had higher emission at 14:00 p.m. and lower emission at 05:00 a.m., especially in the summer; soil respiration correlated significantly with 0 cm soil temperature and 5 cm soil temperature.

2.2 Seasonal variations of CO_2 fluxes

During the whole period, 22 times were totally measured, in which 6 times were of diurnal variations measurement (fig. 1). From the 6 measurements, we can get the average daily soil CO_2 flux and the total daily soil CO_2 flux; then, we can find that the average daily soil CO_2 flux was nearly equal to the soil CO_2 flux measured at 08:00 everyday (fig. 1). As a result, we can estimate the total daily soil CO_2 flux of other 16 times, only by using the soil CO_2 flux measured during 07:00—09:00 in the morning. Fig. 2 shows the pattern of the seasonal changes of whole daily CO_2 fluxes. From fig. 2, it can be seen that the seasonal changes of daily soil CO_2 flux also produced a single-peaked curve obviously. The minimum CO_2 flux took place between December and January. For example, on January 7, 2000, the amount of the daily soil respiration is 0.096 g $CO_2 \cdot m^{-2} \cdot d^{-1}$. The maximum CO_2 flux took place between June and July, for example, on June 28, 2000, the amount of the daily soil respiration is 1.44 g $CO_2 \cdot m^{-2} \cdot d^{-1}$.

2.3 Soil CO_2 emission and soil temperature

From the characteristic of the diurnal and seasonal variations in soil CO_2 emission, we can find that soil CO_2 emission correlate significantly with soil temperature. Soil temperature can be the controlling factors that determine the soil CO_2 emission. Here, we studied the relationship between the soil CO_2 emission and 0 cm soil temperature and 5 cm soil temperature respectively (fig. 3). From fig. 3, it can be seen that the relationships between soil CO_2 emission and soil temperature can be expressed by an exponent function, but a better relationship to 0 cm soil temperature seemly.

2.4 The amount of annual soil CO_2 emission

Two methods were used to estimate the annual soil CO_2 emission. One is to estimate the annual soil CO_2 emission directly using the data of seasonal soil respiration changes (fig. 2); Another is to calculate the annual soil CO_2 emission according to the relationships between soil respiration and 0 cm soil temperature and 5 cm soil temperature (fig. 3). The former may have a less accuracy due to the less numbers of measurements. So the latter is more reliable in estimating the annual soil annual soil CO_2 emission. The daily data on 0 cm soil temperature were taken from

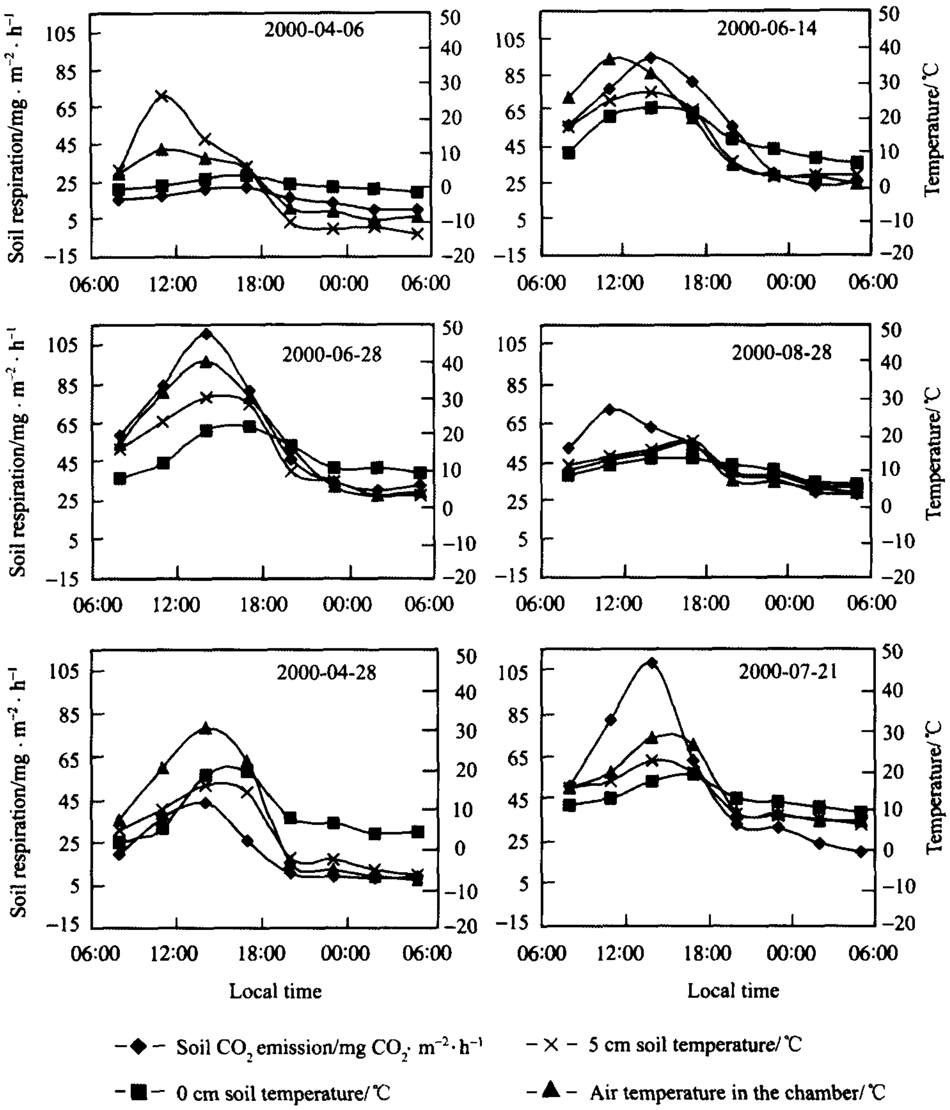

Fig. 1. Diurnal variations of soil CO_2 emission in alpine grassland ecosystem.

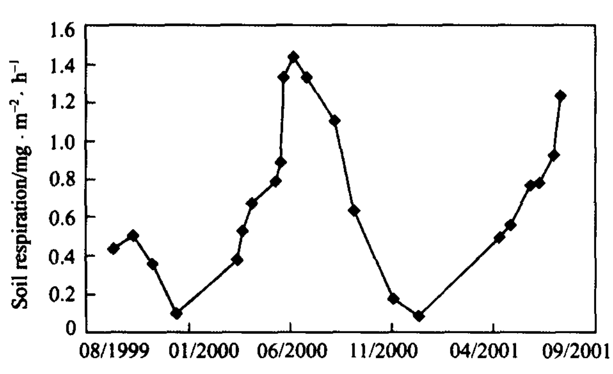

Fig. 2. Seasonal variations of soil CO_2 emission in alpine grassland ecosystem.

the weather station in Pangkog County 2 km away. In fig. 4 we estimated the daily soil CO_2 emission by the daily data of 0 cm soil temperature during 1999, 2000 and 2001, and a comparison was displayed between the estimated and measured values.

To exclude the influence of within-year weather change on soil respiration, we estimated the daily soil CO_2 emission using the average daily 0 cm temperature from the twenty years' meteorological records (1981—2000), which represented the soil CO_2 emission pattern under the normal climate (fig. 5). The mean daily soil CO_2 emission and total annual soil

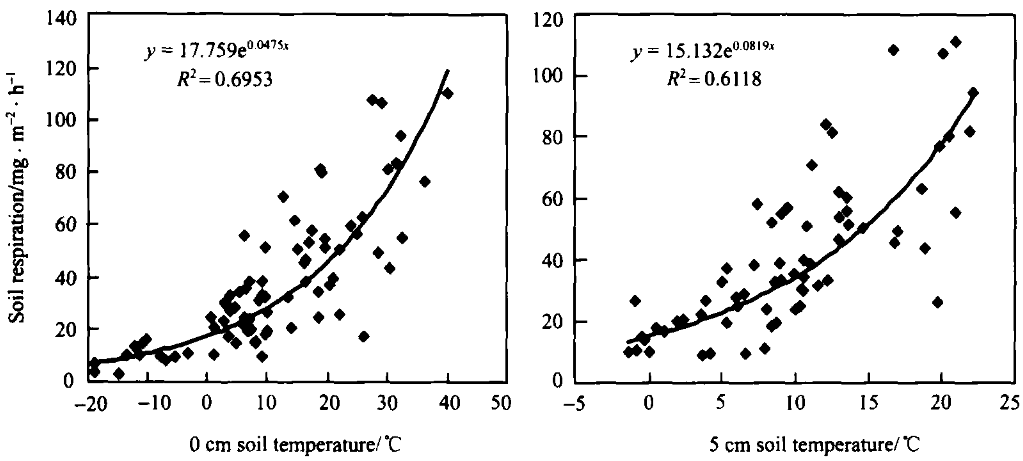

Fig. 3. The relationship between soil respiration and 0 cm soil temperature and 5 cm soil temperature respectively.

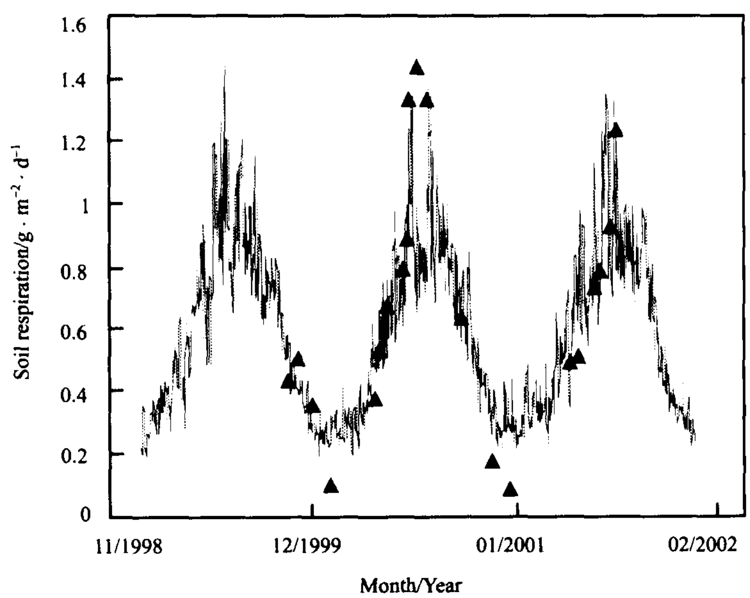

Fig. 4. Annual soil CO_2 emission in alpine grassland ecosystem/1999–2001; –, estimated; ▲, measured.

CO_2 emission are 21.39 $mgCO_2 \cdot m^{-2} \cdot h^{-1}$ and 187.46 $gCO_2 \cdot m^{-2} \cdot a^{-1}$, respectively.

2.5 The carbon balance of the alpine grassland

Net ecosystem productivity (NEP) is the indicator of the carbon balance of an ecosystem, equal to the difference between the net primary production (NPP) and heterotrophic respiration (Rh). An ecosystem is a carbon source if the value of NEP is negative, or a carbon sink if the value is positive.

The NPP of the grassland ecosystem is determined by the maximum biomass in growing season and the minimum biomass in non-growing season. For example, on January 7, 2000 (resting period of the grass) and on August 27, 2000 (maximum biomass period), underground biomass, above-ground biomass and the mounts of litter were measured respectively in alpine grassland. Through these experiments, the NPP was estimated at 225.66 $g \cdot m^{-2} \cdot a^{-1}$ in alpine grassland (table 1). Also based on measurements, we found that the amounts of carbon accounted for 43% of the total biomass. Therefore, we evaluated that the NPP of

Table 1 The determination of NPP of alpine grassland ecosystem

Time	Component	Biomass/g·m^{-2} A	B	C	Mean
January 7, 2000	Above-ground litter	73.36	81.72	69.80	74.96
	Underground biomass	793.28	837.72	749.00	793.32
August 27, 2000	Above-ground biomass	118.68	86.96	100.12	101.94
	Annual litter	11.52	7.76	9.24	9.48
	Underground biomass	969.56	851.48	901.64	907.56
NPP=101.94+9.48+(907.56–793.32)=225.66 g • m^{-2}					

A, B and C stand for replicate.

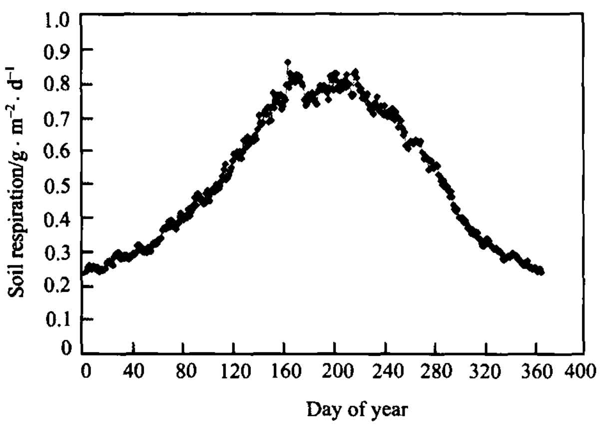

Fig. 5. Annual soil CO_2 emission in alpine grassland ecosystem under normal climate.

the alpine grassland in Pangkog County was 97.03 gC • m^{-2} • a^{-1} in 2000.

Soil respirations consists of root respiration and Rh of the soil microorganisms, Rh accounting for 45%—48% of the total[20—22]. In 2000, the annual soil CO_2 emission was estimated at 211.16 gCO_2 • m^{-2} • a^{-1}, according to the daily soil CO_2 emission of the alpine grassland ecosystem. With the assumption that Rh accounted for 45% of the total, Rh was estimated at about 25.91 gC • m^{-2} • a^{-1}. From above, we calculated that the NPP was 97.03 gC • m^{-2} • a^{-1}. As a result, the NEP of the alpine grassland in Pangkog was 71.12 gC • m^{-2} • a^{-1}, which means that the alpine grassland ecosystem in Pangkog was a carbon sink.

3 Conclusions

In alpine grassland ecosystem, the diurnal variations of the soil CO_2 emission displayed a single-peaked curve obviously; CO_2 flux had maximum emission at 14:00 p.m. and minimum emission at 05:00 a.m., especially in the summer; soil respiration correlated significantly with 0 cm soil temperature and 5 cm soil temperature respectively.

In alpine grassland ecosystem, seasonal variations of the soil CO_2 emission also took on a single-peaked trend. The minimum daily CO_2 respiration rate took place between December and January, with the value of 0.096 g CO_2 • m^{-2} • d^{-1}; the maximum daily CO_2 flux took place between June and July, with the value of 1.44 g CO_2 • m^{-2} • d^{-1}.

Soil temperature was the controlling factors that determine the soil CO_2 emission. The relationships between soil CO_2 emission and soil temperature can be expressed by an exponent function, but a better relationship to 0 cm soil temperature seemly.

With the average daily 0 cm temperature calculated from the twenty years' meteorological records, we evaluated the daily soil CO_2 emission and the annual soil CO_2 emission, which represented the soil CO_2 emission pattern under the normal climate. The mean daily soil CO_2 emission and total annual soil CO_2 emission were 21.39 mgCO_2 • m^{-2} • h^{-1} and 187.46 gCO_2 • m^{-2} • a^{-1}, respectively.

In 2000, the NEP of the alpine grassland ecosystem in Pangkog was 71.12 gC • m^{-2} • a^{-1}, which indicated that the alpine grassland ecosystem in Pangkog was a carbon sink.

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