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Comparative study on CO_2 emissions from different types of alpine meadows during grass exuberance period

HU Qiwu[1,3], *CAO Guangmin*[1], *WU Qin*[1], *LI Dong*[1], *WANG Yuesi*[2]
(Northwest Institute of Plateau Biology, CAS, Xining 810001, China; 2. Institute of Atmospheric Physics, CAS, Beijing 100029, China; 3. Graduate School of CAS, Beijing 100039, China)

Abstract: *Potentillla fruticosa* scrub, *Kobresia humilis* meadow and *Kobresia tibetica* meadow are widely distributed on the Qinghai-Tibet Plateau. During the grass exuberance period from 3 July to 4 September, based on close chamber-GC method, a study on CO_2 emissions from different treatments was conducted in these meadows at Haibei research station, CAS. Results indicated that mean CO_2 emission rates from various treatments were 672.09±152.37 mgm^{-2}h^{-1} for FC (grass treatment); 425.41± 191.99 mgm^{-2}h^{-1} for FJ (grass exclusion treatment); 280.36±174.83 mgm^{-2}h^{-1} for FL (grass and roots exclusion treatment); 838.95±237.02 mgm^{-2}h^{-1} for GG (scrub+grass treatment); 528.48±205.67 mgm^{-2}h^{-1} for GC (grass treatment); 268.97±99.72 mgm^{-2}h^{-1} for GL (grass and roots exclusion treatment); and 659.20±94.83 mgm^{-2}h^{-1} for LC (grass treatment), respectively (FC, FJ, FL, GG, GC, GL, LC were the Chinese abbreviation for various treatments). Furthermore, *Kobresia humilis* meadow, *Potentilla fruticosa* scrub meadow and *Kobresia tibetica* meadow differed greatly in average CO_2 emission rate of soil-plant system, in the order of GG>FC>LC>GC. Moreover, in *Kobresia humilis* meadow, heterotrophic and autotrophic respiration accounted for 42% and 58% of the total respiration of soil-plant system respectively, whereas, in *Potentilla fruticosa* scrub meadow, heterotrophic and autotrophic respiration accounted for 32% and 68% of total system respiration from GG; 49% and 51% from GC. In addition, root respiration from *Kobresia humilis* meadow approximated 145 mgCO$_2$m^{-2}h^{-1}, contributed 34% to soil respiration. During the experiment period, *Kobresia humilis* meadow and *Potentilla fruticosa* scrub meadow had a net carbon fixation of 111.11 gm^{-2} and 243.89 gm^{-2}, respectively. Results also showed that soil temperature was the main factor which influenced CO_2 emission from alpine meadow ecosystem, significant correlations were found between soil temperature at 5 cm depth and CO_2 emission from GG, GC, FC and FJ treatments. In addition, soil moisture may be the inhibitory factor of CO_2 emission from *Kobresia tibetica* meadow, and more detailed analyses should be done in further research.

Key words: CO_2; alpine meadow; grass exuberance period; soil respiration; treatment

1 Introduction

The rising atmospheric greenhouse gases were believed to be the primary cause of global climate change (Tett *et al.*, 1999; Crowley, 2000). Among the greenhouse gases, the concentration of atmospheric carbon dioxide has increased from 280 ppm since pre-industrial times to current 355 ppm, which accounted for 50% of the total greenhouse effect (Neftel *et al.*, 1985; Friedli *et al.*, 1986; Rodhe, 1990; Fan *et al.*, 1998). Elevated CO_2 has a marked effect on terrestrial ecosystem processes (Melillo *et al.*, 1996). The Qinghai-Tibet Plateau, the largest geomorphological unit on the Eurasian, is an important part of the global terrestrial ecosystem. While sensitive to global climate change, the region also plays an active role in moderating such changes, both at the Asian and the global level (Tang *et al.*, 1986; Li *et al.*, 1988). Due to its specially natural and geographic characteristics, the carbon transfer or cycle in plateau ecosystem differed greatly from

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Author: Hu Qiwu (1979-), Master, specialized in grassland ecology. E-mail: huqiwu1979@sohu.com
Cao Guangmin, corresponding author. E-mail: Caogm2002@sina.com

others. Consequently, to discuss the characteristic and mechanism of carbon cycle in plateau ecosystem will greatly contribute to the research of global climate change. Alpine grassland is one of the most important ecosystems on the Tibetan Plateau, which occupies almost 1/3 of the whole plateau area. There have been many reports about CO_2 emissions from alpine grassland on the Tibetan Plateau (Cao *et al.*, 2001; Zhang *et al.*, 2001a, b, c; Cao *et al.*, 2002; Pei *et al.*, 2003). However, there seldom occurred simultaneous investigation on CO_2 emissions from different meadow types. Here, based on field observations during the grass exuberance period of 3 July to 4 September in 2003, studies on CO_2 emissions were conducted simultaneously in three main types of meadows, *Potentilla fruticosa* scrub, *Kobresia humilis* meadow and *Kobresia tibetica* meadow, which are widely distributed on the Tibetan Plateau. The objective of this study was to discuss the discrepancy of CO_2 emission from different meadow types; to distinguish and quantify heterotrophic and autotrophic respiration in the total soil and plant system respiration; and to separate root and soil microbial contributions to soil respiration. Thus, more details are offered to the study on alpine grassland's contribution to atmospheric greenhouse gases.

2 Materials and methods

2.1 Site description

This study was conducted at Haibei Research Station of alpine meadow ecosystem, CAS, which is located in the northeast of the Tibetan Plateau, in a large valley surrounded by the Qilian Mountains, at latitude 37°37'N and longitude 101°19'E (Figure 1). The average altitude of the station area is 3280 m, and the mean annual air temperature is -1.7℃ with maximum of 27.6℃ and minimum of -37.1℃. The annual precipitation ranges from 426 mm to 860 mm, 80% of which falls in the growing season from May to September.

2.2 Experimental design

Three different types of meadows were selected as study sites, including *Kobresia humilis* meadow, *Potentilla fruticosa* scrub meadow as well as *Kobresia tibetica* meadow. Characteristics of the meadows are described as follows:

Kobresia humilis meadow was distributed in a valley surrounded by mountains. This site was dominated by *Kobresia humilis*, *Festuca ovina*, *Elymus nutans*, *Gentiana farreri*, and *Poa spp*, with a vegetation coverage of over 95%. The site is used as winter pasture, and the soil is classified

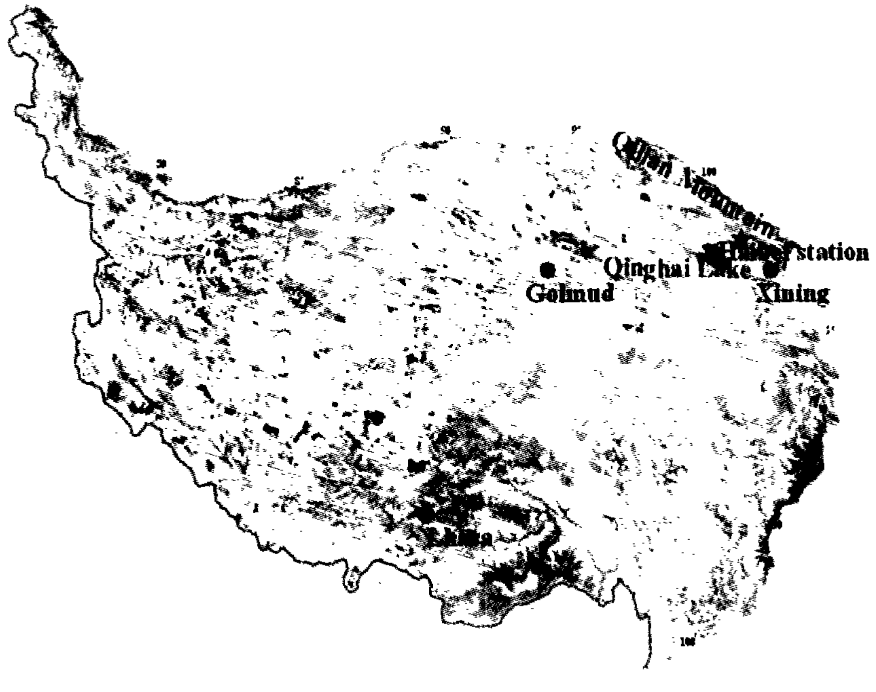

Figure 1 Geographical location of Haibei Research Station

as Mat Cry-Gelic Cambisols (Chinese Soil Taxonomy Research Group, 1995) with soil water content approximately 38%. Furthermore, soil surface layer well developed, no denudation or erosion was found.

Potentilla fruticosa scrub meadow was distributed on the shady slope of mountains, dominated by *Potentilla futicosa*, with herbages of *Kobresia capillifolia*, *Kobresia humilis*, *Saussurea superba* and *Potentilla nivea* interspersed among scrubs. The scrub and herbage accounted for approximately 55% and 40% of the total area, respectively, with 5% of bare patches interspersed among scrubs and herbages. This site is used as summer pasture, and the soil is classified as Mollic-Gryic Cambisols, with soil moisture approximately 40%. Moreover, a deep moss layer and plant residue can often be found on the soil surface of this site.

Kobresia tibetica meadow was distributed at the edge of swamps and lakes, dominated by *Kobresia tibetica*, with *Kobresia humilis*, *Blysmus sinocompressus*, *Carex atrofusca*, *Carex moorcroftii*, and *Pedicularis longiflora* intermingled, and vegetation coverage of 95%. This site is used as winter pasture, and the soil is characterized by high organic carbon and water content, classified as Fibric-Orthic Histosols.

2.3 Treatments

FC, FJ and FL treatments were set in *Kobresia humilis* meadow, meanwhile, GG, GC and GL treatments were set in *Potentilla fruticosa* scrub meadow, in addition, LC treatment was set in *Kobresia tibetica* meadow. FC, GG, GC and LC treatments mean that sample plots were kept natural vegetation coverage, while FJ means that aboveground parts of plants in the sample plot were cut off completely; FL and GL treatments mean that belowground parts of roots in sample plots were excluded. Among the treatments, GG and GC represented scrub cover, and herbage cover dispersed among scrubs, respectively. Moreover, based on the actual condition of different types of meadows, triplicates were set in each treatment according to the principles that average the plant growth regime as well as its coverage, so that the estimate of contribution to atmospheric carbon dioxide from alpine meadow will be more precise.

2.4 Gas sampling and analysis

Carbon dioxide fluxes were measured using static chamber-GC techniques from 3 July to 4 September in 2003. The sample chamber was made of thin stainless steel, containing three parts, top-chamber, mid-chamber and base-chamber, respectively. The top chamber (50×50×50 cm) was equipped with two fans inside the top, a thermometer, gas sampling interface with F46 pipe inside the flank; both mid-chamber (50×50×50 cm) and base-chamber (50×50×50 cm) have a close groove on the upper end, when gas sampling, the grooves were filled with water to avoid gas exchange in and outside the chamber. The top and mid chambers were affixed with a 3 cm deep foam for heat insulation, in addition, with a white waterproof cloth coverage, to ensure that air temperature inside the chamber would not be influenced by the radiation. In this study, the mid-chamber was only used to sample gas in scrub plots due to its height. Before sampling, the base-chamber was inserted into soil, and during the period of experiments, the base-chamber was not taken out to avoid soil disturbance. Gas sampling used 100 ml syringe at intervals of 0 min, 10 min, 20 min and 30 min, and the sampling frequency was twice a week, within two-hours from 09:00 to 11:00. After sampling, gas analysis was conducted as soon as possible.

CO_2 concentration was determined by a Gas Chromatography (HP4890D, Agilent Co. Produced), which was equipped with a flame-ionization detector (FID), before detected by FID, CO_2 must pass a converter (Nickel catalyst), where it was converted into CH_4 reacted with H_2. For CO_2 determination, the GC had a stainless steel column (Packed with Porapak Q, 60-80 mesh, 2 m in length, 2 mm in diameter), FID temperature and column temperature were maintained at 230℃ and 55℃ respectively. N_2 acted as carrier gas with a flow rate of 30 ml/min.

2.5 Flux measurement

CO_2 flux was calculated using the following expression

$$F=\rho\frac{V}{A}\frac{P}{P_0}\frac{T_0}{T}\frac{dC_t}{dt}$$

where F means gas flux; V is air volume inside the chamber; A is the coverage area of the chamber; $\frac{dC_t}{dt}$ is the linear slope of concentration change during sampling period; ρ refers to the gas density under standard status; T_0 and P_0 are the absolute air temperature and pressure under standard status; T is absolute air temperature inside the chamber when sampling; and P is air pressure of sample plots. When value of F is positive, that means gas emission into atmosphere from soil or soil-plant system, while value of F is negative, that represents soil or soil-plant system absorb this gas from atmosphere.

2.6 Environmental factors measurements

When gas was sampling, air temperatures in and outside the chamber and soil temperature (0 cm, 5 cm) were measured simultaneously by a portable thermometer (JM624), and soil water content (0-10 cm) by moisture meter (TDR). Plant biomass was harvested at initiation and the end of the experiment, plant samples were oven dried at 65℃ and then weighed. At the end of the experiment, soil samples were collected from each plot at depths of 0-10 cm, 10-20 cm, 20-30 cm, and 30-40 cm, after air dried, grinded and sieved through a 2 mm mesh, for each soil sample, the following characteristics were measured: organic carbon by TOC-5000A (Japan), and total nitrogen by Kjeldahl (Bremner, 1965).

3 Results

3.1 Variation of CO_2 emissions from different treatments

3.1.1 Variation of CO_2 emissions from FC, FJ and FL treatments in *Kobresia humilis* meadow

During the grass exuberance period from 3 July to 4 September, CO_2 emissions from FC, FJ and FL treatments exhibited similar variation trend, with positive values (Figure 2). Except a few sampling days, CO_2 emission rate was in the order of FC>FJ>FL, with mean value of 672.09± 152.37 mgm^{-2}h^{-1}, 425.41 ±191.99 mgm^{-2}h^{-1}, and 280.36 ±174.83 mgm^{-2}h^{-1}, respectively. The maximum CO_2 emission rates for FC, FJ and FL treatments were 917.89 mgm^{-2}h^{-1}, 860.00 mgm^{-2}h^{-1} and 686.26 mgm^{-2}h^{-1}, respectively, emerged on 7, 26 and 28 August, respectively. However, maybe due to so high soil moisture caused by continuous rainfall, FJ and FL treatments had a minimum CO_2 emission rate on 30 July.

Kim *et al.* (1992) reported average daily CO_2 fluxes for a prairie site dominated by warm-season tallgrasses of 4.1 g CO_2 m^{-2}d^{-1} from May through October. Dagas *et al.* (1999) reported an annual CO_2 flux for a tallgrass prairie site of 0.7 g CO_2 m^{-2}d^{-1}. Consequently, we found that CO_2 emission rate of FC treatment which represented respiration of soil-plant system was much higher than that of values from Kim and Dagas. Meanwhile, soil respiration rate resulted from FJ treatment was similar with those of 441.72 mgm^{-2}h^{-1} from Cao *et al.* (2001), and 410 mg

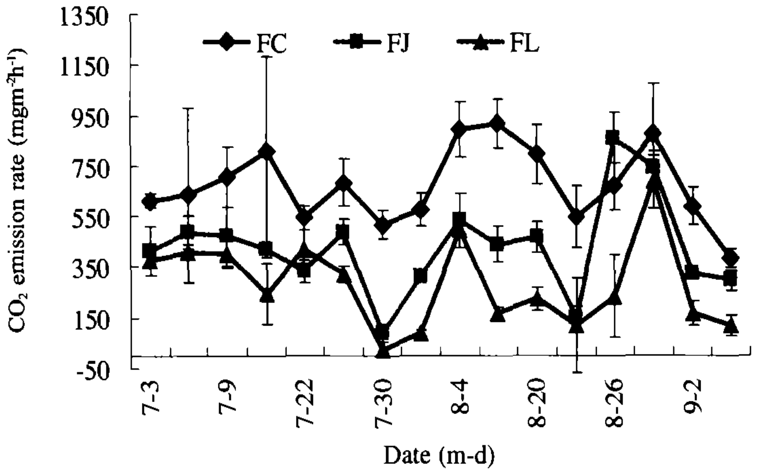

Figure 2 CO_2 emission rate under different treatments from *Kobresia humilis* meadow

CO_2 $m^{-2}h^{-1}$ from Svensson *et al.* (1975); higher than that of average daily emission rate of 0-6 $gm^{-2}d^{-1}$ during the growing season in grassland (Buyanovsky *et al.*, 1987; Norman *et al.*, 1992; Jensen *et al.*, 1996; Knapp *et al.*, 1998; Bremer *et al.*, 1998); in addition, Striegl *et al.* (1998) and Clark *et al.* (1967) reported fluxes measured on bare soils ranging from 94 to 300 mg CO_2 $m^{-2}h^{-1}$, our result from FL fell into this range.

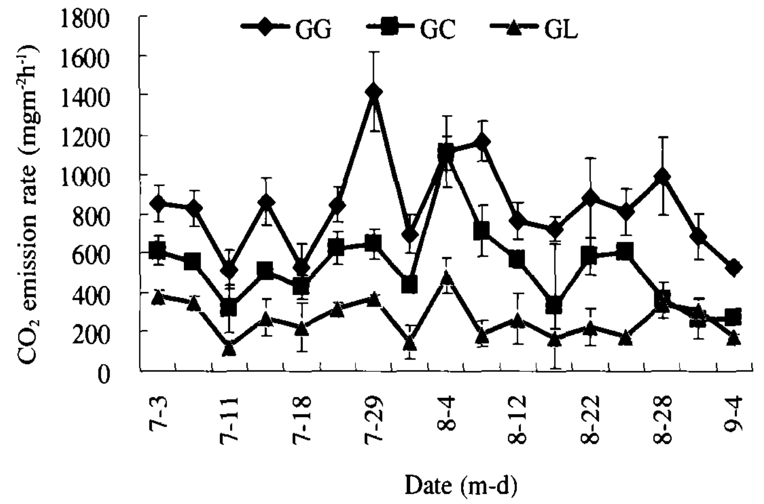

Figure 3 CO_2 emission rate under different treatments from scrub meadow

3.1.2 Variation of CO_2 emissions from GG, GC and GL treatments in *Potentilla fruticosa* scrub meadow Similar to variation of CO_2 emission rates from FC, FJ and FL treatments, GG, GC and GL treatments have the same variation trend of CO_2 emission rates, which was in the order of GG>GC>GL, with values of 838.95±237.02 $mgm^{-2}h^{-1}$, 528.48±205.67 $mgm^{-2}h^{-1}$ and 268.97± 99.72 $mgm^{-2}h^{-1}$, respectively (Figure 3). The maximum CO_2 emission rate for GG, GC and GL treatments were 1418.19 $mgm^{-2}h^{-1}$, 1112.38 $mgm^{-2}h^{-1}$ and 488.73 $mgm^{-2}h^{-1}$, respectively.

3.1.3 Variation of CO_2 emission from LC treatment in *Kobresia tibetica* meadow Based on data of August, the average CO_2 emission rate of soil-plant system from LC treatment was 659.20±94.83 $mgm^{-2}h^{-1}$, with the maximum of 769.15 $mgm^{-2}h^{-1}$ and the minimum of 530.12 $mgm^{-2}h^{-1}$. In contrast to CO_2 emission rates of soil-plant system in *Kobresia humilis* and *Potentilla fruticosa* scrub meadow, *Kobresia tibetica* meadow showed a relatively low variation.

3.2 Discrepancy of CO_2 emission rates of soil-plant system among different types of alpine meadows

During grass exuberance period, *Kobresia humilis* meadow, *Potentilla fruticosa* scrub meadow and *Kobresia tibetica* meadow differed greatly in average CO_2 emission rate of soil-plant system, in the order of GG > FC > LC > GC (Figure 4). We think that differences of vegetation type, plants growth status, soil moisture as well as temperature are responsible for this discrepancy of CO_2 emission rate.

3.2.1 Discrepancy of CO_2 emission rates among GG, GC and FC treatments In terms of GG and GC treatments, they were set in *Potentilla fruticosa* scrub meadow, both treatments had similar environmental conditions, such as radiation, soil moisture, soil organic carbon content, etc. Whereas, average CO_2 emission rate of soil-plant system from GG treatment was 838.95±237.02 $mgm^{-2}h^{-1}$, much higher than that of 528.48 ±205.67 $mgm^{-2}h^{-1}$ from GC treatment. Generally, respirations of soil-plant system were relevant to plant growth status, as well as height, coverage and biomass. In fact, in the whole scrub meadow, scrubs grew much better than herbages interspersed among them. Therefore, we concluded

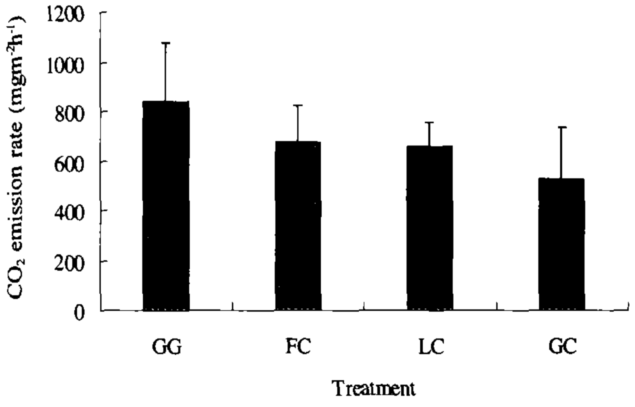

Figure 4 Average CO_2 emission rate from different treatments

Table 1 Organic carbon and total nitrogen content of different soil depth from three different types of meadows

Meadow type	Organic carbon content (%)				Total nitrogen content (%)			
	0-10	10-20	20-30	30-40	0-10	10-20	20-30	30-40
Potentilla fruticosa scrub medow	5.66	3.71	3.05	2.59	0.46	0.39	0.32	0.25
Kobresia humils meadow	5.49	3.29	2.67	1.88	0.50	0.33	0.27	0.21
Kobresia tibetica meadow	22.14	15.31	16.98	9.66	1.19	0.80	0.85	0.56

that different characteristics of both vegetations were responsible for the discrepancy of CO_2 emission rates of GG and GC treatments.

With respect to discrepancy of CO_2 emission rates from GG and FC treatments, due to their similar soil organic carbon content (Table 1) and some other environmental conditions, we attributed the discrepancy to total plant biomass differences. In August, total plant biomass were 3709.92 gm^{-2} for GG treatment and 3152.56 gm^{-2} for FC treatment, respectively.

3.2.2 Discrepancy of CO_2 emission rates among LC, GG and FC treatments Geng *et al.* (2001) reported that CO_2 flux showed significant correlation with the content of soil organic carbon and total nitrogen as well as the ratio of C/N in Xilin River Basin Steppe. In Haibei alpine region, these three meadow types were rich in soil organic carbon and nitrogen, which provided a substantial foundation for the production of CO_2. At 0-40 cm soil depth, organic carbon and total nitrogen were in the order of LC>GG>FC (Table 1). Moreover, through harvest of the plant biomass at the end of the experiment, the aboveground biomass were 598.0 gm^{-2} for LC, 424.3 gm^{-2} for FC and 375.1 gm^{-2} for GG, respectively. Therefore, theoretically, CO_2 emission rate of LC treatment would be much higher than those of the other treatments. However, the results from our measurement showed that CO_2 emission rates were in the order of GG>FC>LC. We surmised that two reasons would be responsible for this result, on the one hand, low soil temperature in alpine region resulted in low activities of microbes as well as its low decomposition rate of organic matter. Bao *et al.* (1993) indicated that microbes in alpine soils showed optimum activities at 35℃, however, during the grass exuberance period of this experiment, the soil temperature (0-30 cm) was far from that optimum temperature of 35℃. On the other hand, excessive soil moisture in LC treatment maybe inhibit the CO_2 emission. During the process of observation, soil moisture

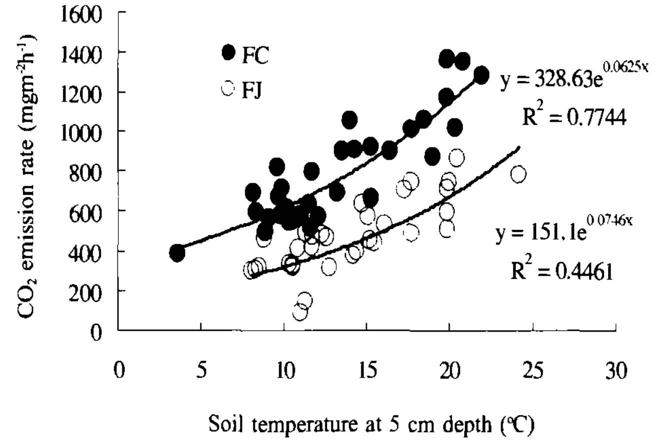

Figure 5 Relationship between temperature and CO_2 emission rate from FC and FJ treatments

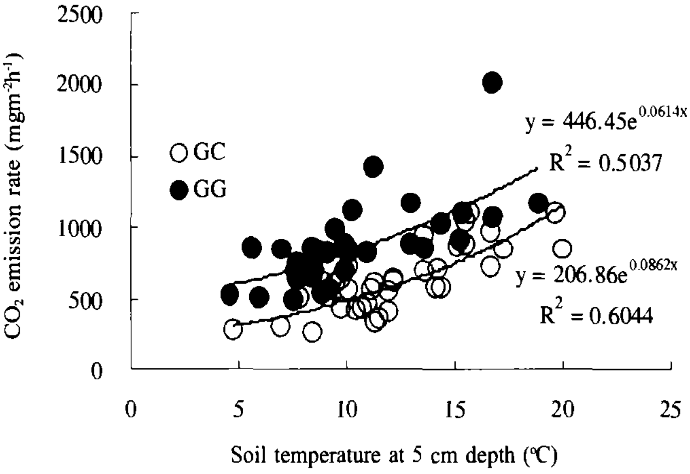

Figure 6 Relationship between temperature and CO_2 emission rate from GC and GG treatments

in GG and FC treatments ranged from 32.4% to 46.2% , for LC treatment, soil moisture from 63% to 70%. Excessive soil water filled in soil porosity, so that not only reduced soil CO_2 release into atmosphere, but increased the soil CO_2 substrate concentration, as high soil CO_2 substrate concentration not only had an inhibitory effect on microbial respiration in soil, but inhibited roots respiration significantly (Harris *et al.*, 1957a, b; Macfadyen, 1973; Koizumih, 1991).

Table 2 Simulated equation derived from temperature and CO_2 emission rate, as well as value of Q_{10}

Treatment	Exponential equation	Value of R^2	Value of Q_{10}
FC	$y = 328.63e^{0.0625x}$	0.7744	1.87
FJ	$y = 151.1e^{0.0746x}$	0.4461	2.11
GG	$y = 446.45e^{0.0614x}$	0.5037	1.85
GC	$y = 206.86e^{0.0862x}$	0.6044	2.37

3.3 Effect on CO_2 emission rate from soil temperature and moisture

Among environmental factors, soil temperature and moisture were considered to be the main factors that influenced CO_2 emission. Rye *et al.* (2002) indicated both respirations of plant roots and soil microbes were sensitive to variation of soil temperature. With respect to soil moisture, when it is sufficient, soil respiration was positively correlated with soil temperature (Mathes *et al.*, 1969; Peterson *et al.*, 1975; Witkamp, 1985); whereas, in arid or semiarid area, soil respiration was influenced by the interaction of soil moisture and temperature. A research conducted in a tallgrass prairie in America showed that variation of soil temperature accounted for 46% of soil CO_2-C flux variance, and variation of soil water content accounted for 26% of the flux variance, while both factors combined into one term that explained about 52% of the flux variance (Mielnick *et al.*, 2000). During the sample days, soil temperature did not reach the optimum temperature for microbial activities, however, due to its long-term adaptation to alpine and humid environment, a small increase of soil temperature will markedly enhance the soil microbial activities. Statistics showed that correlations between CO_2 emission rate from FC, FJ, GG and GC treatments and temperature at 5 cm soil depth were significant at 0.01 level, furthermore, among them, exponential relationships were found (Figures 5 and 6). Moreover, values of Q10 were calculated through the simulated equation based on the exponential relationships (Table 2). As showed in the table, values of Q10 were in the order of GC > FJ > FC > GG, which implied that an identical increase in soil temperature would result in different variation rates of CO_2 emissions, in the order of GC > FJ > FC > GG. Additionally, most research indicated that value of Q10 involved in soil respiration ranged from 2.0 to 2.4. Our result showed that value of Q10 (2.11) from FJ treatment fell into this range.

4 Discussion

4.1 Representative meanings of CO_2 emission from different treatments

Generally, CO_2 emission of soil-plant system could be divided into two parts, i.e., respiration of aboveground plants as well as soil respiration of belowground parts. Furthermore, strictly speaking, soil respiration was the sum of heterotrophic and autotrophic respirations in soil, including three biological processes, which involved soil microbial respiration, live roots respiration and soil fauna respiration; besides, one abiological process was included, that is chemical oxidation of carbon-contained substances. However, soil microbial respiration and root respiration could represent general soil respiration. In our experimental design, CO_2 emissions from different treatments could represent respirations of different parts of ecosystem, in which, respirations of soil-plant system could be obtained from GG, GC, FC and LC treatments, and soil respiration could be obtained from FJ treatment, moreover, FL and GL treatments could be viewed as soil microbial respiration. In addition, comparison of results from different treatments could distinguish and quantify the contribution of each part in the total respirations of soil-plant system, such as aboveground plant parts, belowground roots parts.

Results from FC, FJ and FL treatments in *Kobresia humilis* meadow showed that respiration rate of soil-plant system was 672.09±152.37 $mgm^{-2}h^{-1}$; soil respiration rate was 425.41±191.99 $mgm^{-2}h^{-1}$; and respiration rate of soil with roots exclusion was 280.36 ±174.83 $mgm^{-2}h^{-1}$. Comparison of results from FC and FJ indicated that aboveground parts and belowground parts accounted for 37% and 63% of the total respiration of soil-plant system, respectively, thus, soil respiration contributed greatly to the total system respiration. Due to the comparison of results from FJ and FL, root respiration from *Kobresia humilis* meadow approximated 145 $mgm^{-2}h^{-1}$ of CO_2 contributing 34% to soil respiration, which was similar to the results ranged from 10% to 60% (Wiant *et al.*, 1967; Kucera *et al.*, 1971; Edwards *et al.*, 1975; Chapman *et al.*, 1975; Silvola *et al.*, 1992).

If respiration of soil-plant system was viewed as the sum of heterotrophic and autotrophic respirations of the system, through comparisons of FC and FL, GG and GL, GC and GL, the proportion of heterotrophic and autotrophic respiration to each system respiration could be obtained. In *Kobresia humilis* meadow, heterotrophic and autotrophic respiration accounted for 42% and 58% of the total soil-plant system respiration, respectively, whereas, in *Potentilla fruticosa* scrub meadow, heterotrophic and autotrophic respiration accounted for 32% and 68% of the total system respiration from GG; 49% and 51% from GC. We can conclude that the differences of total biomass were responsible for the discrepancy of the proportion of heterotrophic and autotrophic respiration to each system respiration.

4.2 Contribution to atmospheric CO_2 from alpine meadow

Temperate-region natural grassland ecosystems have extensive fibrous root systems and may be important C sinks for balancing the global C budget (Gifford, 1994; Schimel, 1995; Keeling *et al.*, 1996; Fan *et al.*, 1998). In grasslands, belowground biomass was reported to be 5 to 10 times higher than aboveground biomass in general (Iwaki, 1973). Similarly, in Haibei alpine meadow, the ratio of aboveground to belowground biomass ranged from 6 to 8 (Wang *et al.*, 1988). In order to estimate NEP, we used the following expression:

$$NEP = GPP - RA - RH$$

where NEP is net ecosystem production, i.e., net carbon fixation of ecosystem; GPP is gross primary production; RA and RH are autotrophic and heterotrophic respiration, also viewed as respiration of soil-plant system. During the sampling period, we harvested plant biomass on 30 June and 28 August (Table 3). Additionally, according to literature, respirations of soil-plant system from 09:00 to 11:00 were used to represent average daily respiration rate. Based on the total biomass and respiration rates of soil-plant system from FC and GG treatments, we estimated the NEP of *Kobresia humilis* meadow and *Potentilla fruticosa* scrub meadow during grass exuberance period. Resulted showed that *Kobresia humilis* meadow and *Potentilla fruticosa* scrub meadow had a net carbon fixation of 111.11 gm^{-2} and 243.89 gm^{-2}, respectively. Both meadows served as carbon sink for atmospheric CO_2 during grass exuberance period.

Table 3 Biomass of different types of meadows during grass exuberance period (gm^{-2})

Meadow type	30 June		28 August		Total net biomass
	Above-ground biomass	Below-ground biomass	Above-ground biomass	Below-ground biomass	
Potentilla fruticosa scrub meadow	111.28	2156.61	375.06	3334.86	1442.03
Kobresia humils meadow	95.89	2117.54	424.32	2728.24	939.13

5 Conclusions

(1) Mean CO_2 emission rates from various treatments were 672.09±152.37 $mgm^{-2}h^{-1}$ for FC; 425.41±191.99 $mgm^{-2}h^{-1}$ for FJ; 280.36±174.83 $mgm^{-2}h^{-1}$ for FL; 838.95±237.02 $mgm^{-2}h^{-1}$ for GG;

528.48±205.67 $mgm^{-2}h^{-1}$ for GC; 268.97±99.72 $mgm^{-2}h^{-1}$ for GL; and 659.20±94.83 $mgm^{-2}h^{-1}$ for LC, respectively.

(2) *Kobresia humilis* meadow, *Potentilla fruticosa* scrub meadow and *Kobresia tibetica* meadow differed greatly in average CO_2 emission rate of soil-plant system, in the order of GG > FC > LC > GC.

(3) A significant correlation was found between CO_2 emission rate from FC, FJ, GG and GC treatments and temperature at 5 cm soil depth, and values of Q10 were in the order of GC > FJ > FC > GG.

(4) In *Kobresia humilis* meadow, heterotrophic and autotrophic respiration accounted for 42% and 58% of the total soil-plant system respiration, respectively, whereas, in *Potentilla fruticosa* scrub meadow, heterotrophic and autotrophic respiration accounted for 32% and 68% of total system respiration from GG; 49% and 51% from GC. In addition, root respiration from *Kobresia humilis* meadow approximated 145 CO_2 $mgm^{-2}h^{-1}$, contributing 34% to soil respiration.

(5) During the experiment period, *Kobresia humilis* meadow and *Potentilla fruticosa* scrub meadow had a net carbon fixation of 111.11 gm^{-2} and 243.89 gm^{-2}, respectively.

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