

# Relations between Carbon Dioxide Fluxes and Environmental Factors of *Kobresia humilis* Meadows and *Potentilla fruticosa* Meadows

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**Abstract** Carbon dioxide fluxes of *Kobresia humilis* and *Potentilla fruticosa* shrub meadows, two typical ecosystems in the Qinghai-Tibet Plateau, were measured by eddy covariance technology and the data collected in August 2003 were employed to analyze the relations between carbon dioxide fluxes and environmental factors of the ecosystems. August is the time when the two ecosystems reach their peak leaf area indexes and stay stable, and also the period when the net carbon absorptions of *Kobresia humilis* and *Potentilla fruticosa* shrub meadows reach  $56.2 \text{ g C} \cdot \text{m}^{-2}$  and  $32.6 \text{ g C} \cdot \text{m}^{-2}$ , with their highest daily carbon dioxide absorptions standing at  $12.7 \mu\text{mol} \cdot \text{m}^{-2} \cdot \text{s}^{-1}$  and  $9.3 \mu\text{mol} \cdot \text{m}^{-2} \cdot \text{s}^{-1}$ , and their highest carbon discharges at  $5.1 \mu\text{mol} \cdot \text{m}^{-2} \cdot \text{s}^{-1}$  and  $5.7 \mu\text{mol} \cdot \text{m}^{-2} \cdot \text{s}^{-1}$ , respectively. At the same photosynthetic photo flux densities (PPFD), the carbon dioxide-uptake rate of the *Kobresia humilis* meadow is higher than that of the *Potentilla fruticosa* shrub meadow; where the PPFD are higher than  $1,200 \mu\text{mol} \cdot \text{m}^{-2} \cdot \text{s}^{-1}$ . The carbon dioxide uptake rates of the two ecosystems declined as air temperature increased, but the carbon dioxide uptake rate of the *Kobresia humilis* meadow decreased more quickly ( $-0.086$ ) than that of the *Potentilla fruticosa* shrub meadow ( $-0.016$ ). Soil moistures exert influence on the soil respirations and this varies with the vegetation type. The daily carbon dioxide absorptions of the ecosystems increase with increased diurnal temperature differences and higher diurnal temperature differences result in higher carbon dioxide exchanges. There

exists a negative correlation between the vegetation albedos and the carbon dioxide fluxes.

**Keywords** alpine meadow, vegetation type, net carbon dioxide exchange, eddy covariance technology

## 1 Introduction

The meadow ecosystems of the Qinghai-Tibet Plateau is distributed largely over an elevation of 3,000 m, where one third of the area is occupied by alpine meadows and alpine scrubland meadows, which form the vastest meadow ecosystem of the Qinghai-Tibet Plateau. Meadows are important components of the terrestrial ecosystem, with one third of the total land area, and play a basic role in global carbon recycling (Hall and Scurlock, 1991; Scurlock and Hall, 1998). Scurlock and Hall (1998) reported that the annual carbon absorption of temperate and tropical grasslands is approximately 0.5 Pg, which is comparable with the total  $\text{CO}_2$  content of the air. However, meadow ecosystem investigations are so far mainly focused on the low altitude region, while research on the carbon income and expenses of higher altitude meadow ecosystems are rare, especially in the Qinghai-Tibet Plateau. This status quo raised the significance of research on the carbon recycling of high altitude ecosystems both within the Qinghai-Tibet Plateau and the world's high altitude meadow ecosystems.

The soil of the alpine meadow and the alpine scrubland meadow was formed after the uplifting of the Qinghai-Tibet Plateau, with the pattern of cambisols engendered during the long term cold climate (Li et al., 2001a). Due to the low

temperature and high water contents of the soil, the organic residues in ecosystems with this kind of soil have a slow decomposition rate (Zhao and Zhou, 1999), and subsequently with high organic contents in the soil, the decomposition process will be accelerated by the calefacient globular climate. It was indicated recently that the temperature of the Qinghai-Tibet Plateau is continuously increasing, resulting in the degradation of the seasonal frozen regions and permafrost (Fun et al., 2001), during which the moisture and temperature changes will undoubtedly affect the dynamics of the soil organic materials as well as other greenhouse gases. However, little is known about the probable variation that will occur to the soil of the meadow ecosystem in this region.

The temperature of the Qinghai-Tibet Plateau is low at night, and even decline to minus in the warmest July morning, while the diurnal solar radiation is strong with a high temperature. This kind of environment is propitious for diurnal photosynthesis and carbon absorption, but adverse for carbon decomposition during nights, which endows the ecosystem with a higher capacity of carbon amassment (Zhao et al., 2005a; Zhao et al., 2005b). The results of Gu et al. (2003) have primarily proved that large diurnal temperature differences contribute to the carbon amassment of alpine meadows (Zhao et al., 2005a). However, it still remains unclear whether other plateau ecosystems experience the same effect.

Here we have used eddy covariance technology to measure the CO<sub>2</sub> fluxes of *Kobresia humilis* and *Potentilla fruticosa* shrub meadows, within a long-term period. The steady data in August, with its highest leaf area index (LAI), was chosen in this paper to compare the carbon recycling process and environmental effects between the two typical ecosystems in the Qinghai-Tibet Plateau.

## 2 Materials and methods

### 2.1 Research sites and profile

This study is carried out in August 2003 at the Haibei Alpine Meadow Ecosystem Research Station of the Chinese Academy of Science, which is in the Menyuan Hui Nationality autonomous county of the Tibetan autonomous prefecture in Haibei of Qinghai Province, the northeast corner of the Qinghai-Tibet Plateau, also localizes to the western part of the Datong river valley in the south foot of the eastern part of the Qilian mountains' north branch. The geographical location is 37°29'–37°45'N, 101°12'–101°23'E, with a vast terrain and an altitude of 3,200–3,600 m. This region is in the

hinterland of Asia, with a typical plateau continental climate, and weak southeast and southwest monsoons. Because of the altitude, the air temperature is extremely low. There is no apparent seasonal difference according to the seasonal criteria, with the separation of only cold and warm seasons, as well as dry-wet seasons. The atmosphere is thin with high diaphaneity. No absolute frost period exists, and the relative frost periods last about 20 d. All climate phenomena during winter, including frost, icing and snowfall (sleet) etc. can be seen in the hottest month of July. The cold season exhibits chilliness, desiccation and is long-lasting, while the warm season has a short cool and wet climate.

### 2.2 Measurement and data processing

Shoot and root biomass, leaf area index and soil organic matter, etc. were measured on August 30. Reaping method was used to obtain shoot biomass. The shoot part of six randomly selected samples of 50 cm × 50 cm within the two different kinds of vegetations were cut close to the ground with a scissor. From these six samples, three secondary samples of 25 cm × 25 cm were randomly selected, with three perpendicular levels of 0–10 cm, 10–20 cm and 20–40 cm. The samples were taken out with spade and knife, and the root and sack duly screened out. They were then washed clean in the river. The collected samples were dried in a constant temperature oven at 65°C until they achieved stable weight and weighed with g·m<sup>-2</sup>. Leaf area index was measured with a Leaf Area Meter (Li-3100, Li-cor Inc., Nebraska, USA). Soil organic matters were set out with Potassium Dichromate Oxidation-Outer Heating technology in the testing center of the Northwest Plateau Institute of Biology, Chinese Academy of Sciences. The soil samples were collected by layers when picking up the root biomass samples. The above data were analyzed and shown in Table 1, also with the investigation results of the vegetation community around the observation station.

CO<sub>2</sub> flux observation towers (eddy covariance observation system) were set up with planar hypsography on an open landform of *Kobresia humilis* and *Potentilla fruticosa* shrub meadows with geographical coordinates of 37°29'N, 101°23'E at an elevation of 3,180 m and 37°29'N, 101°23'E at an elevation of 3,250 m, respectively. The heartland had enough "storm waves" (Fig. 1). The observation system is 220 m above the ground, with a CSAT type ultrasonic anemometer (CSI) and a LI-7500CO<sub>2</sub>/H<sub>2</sub>O infrared analyzer (LI-COR, Inc.). Other observation parameters are shown in Table 2.

**Table 1** Vegetation character and correlation element

Type	Dominant species	Plant height /cm	Soil type	Above-ground biomass / (g·m <sup>-2</sup> )	Above-ground biomass / (g·m <sup>-2</sup> )	Leaf area index / (m <sup>2</sup> ·m <sup>-2</sup> )	Soil organic matter/%		
							0–10 cm	10–20 cm	20–40 cm
Alpine shrub	<i>Potentilla fruticosa</i>	60–70	Mol-Cryic Cambisols	278.29	339.59	2.6	7.54	5.71	3.68
Alpine meadow	<i>Kobresia humilis</i>	25–30	Organic-Cryicgleysols	1 467.56	1 276.06	2.8	5.19	5.01	3.04

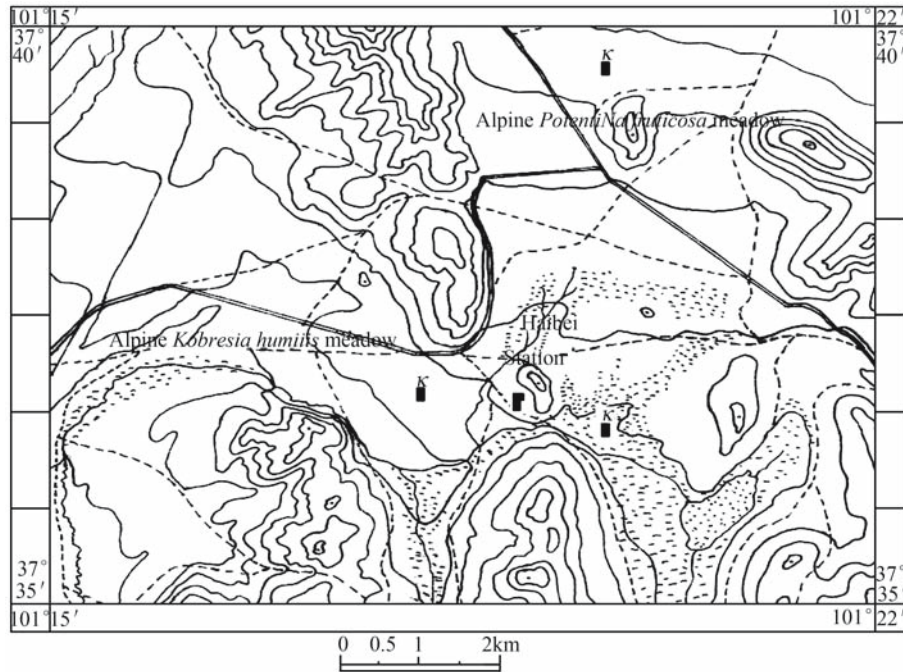


Fig. 1 Relief map of the flux tower

Table 2 Measurements of elements and instruments used

Meteorological elements	Instruments or sensor	Location /cm
CO <sub>2</sub> and H <sub>2</sub> O concentrations	Li-7500, Li-Cor, USA	220
Vertical wind and air temperature	CSAT3, CSI, USA	220
Net radiation	CNR-1, Kipp and Zonen, Netherlands	150
Photosynthetic photon flux density	Li-190SB, Li-Cor, USA	150
Wind speed and direction	014A and 034A-L, CSI, USA	110,220
Air temperature and humidity	HUMP45C, CSI, USA	110,220
Soil surface temperature	107, Csi, USA	0
Soil heat flux	HFT-3, CSI, USA	-2
Soil temperature	105T, CSI, USA	-2, -5, -10, -20, -30, -40, -50, -60, -70
Soil water content	TDR, CS615, CSI, USA	-5, -20, -50

Data were collected from August 1 to 31. When there is rainfall or dew in the morning, some beads often exist on the detector of the CO<sub>2</sub>/H<sub>2</sub>O analyzer, which has some impact on the fluxes. This kind of data as well as some apparent “wild point” should be deleted while setting up statistics and the fluxes values should be amended with the Webb-Pearman-Leuning (WPL) correction (Webb et al., 1980). While amending, use formula (1) to repair the lost flux data when  $U_* \leq 0.2 \text{ m} \cdot \text{s}^{-1}$  at night, use formula (2) to compensate for the lost flux data at diurnal time.

$$F_c = R_{10} Q_{10}^{(T_s - 10)/10} \quad (1)$$

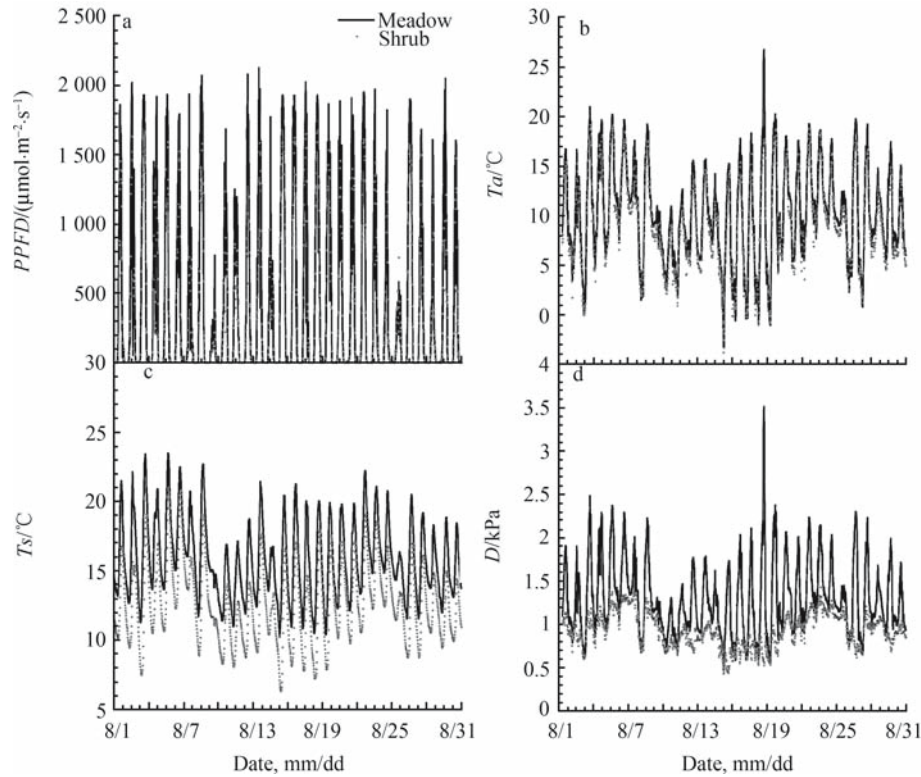
$$F_c = \frac{a_1 \cdot \text{PPFD}}{a_2 + \text{PPFD}} + a_0 \quad (2)$$

In formula (1),  $R_{10}$  represents the system respiration at 10°C;  $Q_{10}$  indicates the system respiration when increasing 10°C; In formula (2),  $a_0$ ,  $a_1$  and  $a_2$  are fitting constants.

### 3 Results and analysis

#### 3.1 Variation characteristics of photosynthetic photo flux densities (PPFD), air temperature (Ta), soil temperature (Ts) of 5 cm and actual vapor pressure (D)

Because of the high altitude, transparent atmosphere and strong solar radiation of the experimental area, the PPFD is subsequently high (Fig. 2(b)), with the average value reaching  $27.45 \text{ mol} \cdot \text{m}^{-2} \cdot \text{d}^{-1}$  and the highest value of the 2 at  $330 \text{ mol} \cdot \text{m}^{-2} \cdot \text{s}^{-1}$ . The Ta is low: the average temperature of the *Kobresia humilis* and *Potentilla fruticosa* shrub meadow vegetations in August are  $10.04^\circ\text{C}$  and  $9.96^\circ\text{C}$ , respectively. The diurnal difference of the air temperature is dramatic, with the lowest temperature descending to  $-3^\circ\text{C}$ , and the highest point reaching  $15^\circ\text{C}$ . This acute variation of air temperature occurs daily, and most especially during the month of August when the Qinghai-Tibet Plateau experiences



**Fig. 2** Change in (a) photosynthetic photon flux density (PPFD); (b) air temperature; (c) soil temperature at a depth of 5 cm; and (d) air vapor pressure deficit ( $D$ )

a transition from warm to cold season. For instance, the average air temperature of the *Kobresia humilis* meadow is between 3.79–27.53°C, and that of the *Potentilla fruticosa* shrub meadow is between 3.87–19.48°C (Fig. 2). However, at the same time, the  $T_s$  level is relatively stable with an average difference value of 7.39 and 6.76°C, and an average value of 15.75°C and 12.46°C, respectively, for the two vegetation types (Fig. 2). The variation range is unapparent (Fig. 2), 0.48–3.51 kPa and 0.43–1.43 kPa, respectively for *Kobresia humilis* and *Potentilla fruticosa* meadows.

From Fig. 2(b)–(d), it is indicated that the altitude of the *Potentilla fruticosa* shrub meadow is higher than that of the *Kobresia humilis* meadow. With different vegetation (Fig. 2), soil types, and distinct soil structure distribution, the  $T_a$ ,  $T_s$ , and  $D$  values of the *Kobresia humilis* meadow is significantly higher than that of the *Potentilla fruticosa* shrub meadow ( $T_a$ :  $t = 7.29$ ,  $df = 3,140$ ,  $P < 0.0001$ ;  $T_s$ :  $t = 36.65$ ,  $df = 3,010$ ,  $P < 0.0001$ ;  $D$ :  $t = 39.55$ ,  $df = 4,436$ ,  $P < 0.0001$ ).

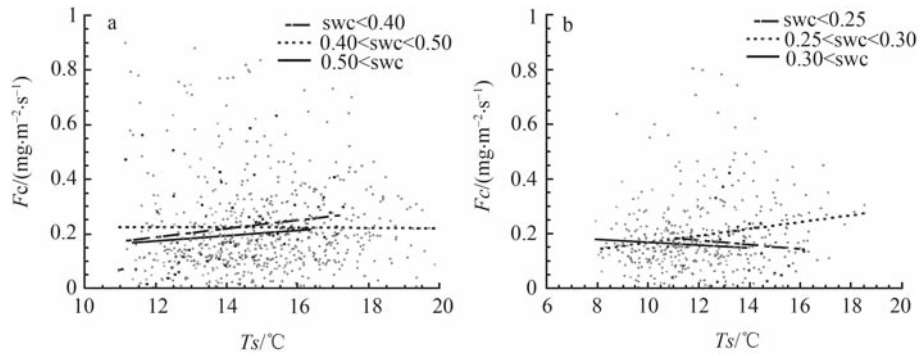
### 3.2 The effects of soil temperature and moisture on net carbon dioxide exchange

The moisture content of 5 cm soil was first divided into three interzones during the observation period when detecting the influence of moisture proportion on the  $\text{CO}_2$  discharges. Due to the moisture content difference of the meadows, the *Kobresia humilis* meadow was divided into three interzones of <0.40, 0.40–0.50 and >0.50, and the *Potentilla fruticosa* shrub meadow of <0.25, 0.25–0.30 and >0.30. The relationship between  $\text{CO}_2$  fluxes and soil temperature was analyzed and shown in Table 3, Fig. 3.

It can be seen from Table 3 and Fig. 4 that the relationship of respiration capacity and  $\text{CO}_2$  fluxes with soil temperature depends both on moisture content and vegetation type. In the *Kobresia humilis* meadow area, when soil moisture content is <0.40 or >0.50,  $\text{CO}_2$  flux increases with rising of soil temperature; when soil moisture content is between 0.40–0.50,

**Table 3** Relationship between nighttime  $\text{CO}_2$  flux density ( $F_c$ ) and nighttime 5 cm soil temperature ( $T_s$ )

Type	Soil water content, $(\text{m}^3 \cdot \text{m}^{-3})$	$R_{10}/[\text{mg} \cdot (10^\circ\text{C})^{-1}]$	$Q_{10}/[\text{mg} \cdot (10^\circ\text{C})^{-1}]$	Asymp. Sig.
Alpine meadow	< 0.40	0.16	2.00	$F_{(2,63)} = 90.03^{**}$
	0.40–0.50	0.22	0.98	$F_{(2,519)} = 455.54^{**}$
	0.50 <	0.16	1.55	$F_{(2,141)} = 137.11^{**}$
Shrub meadow	< 0.25	0.18	0.70	$F_{(2,23)} = 25.76^{**}$
	0.25–0.30	0.17	1.85	$F_{(2,355)} = 374.75^{**}$
	0.30 <	0.18	0.75	$F_{(2,59)} = 82.99^{**}$



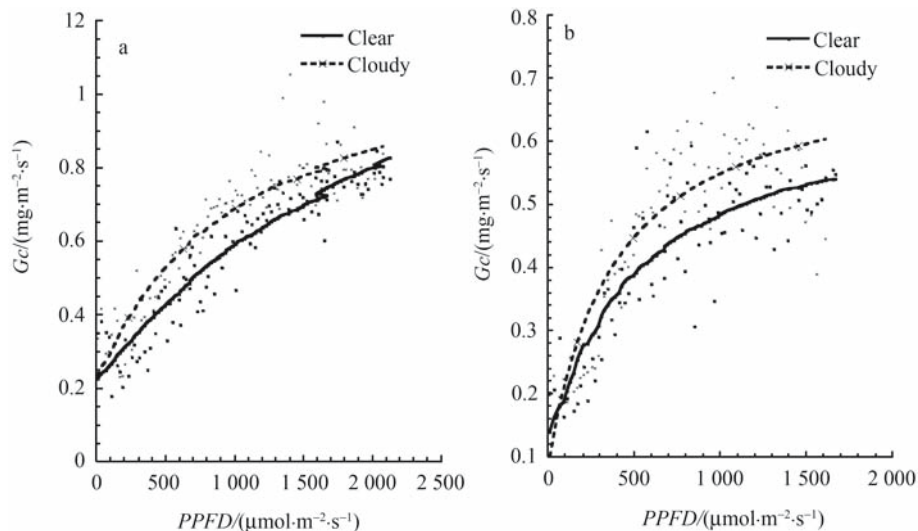
**Fig. 3** Relationship between nighttime CO<sub>2</sub> flux density ( $F_c$ ) and nighttime 5 cm soil temperature ( $T_s$ ) for (a) alpine meadow and (b) shrub under 3 levels of soil moisture (SWC)

CO<sub>2</sub> flux does not change significantly with the variation of soil temperature (Table 3). It is the opposite situation in the *Potentilla fruticosa* shrub meadow: when soil moisture content is <0.25 or >0.30, CO<sub>2</sub> flux decrease with the increase of soil temperature; when soil moisture content is between 0.25–0.30, they are directly proportional. From Table 3, we can also see that under different soil moisture conditions, the  $Q_{10}$  values of the two vegetations are distinct. For the *Kobresia humilis* meadow, the  $Q_{10}$  values is higher when moisture content is <0.40 or >0.50 than that of between 0.40–0.50, while for the *Potentilla fruticosa* shrub meadow, the  $Q_{10}$  values are lower when moisture content is, <0.25 or >0.30 than that of between 0.25–0.30. Whether there is lower or higher moisture content in the *Potentilla fruticosa* shrub meadow, the  $Q_{10}$  values stay relatively stable.

### 3.3 Relationships between PPRD and CO<sub>2</sub> exchanges

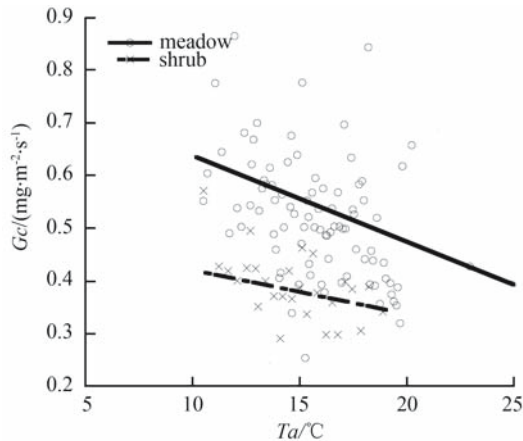
In order to test the effects of PPF<sub>D</sub> on the CO<sub>2</sub> exchanges, we analyzed the relationship of PPF<sub>D</sub> and total carbon absorption ( $G_c$ ) under different weather conditions.  $G_c$  is obtained

with the sum of CO<sub>2</sub> flux and predicted ecosystem discharges ( $Re$ ), namely:  $G_c = F_c + Re$ , where  $Re$  is acquired from formula (1). The relationship of PPF<sub>D</sub> and total carbon absorption ( $G_c$ ) under different weather conditions are shown in Fig. 4. It is indicated that under different weather conditions, the two are in direct proportion. With lower PPF<sub>D</sub>,  $G_c$  increases dramatically with an increase in PPF<sub>D</sub>, while it is the opposite when PPF<sub>D</sub> has a higher value, with a PPF<sub>D</sub> independent manner. With the same PPF<sub>D</sub> conditions, the  $G_c$  of the *Kobresia humilis* meadow ( $26.41 \text{ g} \cdot \text{m}^{-2} \cdot \text{day}^{-1}$ ) is higher than that of the *Potentilla fruticosa* shrub meadow ( $20.02 \text{ g} \cdot \text{m}^{-2} \cdot \text{day}^{-1}$ ) ( $t = 14.84, df = 1,491, P < 0.001$ ). The average daily  $G_c$  on a non-cloudy day is significantly higher than that of a cloudy day, although it depends on the vegetation. For the *Kobresia humilis* meadow,  $G_c$  ( $26.41 \text{ g} \cdot \text{m}^{-2} \cdot \text{day}^{-1}$ ), compared with  $G_c$  ( $25.28 \text{ g} \cdot \text{m}^{-2} \cdot \text{day}^{-1}$ ) ( $t = 2.10, df = 1,303, P < 0.05$ ); While for the *Potentilla fruticosa* shrub meadow,  $G_c$  ( $20.61 \text{ g} \cdot \text{m}^{-2} \cdot \text{day}^{-1}$ ) versus  $G_c$  ( $19.39 \text{ g} \cdot \text{m}^{-2} \cdot \text{day}^{-1}$ ) ( $t = -2.15, df = 560, P < 0.05$ ). When PPF<sub>D</sub> >  $1,200 \mu\text{mol}/\text{m}^2 \cdot \text{s}^{-1}$ , net CO<sub>2</sub> exchanges ( $F_c$ ) decreases dramatically with the temperature growth from



**Fig. 4** Correlation between gross CO<sub>2</sub> uptake ( $G_c$ ) and photosynthetic photon flux density (PPFD) for (a) alpine meadow and (b) shrub under two typical weather conditions: clear days and cloudy days

10–20°C (Fig. 5). Moreover, the decreasing rate of the *Kobresia humilis* meadow is sharp as compared with that of the *Potentilla fruticosa* shrub meadow. These results proved that at a higher PPFD level, temperature has a higher impact on respiration than PPFD, and different vegetations have distinct sensitivity to the effectors.



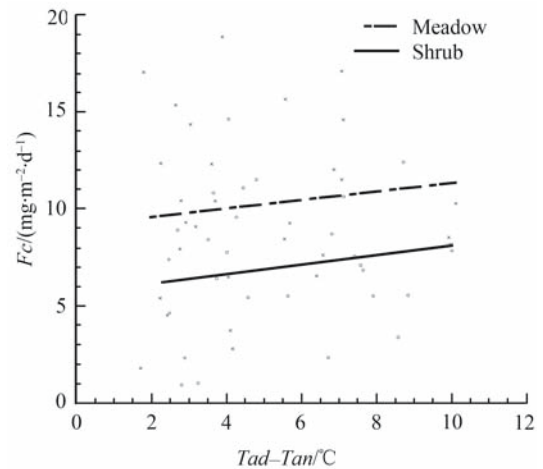
**Fig. 5** Correlation between air temperature ( $T_a$ ) and the net ecosystem exchange of  $\text{CO}_2$  ( $F_c$ ) when  $\text{PPFD} > 1,200 \mu\text{mol}/\text{m}^2\text{s}$ . The linear relations are given for meadow  $F_c = -0.086T_a + 0.5078$ ,  $F_{(1,131)} = 9.92$ ,  $P < 0.001$ , and for shrub  $F_c = -0.0163T_a + 0.8010$ ,  $F_{(1,439)} = 64.30$ ,  $P < 0.001$

### 3.4 Relations of diurnal temperature difference and $\text{CO}_2$ exchanges

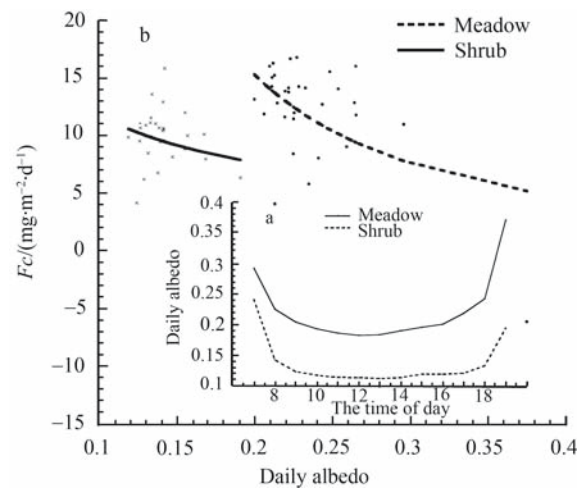
Because alpine meadow plants have cold resistant capacities, they can grow normally and have photosynthetic processes even when environmental temperature is lower than  $-7^\circ\text{C}$ . The average diurnal temperature (from sunrise to sunset) of the *Kobresia humilis* and the *Potentilla fruticosa* shrub meadows in August are relatively low, about  $11.43^\circ\text{C}$  and  $11.02^\circ\text{C}$ , respectively, while the temperature of the two vegetations at night are  $7.07^\circ\text{C}$  and  $6.07^\circ\text{C}$ , respectively. The diurnal temperature difference can reach  $11^\circ\text{C}$ . In order to make clear the effects of temperature difference on net  $\text{CO}_2$  exchanges of the ecosystem, the relationship between the two is shown in Fig. 6. Although the relationship between them is not significant, net  $\text{CO}_2$  exchanges increases along with the expansion of diurnal temperature difference.

### 3.5 Relations of vegetation albedos ( $A$ ) and net $\text{CO}_2$ exchanges ( $F_c$ )

Figure 7 shows the relationship of  $A$  and  $F_c$ , which indicates that the albedos of the two vegetations vary with the same trend that  $A$  value is high, both in the morning and night, and low around noon time, which shows a “U” type distribution. However, the  $A$  value of the *Kobresia humilis* meadow is higher than that of the *Potentilla fruticosa* shrub meadow.  $F_c$  shows a negative correlation with vegetation albedos and



**Fig. 6** Relationship between net daily  $\text{CO}_2$  exchange ( $F_c$ ) and day/night temperature difference ( $T_{ad}-T_{an}$ ). The linear relations are given for meadow  $F_c = 0.2194(T_{ad}-T_{an}) + 9.1116$ ,  $F_{(1,26)} = 0.36$ ,  $P > 0.05$ , and for shrub  $F_c = 0.2496(T_{ad}-T_{an}) + 5.6527$ ,  $F_{(1,26)} = 0.69$ ,  $P > 0.05$

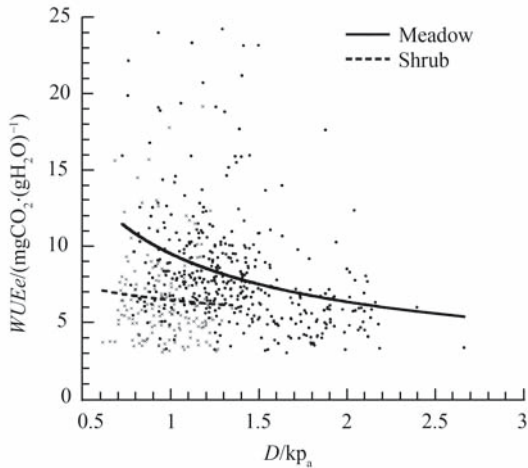


**Fig. 7** Relationship between net daily  $\text{CO}_2$  exchange ( $F_c$ ) and daily albedo ( $A$ ). Logarithmic fits to the data are given for meadow  $F_c = 0.96A^{-1.72}$ ,  $F_{(2,30)} = 126.30$ ,  $P < 0.001$ , and for shrub  $F_c = 2.81A^{-0.62}$ ,  $F_{(2,30)} = 191.36$ ,  $P < 0.001$

the *Kobresia humilis* meadow was more sensitive to the vegetation albedos' effects.

### 3.6 Water usage efficiency ( $WUE_e$ ) of the ecosystem

When evaluating the  $WUE_e$ , we used the Baldocchi (1994) method and calculated carbon absorption and evaporation of the plant photosynthesis via the use of  $\text{CO}_2$  flux and water vapor flux.  $WUE_e$  is defined as the ratio of total  $\text{CO}_2$  absorption ( $G_c$ ) with water vapor flux ( $E$ ), namely  $WUE_e = G_c/E$ . From Fig. 8, it is suggested that  $WUE_e$  is large when saturated water vapor pressure ( $D$ ) is low, and when  $D$  reaches a higher level,  $WUE_e$  remains at a relatively

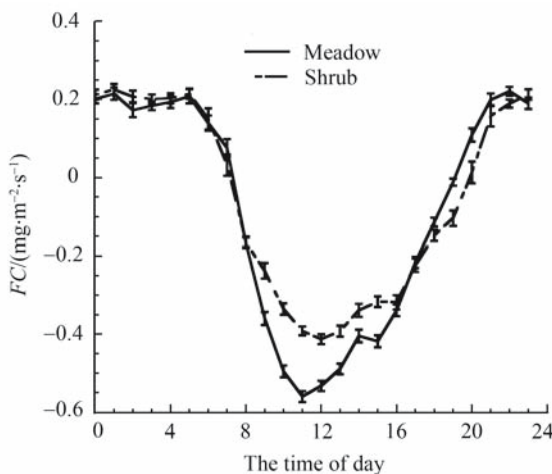


**Fig. 8** Relationship between daytime water use efficiency ( $WUE_e$ ) and vapor pressure deficit ( $D$ )

stationary status. The  $WUE_e$  value of the *Kobresia humilis* meadow is also larger than that of the *Potentilla fruticosa* shrub meadow.

### 3.7 Net $CO_2$ exchanges of ecosystem

The daily net  $CO_2$  exchanges of alpine meadow ecosystems vary dramatically. The plant growth begins their maturation in August and the dry matters of plants accumulate increasingly (Li et al., 2001b). During daytime, near surface (function layer) absorption of  $CO_2$  varies greatly, and so does the  $CO_2$  discharges during night time. The exchanges also vary in a vegetation dependent manner (Fig. 9): the maximum  $CO_2$  absorption of the *Kobresia humilis* meadow is apparently larger than that of the *Potentilla fruticosa* shrub meadow, while it is the opposite for the maximum carbon dioxide discharges, which may result from the longer plant height and stronger thermal energy retention capacity of the *Potentilla fruticosa* shrub meadow. The results indicate that the net  $CO_2$



**Fig. 9** Diurnal courses of hourly mean  $CO_2$  exchange flux ( $F_c$ )

exchanges of the two typical alpine meadow ecosystems are  $-56.16$  and  $-32.62$   $g\ C\cdot m^{-2}$ , respectively in August, from which it can be seen that the  $CO_2$  absorption of the *Kobresia humilis* meadow can be 42% higher than that of the *Potentilla fruticosa* shrub meadow.

## 4 Discussion

This study's findings indicate that the alpine meadow ecosystem of the Qinghai-Tibet Plateau has a higher net  $CO_2$  absorption compared with other coordinative meadow ecosystems (Hum and Knapp, 1998; Frank and Dugas, 2001; Hunt et al., 2000), which confirms the observation results that alpine meadows have relatively higher productivity during a short period (Li et al., 2004). However, the maximum  $CO_2$  absorption in the daytime and discharges at night for these two ecosystems are correspondingly low, suggesting that their potential capacities for  $CO_2$  exchanges are weaker than that of congener meadow or forest ecosystems with the same latitude, which may be referred to as the low temperature limitation (Kato et al., 2004).

The comparison of carbon fixation rates between the two meadow ecosystems in August shows that the carbon absorption rate of the *Kobresia humilis* meadow is apparently higher than that of the *Potentilla fruticosa* shrub meadow. There are three probable factors that may result in this differentiation: 1) *Kobresia humilis* meadow has a higher leaf area index, and so has more carbon fixed during photosynthesis; 2) the soil moisture condition of the *Kobresia humilis* meadow is more propitious for photosynthesis than that of the *Potentilla fruticosa* shrub meadow (Fig. 5); 3) the organic matter of *Potentilla fruticosa* shrub meadow soil is higher, which results in more soil respiration and decreased net productivity.

With the warming status quo of the global climate, the soil organic carbon is suffering the influence of temperature and rainfall factors, and the decomposition rates may be accelerated, which will have a feed-forward effect on the warming progression. The fact that soil organic matters of the *Potentilla fruticosa* shrub meadow are distinguishably higher than that of the *Kobresia humilis* meadow (Table 1), while the net  $CO_2$  exchanges is not that comparable, indicates that the  $CO_2$  exchanges of ecosystems is not directly proportional to the soil organic matter content.

The major  $CO_2$  resource of the meadow ecosystem is often from the soil; respiration of the latter is also affected by the soil moisture and temperature conditions, as well as the distinct vegetation community and geographical locations (Singh and Gupta, 1977). Rey et al., (2002) pointed out that the plant root respiration and soil microorganism activity are quite sensitive to the soil temperature variation, and soil respiration rates are positively correlated with soil temperature under sufficient soil moisture, which cannot be a restricting factor (Witkamp, 1969; Mathes and Schridfer, 1985; Peterson and

Billings, 1975). When moisture content becomes the major impact factor in some dry and semi-dry areas, it functions together with the temperature factor. Although the soil temperature of alpine meadows do not reach the best temperature for microorganism activity (Bao et al., 1991), their adaptability to the cold and wet environment during long term is so strong that their activities are sharply enhanced when there is an increase in the environmental temperature. The results of this paper show that with no consideration to the soil moisture analysis, the alpine meadow's soil respiration in the Qinghai-Tibet Plateau presents an exponential relation with the soil temperature. Depending on whether the moisture level is lower or higher, soil respiration of the two kinds of vegetations are sensitive to the soil temperature, with opposite responding trends. These findings suggest that CO<sub>2</sub> fluxes are positively related to soil temperature without considering soil moisture, which corresponds with previous research results. When soil moisture is taken into consideration, the relation between CO<sub>2</sub> fluxes and soil temperature is dependent on both the soil moisture and vegetation types, with the consensus that soil respiration has a fitting range. Kucera and Kirlchan (1971) found that stagnation of soil respiration will occur when moisture content of meadow soil reaches saturation or permanent wilting. Wang et al. (2003) reported that lower or exorbitant moisture contents may inhibit the CO<sub>2</sub> discharges of the broadleaved-Korean pine forests. The results in this paper also identified that there exists a  $Q_{10}$  value <1 for the *Potentilla fruticosa* shrub meadow, which indicates that lower or higher moisture conditions have large impacts on soil respiration. Moreover, under proper moisture conditions, soil respiration of the *Kobresia humilis* meadow is not positively connected with soil temperature. These findings suggest that soil temperature and moisture are two major factors that have influence on the ecosystem CO<sub>2</sub> discharges, which is not consistent with the conclusion drawn by Zhang et al. (2001) and Zhou et al. (2003).

Vegetation albedo is one of the most important microclimate parameter, for its vital role in energy distribution and pivotal impact action in the soil-vegetation carbon fixation. The results in this paper suggest that the decreasing CO<sub>2</sub> fluxes phenomenon with increasing albedo is due to different vegetation types and distinct vegetation communities (diverse plant species, layer structures, heights and vegetation fraction) that result in the distinguishable albedos of the underlying surface. At the same time it is suggested that the underlying surface albedo is another important factor that affects the system's CO<sub>2</sub> fluxes.

From the time Tanner and Sinclair (1983) defined WUE<sub>e</sub>, vis-à-vis the ratio of dry matter productivity (NPP) with water vapor flux, lots of research suggested the negative correlation of WUE<sub>e</sub> and saturated water vapor pressure. The result in this paper is consistent with previous reports that the relationship of the two in the alpine meadow ecosystems of the Qinghai-Tibet Plateau also satisfies the inverse proportion, and that WUE<sub>e</sub>s differ with distinct meadow types.

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