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Study on Soil Respiration Characteristics and Carbon Balance of *Kobresia pygmaea* Meadow in Qinghai-Tibet Plateau, China

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Abstract

Although soil respiration is the largest contributor to C flux from terrestrial ecosystems to the atmosphere, our understanding of its characteristics and carbon budget in alpine meadow is rather limited because of extremely geographic situation. This study was designed to examine soil CO_2 efflux characteristics of diurnal and seasonal variation, thus obtaining estimates of carbon balance of *Kobresia pygmaea* meadow in Qinghai-Tibet plateau. The results showed that the soil respiration of diurnal and seasonal rate changed little in growing season and was mainly affected by temperature, and single peak curve that showed afternoon appeared. Composite model which was set by soil respiration rate, soil moisture content and temperature (atmospheric temperature and soil temperature) could explain better the variations of soil respiration rate. The variation range of Q_{10} ranged from 1.28 to 2.34, which was sensitive to temperature in green-up period and late growth stage, and decreased in growth peak period. Meanwhile, during the growing seasons the observed amount of annual carbon fixation via primary production for *Kobresia pygmaea* meadow ecosystem was about 120.21 g $C{\cdot}m^{-2}{\cdot}a^{-1}$. The carbon dioxide output via soil heterotrophic respiration was about 37.54 g $C{\cdot}m^{-2}{\cdot}a^{-1}$. So carbon budget had more input than output. The *Kobresia pygmaea* meadow ecosystem has stronger potential to absorb carbon dioxide, it was a sink of atmospheric CO_2, and the plant community had a net carbon gain of 82.67 g $C{\cdot}m^{-2}{\cdot}a^{-1}$.

Keywords

Soil Respiration, *Kobresia pygmaea* Meadow, Carbon Balance/Budget,

Qinghai-Tibet Plateau

1. Introduction

An increase in the emission of greenhouse gases such as carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O) from the soil surface to the atmosphere has been of worldwide concern over the last several decades [1]. Carbon dioxide is recognized as a significant contributor to global warming and climatic change [2]. Observantly, acting as one kind of greenhouse gas, its precise measurements of source, sink and flux characteristics are important to study intensively global carbon cycling and balance.

Soils are of particular importance in the atmospheric CO_2 budget and a large reservoir of terrestrial ecosystem, which is recently estimated at 1600 Pg and more than twice the atmospheric CO_2-pool, 750 Pg [3] [4]. Hence approximately 68 - 75 Pg passes through terrestrial soils each year, accounting for 10% of the atmospheric CO_2 [5] [6]. Soil respiration (*Rs*) plays a large role in carbon (C) cycling in terrestrial ecosystems, including root respiration and microbial respiration [7]. The contribution of root respiration to *Rs* depends on plant phenology, nitrogen content, and mycorrhizal association. Microbial respiration primarily depends on the availability of substrate and community composition [7]. Both components are affected by temperature and moisture [8]. Interest in grassland and forest ecosystem that controls soil CO_2 respiration is growing because of the potential for climatic change in a certain region of China to affect net soil CO_2 productivity and exchange between soil and atmosphere [9]. Knowledge about its characteristics and carbon budget in alpine meadow of Qinghai-Tibet plateau is still rudimentary.

Grasslands are mostly distributed beyond forest zone and around 4200 m a.s.l in Qinghai-Tibet plateau. Over 60% of grasslands in the plateau are alpine meadow and alpine steppe, which provide extensive feed bases for Tibetan sheep and yak [9]. Due to the high elevation and cold conditions, decomposition rate of litter does change slowly each year, especially above 4200 m height. Release of soil carbon is little and carbon accumulation has great capacity, which was reported that alpine meadow soil and mountain soil in the plateau contain more plentiful organic matter and carbon density than soils in areas with similar altitude [10]. Therefore in the background of global warming, the permafrost in the plateau appears more sensitive to global change, possibly leading to higher carbon emission. Meanwhile, transform between carbon sink and source is quicker in alpine soil than plain in the space scale. Is the carbon sink or source of atmospheric CO_2? And how insensitive is it to meadow in Qinghai Tibet plateau? All these are serious questions that attract many people's eyes in the future. Study on CO_2 efflux characteristics of diurnal and seasonal variation, and estimates of carbon balance of alpine meadow does not only give a better understanding of terrestrial ecosystem carbon pool and better prediction on climate change, but provide recommendation for grazing management and sustainable development of alpine meadow resources as well. However, little information is available on soil respiration. It is necessary to improve our knowledge of carbon input and output, and carbon balance of alpine meadow ecosystem. Our specific aims were: 1) to describe diurnal and seasonal soil respiration characteristics of *Kobresia pygmaea* meadow, 2) to evaluate carbon input and carbon output of the ecosystem, and 3) to estimate the relative contributions of roots system, aboveground live matter, litter mass, and livestock intake of the carbon balance.

2. Materials and Method

2.1. Site Description

The Yangtze, Yellow and Yalu Tsangpo Rivers, known as the "water tower of China", locates on Qinghai-Tibetan plateau, northwest China. The experiments were conducted at the site (27˚35' - 36˚35'N, 89˚35' - 97˚55'E) in the source region of three headwater. This site belongs to the Alpine Meadow Ecosystem Research Station (AMERS), owned by the department of agriculture, P.R. China. The site experiences a typical plateau continental climate which is dominated by the southeast monsoon from May to September in summer and high pressure from Siberia in winter. Summers are short and cool, and winters are long and severely cold. Mean annual air temperature was −6.4˚C - 4.3˚C, the average air temperature was 11.7˚C - 21.0˚C in July, −27.9˚C - 14.3˚C in January and mean annual precipitation was 374.2 - 721.2 mm (The Livestock Husbandry Programming Office of Qinghai Province, 1984). Over 80 per cent of them which falls during the summer monsoon season [10]. There was mainly dominated by *Kobersia pygmaea* and companied by *Kobresia kansuensis*, *Poa crymophila*, *Aster alpinus*, *Oxytropis kansuonisis* and so on. The soil is characterized by alpine meadow soil, which contains more plentiful organic matter and the average soil bulk density is 1.290 g/cm^3. Most root systems penetrate to a depth of 30 cm with the highest root density in the top 20 cm [10].

2.2. Soil CO_2 Fluxes Measurements

Soil CO_2 flux was measured during the growing season of 2012, with an LI-8100 Automated Soil CO_2 Flux System (LI-COR, Lincoln, Nebraska, USA) equipped with a short-term monitoring chamber (LI-8100L). Before measurement, litter on soil surface was cleared and three steel collars (21.34 cm outer diameter, 20.3 cm inner diameter and 20 cm high) were inserted into the soil, with a 5-cm wall exposed above the soil surface for installing the monitoring chamber. This was done at least 24 h prior to measurement to minimize the disturbing effect on the measurement. Each measurement was commenced at 07:00 and ended at 07:00 (Beijing time) on the next day. During measuring period, CO_2 flux value was documented for every 15 min and each measurement length was 3'. Air temperature 10 cm above the soil surface and soil temperature at 5 cm depths were monitored automatically by the temperature probes equipped with LI-8100 System.

All the observations were measured in clear days. Daily meteorological data, such as geothermal data, are taken from 20-km-away Qingshui River.

2.3. Sample Collection and Measurements

The plant biomass was clipped flush to the ground from 6 representative 50 × 50 cm quadrates per plots on different growing months around the chamber. Air-dried litter samples (10 g oven-dry mass) of mixed community litter samples collected from the meadow community grazed by yaks were placed in 10 cm - 20 cm litterbags constructed from 1 mm mesh nylon cloth. In total six litterbags containing the mixed community litter were put placed back into their plots of origin on 1 June 2012, and were taken back to the laboratory on 13 August 2012, to measure litter mass loss and litter decomposition rates.

Roots were sampled from 0 to 30 cm after pant clipping at experimental plots, with 6 replications, which was located alongside the above-ground biomass quadrate. The samples were first washed and then oven-dried at 80˚C for 72 h before being weighed. Vegetation samples ground in agate mortar were analyzed for chemical analysis carbon concentration by dry combustion in VarioEL elemental analyzer.

2.4. Data Calculation and Analysis

Carbon balance/budget was used the following equation,

$$\text{Carbon input} = NPP \times \text{carbon concent\%} \tag{1}$$

$$\text{Carbon output} = RS \times 45\% \tag{2}$$

$$NEP = \text{Carbon input} - \text{Carbon output} \tag{3}$$

where carbon output was calculated by soil heterotrophic respiration. *RS* was calculated according to the seasonal change dynamic soil respiration rate and soil moisture, air temperature index fitting equation. Carbon input could be calculated by multiplying net primary production (*NPP*) with carbon content.

Pearson correlation analysis was used to measure the relationships between CO_2 fluxes and environmental factors by SPSS13.0 software. Exponential regression was performed to the dependency of CO_2 flux against the corresponding soil temperature at a depth of 5 cm by Origin8.0 software.

3. Results

3.1. Temporal Variation of Soil Reparation and Its Affecting Factors

3.1.1. Diurnal Variation of Soil Reparation

Generally, sampling date affected CO_2 fluxes (**Figure 1**). The Diurnal variations in the soil CO_2 flux rates were different during the study period. The soil CO_2 flux rates showed clear diurnal variations, where the rates increased at daytime, with maximum values at afternoon. During the sunset, the soil CO_2 flux declined again, reaching values close to those at dawn. The peak of daily CO_2 flux occurred

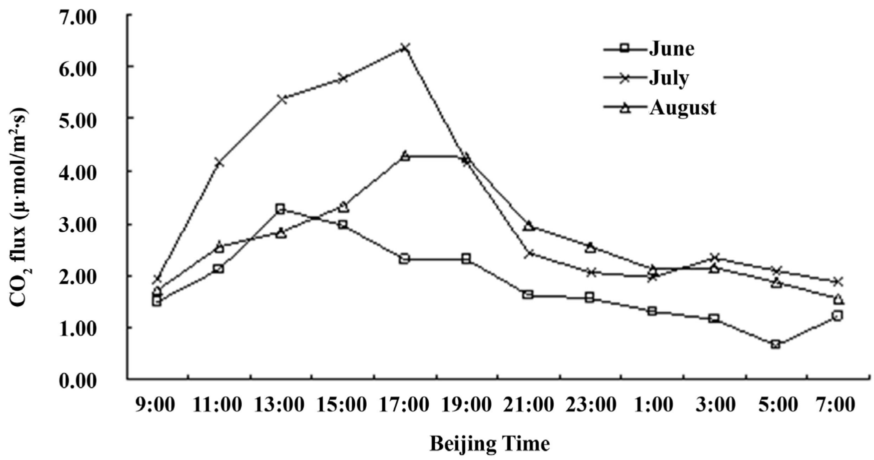

Figure 1. Diurnal variation of soil preparation of *Kobresia pygmaea* meadow.

during Beijing time 13:00-15:00 in June, and the bathos appeared during 1:00-3:00, the average diurnal CO_2 fluxes were 1.82 (ranged 0.25 - 3.65 μ·mol/m^2·s). Both July and August the peak during 15:00-17:00, and the bathos was 3:00-5:00. The average value were 3.37 (ranged 1.85 - 6.39 μ·mol/m^2·s), 2.68 (ranged 1.57 - 4.29 μ·mol/m^2·s), respectively. Therefore, CO_2 fluxes were matched with plant grown period during the growing season.

3.1.2. Correlation of Soil Respiration with Its Factors

Pearson correlation analysis was used to measure the relationships between CO_2 fluxes and the corresponding 5 cm soil temperature (ST) and air temperature (AT) and soil moisture (SM), the results showed (Table 1) that the positive correlations between CO_2 flux and ST and AT in different months were obviously significant ($P < 0.01$). The correlation of ST was better than AT, with the strength of the relationship being quite high. This identified soil respiration was sensitivity to ST, especially at 5 cm. Meanwhile, its correlation was smaller in warming month (July) than cooling moth (June, August). The negative correlation was appeared between CO_2 flux and SM, the strength of the relationship being quite low.

3.1.3. Regression of Soil Reparation with Soil Temperature and Q_{10} Value in Different Month

An exponential regression of each CO_2 flux against the corresponding soil temperature at a depth of 5 cm (Figure 2) was highly significant (R^2 of 0.8901, 0.6603, and 0.6102, $P < 0.001$) in different month. Exponential regression model provided positive relationship between soil CO_2 flux and soil temperature. It indicated that soil temperature was a positively controlling factor for soil CO_2 flux. On the other hand, the trend was highest in August which the temperature reached −4.7˚C after growing period. Therefore, soil respiration was limited and more sensitive to temperature.

Short-term Q_{10} (temperature coefficient) of each month with the growing season was calculated from exponential regression equations and fitted with data

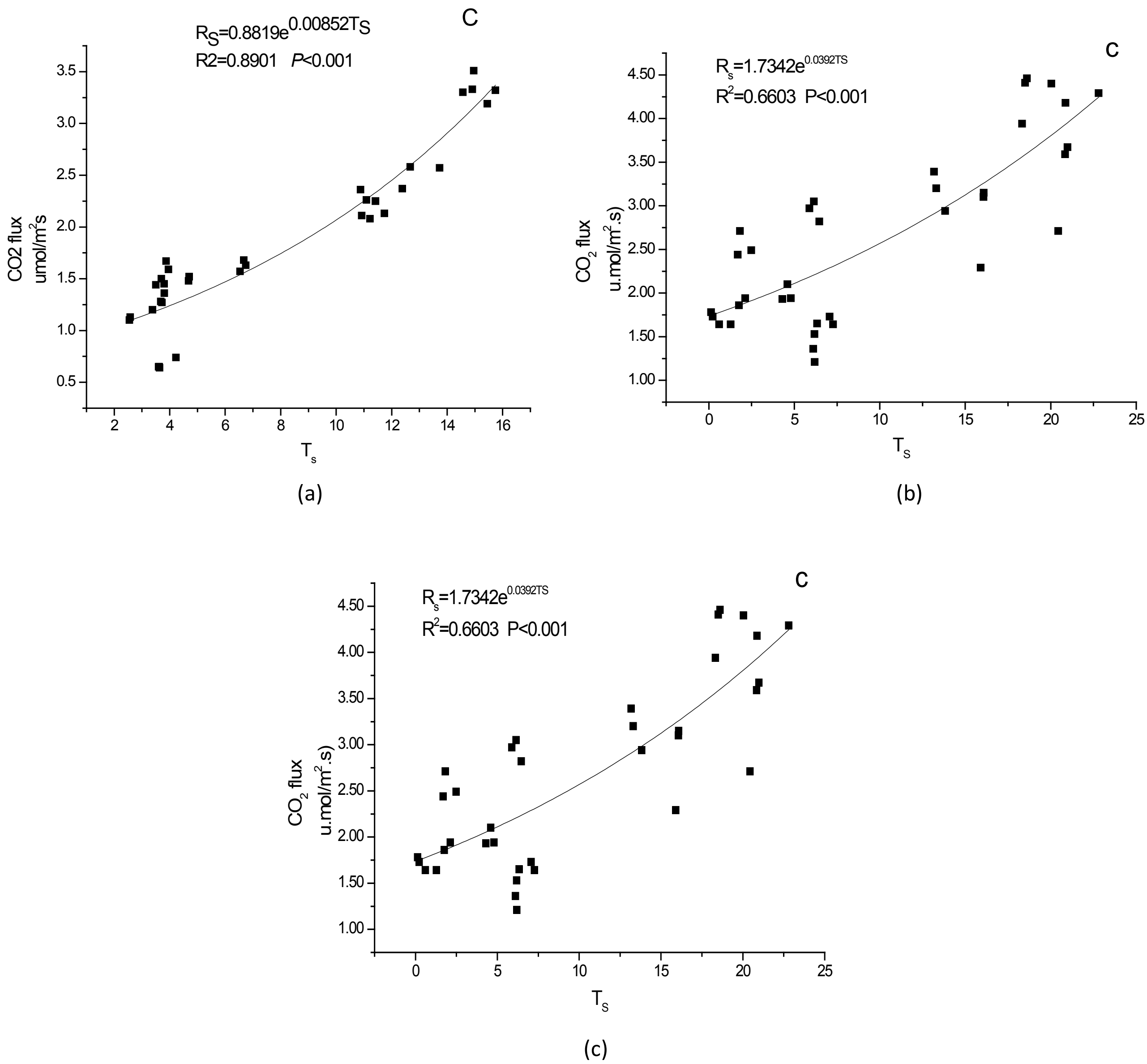

Figure 2. Regression analysis of soil reparation with soil temperature in June (a), July (b) and August (c).

Table 1. Correlation of soil respiration with temperature factors and Q_{10} value in different months.

Month	Soil temperature	Air temperature	Soil moisture	Q_{10} Value
June	0.934**	0.539**	−0.519**	2.34
July	0.654**	0.681**	−0.743**	1.28
August	0.893**	0.584**	−0.734**	2.19

Note: Dependence of environmental variables on different months as determined by multiple regression. Values shown are regression was performed for each variable. **, 0.01 ≥ P ≥ 0.001 for tests of significant difference of parameter from 0.01.

in Figure 2, which exhibited strong seasonal variations. The mean temperature coefficient was 2.34 in June, 1.28 in July, and 2.19 in August in the *Kobersia* *pygmaea* meadow soil (Table 1). The Q_{10} in the soil from over-winter period was significantly lower than that in soils from a growing period ($P < 0.01$). This result was consistent with previous studies which had shown that the Q_{10} for soil respiration was higher at lower temperatures or in ecosystems associated with low soil temperatures [8].

3.2. Seasonal Variation of Soil Reparation

3.2.1. Seasonal Dynamics of Carbon Flux

The total diurnal respiration rate was calculated by the integral of CO_2 flux to time, and the average total daily respiration rate was the day of time ratio. The results showed (Figure 3) the carbon flux difference significantly between each month ($p < 0.05$). In the whole growing season, the largest of soil carbon flux in late July to early August, which was the herbage growth period, and turned declined in over-green and the grass withered and yellow. In experiments, Carbon month flux in July has increased by 45.93 per cent, 20.52 per cent, separately on tested month. And the maximum CO_2 emissions were June-August in the summer, whose soil respiration amount was 23.88 μg·C/m²·M.

3.2.2. Composite Model of Soil Respiration Flux with Temperature (Soil Temperature) and Soil Moisture

Soil respiration is usually affected by many factors interacted, although it is often difficult to separate. Similar to other physiological processes of plants and microorganisms, soil respiration usually produces response to restrict factor [11]. The composite model was found by soil respiration, soil moisture, soil temperature (Table 2), Soil respiration and soil temperature, soil moisture content of determination

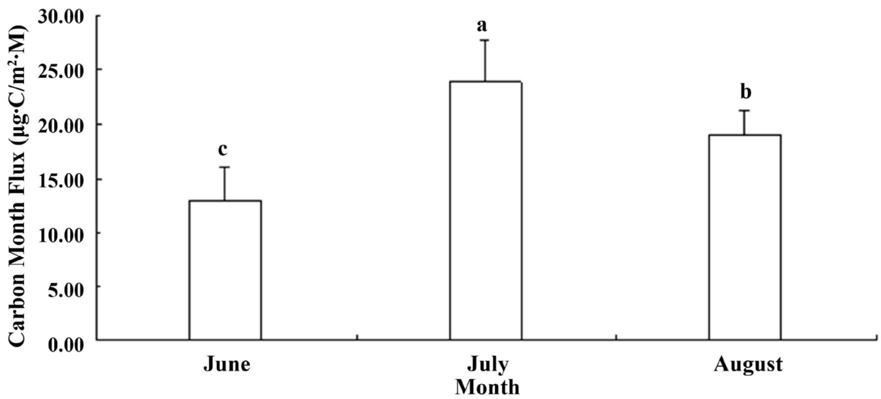

Figure 3. Seasonal dynamics of carbon flux of *Kobresia pygmaea* meadow. Note: the superscript of data with the same letter in one bar are not significantly different at $P < 0.05$ level.

Table 2. The composite model of soil respiration flux with temperature (soil temperature) and soil.

Composite Model	R^2	*P* value
$R_S = -0.60e^{-0.093Ts} + 0.010 \times W_S$	0.84	0.0001
$R_S = -2.20e^{-0.056Ta} + 0.019 \times W_S$	0.52	0.0001

Note: *Ts* is temperature, W_S is moisture.

coefficient (R^2 = 0.84, P < 0.001) was larger than that of soil respiration and soil temperature R^2 (R^2 = 0.61, P < 0.001). Meanwhile the regression of soil respiration, soil moisture and soil temperature significantly (P < 0.01), which provided positive relationship. This elucidates composite model which was set by soil respiration rate, soil moisture content and temperature (atmospheric temperature and soil temperature) could explain better the variations of soil respiration rate.

3.3. Carbon Input

Net primary productivity (*NPP*) are markers of ecosystem carbon balance, is also the main way that carbon input [6]. Through *NPP* of each carbon input component with carbon content converted into carbon quantity (see **Table 3**), The carbon input order per unit area varied in the order of roots > the aboveground live > livestock intake > litter mass, with the values of 96.76, 14.54, 5.29, and 0.60 g $C \cdot m^2 \cdot a^{-1}$, occupied by 82.57 per cent, 12.41 per cent, 4.51per cent, and 0.51 per cent, respectively, in which roots were the main part of the total input of carbon sequestration.

3.4. Carbon Output

Using the daily meteorological data and the average soil moisture during the month, according to the seasonal change dynamic soil respiration rate and soil moisture, air temperature index fitting equation of calculating the total soil respiration ($R_S = 1.18 \times e^{0.091 Ta - 0.0044 Ws}$, R^2 = 0.52, P < 0.001), the results showed *Kobresia pygmaea* meadow released high amount of soil respiration, which reached to 296.02 g $CO_2 \cdot m^2 \cdot a^{-1}$. Generally, soil respiration includes root respiration and soil microbial respiration, in which soil heterotrophic respiration (*Rh*) occupied for 45% - 48% of the total [12] [13] [14]. According to the soil heterotrophic respiration accounted for 45%, carbon output of *Kobresia pygmaea* meadow was 36.33 g $C \cdot m^2 \cdot a^{-1}$.

3.5. Carbon Balance

The grassland ecosystem carbon balance mainly includes two carbon input and output process. Carbon input mainly comes from grassland vegetation for CO_2 fixing, the output of carbon mainly includes grassland community respiration, litter decomposition and soil carbon release, etc. Through the calculation of NEP

Table 3. Estimates of carbon input of *Kobresia pygmaea* meadow.

Resource	Total ($g \cdot m^2 \cdot a^{-1}$)	C content (%)	Carbon input ($g\ C \cdot m^2 \cdot a^{-1}$)	Ratio (%)
Aboveground live	34.32	42.36	14.54	12.41
Roots	208.54	46.40	96.76	82.57
Litter mass	1.40	43.05	0.60	0.51
Livestock intake	12.51	42.36	5.29	4.51
NPP		117.19		

= *NPP* − *Rh* could be obtained the carbon balance value was 82.67 g $C \cdot m^2 \cdot a^{-1}$ (**Figure 4**), which calcified *Kobresia pygmaea* meadow of Qinghai-Tibet plateau was carbon sink.

4. Discussion

Alpine meadow is an important material base for livestock farmers and herdsmen on Qinghai-Tibet plateau. The ecosystem structure is simple, and the function weak; therefore it is susceptible to interference and destruction of human activity. In the development of long-term evolution, the alpine grassland productivity has produced many organisms and rich biodiversity. Meanwhile it provides farmers with plenty of biological resources. However, the use of these resources value mostly is out of our understanding and lack of effective management. Grazing is one of the simplest and the most economic ways of grassland utilization, which affects the grassland vegetation net primary productivity from all aspects. Moreover, the largest contributor of primary productivity was underground dry mass [15]. Some studies found that underground primary productivity reached to 5112 g/m^2, 4948.8 g/m^2, respectively, on summer and winter pasture in *Kobresia pygmaea* meadow-Yak grazing systems [15]. In *Stipa breviflorea* desert steppe, it was 962.78 g/m^2 [16], and both were not distinguished between dead and living root. On the other hand, the net primary productivity of dry matter in alpine grassland ecosystem was 225.66 $g \cdot m^2 \cdot a^{-1}$ [6], which was close to this study. The causes of these differences may be the stage in yellow after the next green period. There is also a process of slow growth, and influence on the accumulation of net primary productivity. The other may be different vegetation types of plant community, species composition, its vegetation growth environment conditions and chosen way of grassland utilization. Therefore those need further study on net primary productivity and environmental or grassland utilization way relationship.

The grass carbon balance issue has always been difficult for qualitative question. It is mainly because the carbon input and output are not synchronized, the ground part of the carbon decomposed faster than underground part, which is affected by both nature and humans. Studies have shown that annual

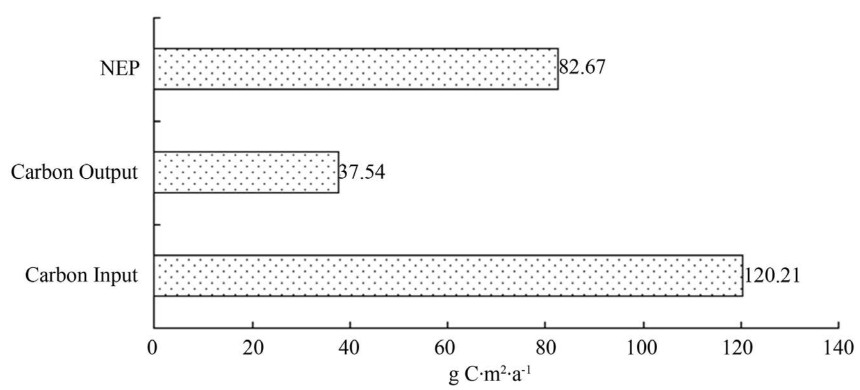

Figure 4. Estimates of carbon balance in *Kobresia pygmaea* meadow (g $C \cdot m^2 \cdot a^{-1}$).

NPP density was 190.39 g C·m^{-2} [17], 214.64 g C·m^{-2} [18] in the Qinghai-Tibet plateau alpine meadow. Moreover, *Kobresia humilis* meadow exhibited a weaken carbon sink, but was carbon source experiencing degradation, which was influenced by hydrothermal conditions [19]. These experiments show that the carbon source or sink balance of grassland ecosystem is basically consistent with other studies [20]. Carbon output test showed that grassland carbon emission enhanced in summer and decreased in winter, which presented significantly seasonal variation and the CO_2 flux variation is given priority to with single-peak curve [6]. Study also found that soil carbon emissions were less on heavy degradation degree of alpine meadow [19]. It is supposed that less carbon input component enter to soil because the soil organic matter is lacking, the surface layer of grassland is degraded, and the hydrothermal condition is unstable. In addition, the degradation was caused by underground root growth and development, which led to the decrease in the respiration. In fact, the carbon source and sink characteristics of grassland influenced by hydrothermal conditions change, and different years showed different characteristics of carbon sink [21]. On the other hand, the estimation of the carbon cycle process is complex, and the parameters of the model involve the reference factor, the number of observation time, and so on. Therefore, the models and results of this experiment need to be verified by long-term measurements.

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Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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