The Influence of Degradation of Alpine Swamp Wetland On Ecosystem Respiration And Its Components

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Abstract

Three degradation stages of alpine swamp wetland (none, light and severe degeneration levels) were addressed through measuring the respiratory components rate of ecosystem during the peak period of vegetation growth (July to August), so as to analyze the impacts of degradation on ecosystem respiration and its components in alpine swamp wetland on the Qinghai-Tibet Plateau. Two methods which are root separation and herbicide spraying, were used for determination and measurement of respiratory components. The results showed that degradation of alpine swamp wetland can significantly increase soil respiration rate and microbial respiration rate. Moreover, the proportion of vegetation respiration and microbial respiration in ecosystem respiration changed significantly ($P < 0.05$). There was a significant positive correlation between vegetation respiration and ecosystem respiration rate at all the degradation levels ($P < 0.05$). Canopy respiration and ecosystem respiration were highly correlated between none and severe degraded wetlands ($P < 0.05$), it was also found that there was significant positive correlation among soil respiration rate, root respiration rate and ecosystem respiration in light degraded wetland. There was a positive correlation between root respiration and soil respiration in none and light degraded wetland ($P < 0.05$). The Q_{10} change ranges of ecosystem respiration, vegetation respiration, canopy respiration, soil respiration, root respiration and soil microbial respiration during the degradation stage of alpine swamp wetland were 1.41–1.50, 1.81–1.94, 4.46–6.93, 1.41–2.40, 2.84–5.97 and 1.99–3.74, respectively. The degradation of alpine wetland affects firstly the ecosystem respiration and its components, and then will affect the carbon cycle process. Therefore, it is very important to protect and restore the alpine wetland on the Qinghai-Tibet Plateau.

Introduction

Due to the influence of global climate change and human activities, the degradation of alpine swamp wetland is aggravating everyday, and the degradation succession to alpine meadow appears (Li et al., 2018). Some scholars used remote sensing and GIS technology to interpret the changes of marsh area in the eastern margin of the Qinghai-Tibet Plateau since the 1990s, and found that the wetland area is decreasing from 1991 to 2016 with the area decreasing from 6739.89 km² to 5649.35 km² and a decrease of 1090.54 km² in 26 years (Hou et al., 2020). The degradation of alpine swamp wetland undoubtedly plays an important role in the global environmental biogeochemical cycle. In the biogeochemical cycle of carbon element, net ecosystem carbon exchange is one of the key processes that affect the carbon sink function of grassland ecosystem (Chapin et al., 2002). In this process, CO₂ cycle is the main component, followed by CH₄ and CO (Cao et al., 2013). The carbon storage of alpine swamp is much higher than that of other types of wetlands (Gao et al., 2008). Moreover, the degradation of alpine wetland can lead to the imbalance of groundwater. As a result, soil physical properties changed, soil temperature increased, aeration improved, the number of aerobic microorganisms increased, the decomposition rate of plant residues accelerated, and the amount of CO₂ emitted to the atmosphere increased (Wang, 2015). The change of atmospheric CO₂ concentration is closely related to the net amount of CO₂ absorbed or released by wetland ecosystem, resulting in the change of the original carbon balance between land and atmosphere. Therefore, studying the response of CO₂ flux to degradation in alpine swamp wetland will help to assess the impact of climate change and human intervention on carbon balance pattern of alpine swamp wetland ecosystem in the future.

CO₂ exchange between alpine swamp wetland and atmosphere mainly depends on the balance of photosynthesis and respiration, including two important ecological processes: carbon fixation by photosynthesis of plants and carbon release by respiration of ecosystem (Chapin et al., 2002). Among them, ecosystem respiration is a very complex ecological process, the ecological and biological processes of each component of ecosystem respiration are different (Wang et al., 2011), whose response to alpine swamp degradation may also be different, and the differentiation of ecosystem respiration components is very important for understanding ecosystem respiration mechanism and its response to swamp wetland degradation. So far, researchers have developed and implemented a variety of monitoring technologies for respiratory component separation data. The common methods are ditch digging, isotope labeling, root biomass extrapolation and root separation (Ma et al., 2018; Chen et al., 2013; Chen et al., 2009). In addition, some scholars also used herbicide spraying method to separate and determine soil respiration components (Li et al., 2018). At present, there are few reports about the corresponding changes of respiration components in alpine swamp wetlands with different degradation degrees. The existing problem is that the methods used in previous studies have their own advantages and disadvantages, and difference of respiratory components is large. It is not conducive to horizontal comparison and data comprehensive analysis between different studies and different stages of grassland degradation (Remus & Jürgen, 2016). Meanwhile, it is urgent to explore the applicability of new determination methods to compare and integrate different methods, so as to ensure the improvement of the accuracy of the test results after the test. Based on this, this study takes different degradation stages (non degradation, light degradation and severe degradation) of alpine swamp wetland as objects, adopts the most common root separation method and the herbicide spraying method in latest research method, and subdivide the respiratory components of wetland ecosystem. All of them are trying to systematically analyze which components in the process of CO₂ emission in alpine swamp wetland lead to the change of carbon exchange in different degradation stages and explore the reasons for the variation. Under the background of global climate change, it can be provided a basic data for understanding the carbon budget response of alpine swamp wetland.

Materials And Methods

Research area

The sample site is located at Dawu Town, Maqin County, Guoluo Tibetan Autonomous Prefecture, Qinghai Province, west China (34° 27' 48" N, 100° 12' 49" E, with an average altitude of 3730 m). Meteorological characteristics in the study area are displayed with continental cold humid climate, an

average annual temperature of -3.9°C , average precipitation is 423–565 mm. The resources of alpine wetland are rich in this area and the current grazing level is winter grazing. The plant communities in the research site are mainly composed of cyperaceae, gramineae and other families. Because of the aggravation of the drought in alpine swamp wetland, the number of the freeze-thaw mound increases, but the size decreases conspicuously. Then the severe degree of drought will be reached, and the freeze-thaw mound disappears, and finally becomes alpine meadow. The area of the research site is 4 ha. The scope of research area and the composition of dominant species, coverage of dominant species, average height of vegetation, amount of freeze-thaw mounds and size of freeze-thaw mounds in alpine swamp wetland are detailed in the literature (Lin et al., 2019).

Experimental Design

The alpine swamp wetland stage 1 (Non-degradation, ND, Fig. 1a), stage 2 (Light degradation, LD, Fig. 1b) and stage 3 (Severe degradation, SD, Fig. 1c) were selected based on the three stages of the drought process in alpine swamp wetland which was dominated by *Kobresia tibetica*. Vegetation coverage and amount of freeze-thaw mounds were recorded. Radially sampling lines, three in total, were randomly selected starting from alpine wetland center as shown in Fig. 1d, six sampling points were decided by an interval of 25 m resulting in two points for each wetland type on one line. Thus, there were six samples in each drought process stages of alpine swamp wetland (Fig. 1d).

Ecosystem respiration (R_e) is composed of vegetation autotrophic respiration (R_v) and ecosystem heterotrophic respiration (Fig. 2). From the perspective of space, ecosystem respiration is composed of two parts: vegetation canopy respiration (R_{vc}) in aboveground part and soil respiration (R_s) in underground part. R_s is composed of soil microbial respiration (R_m), root respiration (R_r), chemical oxidation of soil carbonaceous minerals and animal respiration. In common ecosystems, the proportion of the last two components of soil respiration is very small, which can be ignored (Li et al., 2018), therefore, the heterotrophic respiration value can be expressed by R_m .

So, four 25 cm $\times$ 25 cm neighboring sample plots are set at one sampling point (Fig. 3). Three different treatments and one control are randomly assigned to measure and split the respiratory components of the ecosystem. Referring to the research method of Li et al. (2018), two weeks before the beginning of the determination, a sample was randomly selected from each block and sprayed with 41% glyphosate isopropylammonium salt solution to diluted 150 times. After two days, all the vegetation in the sample was killed and remained in the sample in a withered state, maintaining the natural shade when the plants in the sample survived and determining the corresponding pesticide-treated soil microbial respiration rate (R_p). In another random sample in the block, root removal method was used to remove roots in 0–40 cm soil layer by 0–5 cm, 5–10 cm, 10–15 cm, 15–20 cm, 20–25 cm, 25–30 cm, 30–35 cm and 35–40 cm layers (each layer of soil was sealed with preservative film), place transparent nylon mesh along the edge of the pit (to ensure the underground water and air circulation and prevent the surrounding vegetation roots from entering). Then, the rootless soil was backfilled layer by layer, and the observed value was soil microbial respiration rate without root treatment (R_{nr}). The remaining sample was the same as the previous method of measuring soil respiration rate. The vegetation on the ground was cut off, and the newly germinated vegetation on the ground was cut off on the day before each measurement. The soil respiration rate was measured by keeping the surface bare. A total of 72 samples were set up in ND, LD and SD stages. The control, mowing, pesticide-treated and without root treatments were repeated for 6 times at each stage.

Field Data Measurement

The multi-functional instrument TARGAS-1 portable photosynthesis system (<https://ppsystems.com/targas-1/>) used in this study is produced by PP SYSTEM company, it has a good performance in CO_2 measurement (Li et al., 2020). Ecosystem respiratory was measured during the peak period of plant growth (mid-July to mid-August) from 08:00 to 12:00 every 7–10 days with the single measurement time of 300 s. In order to avoid “ CO_2 starvation” in the ecosystem, after each measurement, the assimilation box is picked up and ventilated for 10 s to ensure that the gas concentration inside and outside the box is uniform. Due to the influence of water vapor on CO_2 absorption, the test data should be measured in sunny weather as soon as possible.

The value of soil temperature, moisture and soil electrical conductivity at 0–20 cm were measured by TDR 350 soil moisture, temperature and conductivity meter produced by Spectrum Company (U.S.). The measurement time is synchronized with the respiration measurement.

Data analysis

Split calculation of ecosystem respiratory components:

$$R_v = R_e - R_m$$

1

$$R_{vc} = R_e - R_s$$

2

$$R_r = R_s - R_m$$

3

Where R_m is determined by comparing the soil microbial respiration R_p under pesticide-treated and the soil microbial respiration R_{nr} under without root treatment by paired sample t test. If the tested results show that there was no significant difference in microbial respiration rate between the two treatments, it is necessary to further compare the differences of soil moisture, temperature and electrical conductivity between the treatment and the control. There is no difference between the two, and the respiratory rate without difference is taken for subsequent analysis and calculation. For example, the test results show that there is significant difference in microbial respiration rate between the two treatments, Then R_m value comes from the most commonly used without root method.

The proportion of ecosystem respiration components in ecosystem respiration can be calculated according to the following formula:

$$f(s/e) = R_s / R_e$$

4

$$f(vc/e) = R_{vc} / R_e$$

5

$$f(v/e) = R_v / R_e$$

6

$$f(r/e) = R_r / R_e$$

7

$$f(m/e) = R_m / R_e$$

8

The ratio of soil microbial respiration and soil root respiration to soil respiration can be calculated according to the following formula:

$$f(r/s) = R_r / R_s$$

9

$$f(m/s) = R_m / R_s$$

10

One-way ANOVA and Duncan are used to analyze the differences of respiration components and their proportions in different degradation stages of alpine swamp wetlands and the respiration rate of soil microorganism under the treatment of R_p and R_{nr} .

The relationship between respiration and soil temperature adopts exponential model:

$$R = a \times e^{b \times T}$$

11

The relationship between respiration and soil moisture adopts linear model:

$$R = a \times W + b$$

12

The comprehensive effect of soil temperature and moisture on respiration adopts the commonly used model:

$$R = a + b \times T - c \times W$$

13

Where R represents respiration rate, T represents 0–20 cm soil temperature, W represents soil moisture at 0–20 cm, and a , b , c are the undetermined parameters in the model. The temperature sensitivity (Q_{10}) of respiratory rate is determined by an exponential model (Formula 11), where b is the constant b obtained from the exponential model and plotted with origin 2018.

Result And Analysis

Soil temperature, moisture and electrical conductivity under different treatments

As shown in Fig. 4, there were no significant differences between soil temperature and soil conductivity under Re/Rvc, Rs, Rp/Rr and Rnr/Rr treatments at ND, LD and SD alpine swamp wetlands, but there are significant differences in soil moisture. Compared with Re/Rvc, Rs and Rp/Rr soil moisture, Rnr/Rr treatment will significantly reduce soil moisture ($P < 0.05$). The ND of soil moisture decreases by 12.85% after treatment with Rnr. LD and SD are 17.14% and 14.64% respectively, indicating that the effect of without root on soil moisture is greater than that of pesticide-treated.

Comparison of respiratory components between different degradation stages

There are significant differences in Re, Rs at different degradation stages ($P < 0.05$) (Fig. 5), where Re, Rs of ND are $0.60 \text{ g}\cdot\text{m}^{-2}\cdot\text{h}^{-1}$, $0.34 \text{ g}\cdot\text{m}^{-2}\cdot\text{h}^{-1}$, respectively, and Re, Rs of LD and SD are obviously higher than those of ND. LD Re, Rs are $0.75 \text{ g}\cdot\text{m}^{-2}\cdot\text{h}^{-1}$, $0.56 \text{ g}\cdot\text{m}^{-2}\cdot\text{h}^{-1}$, respectively, which are increased by 25.53%, 63.91% compared with ND. The SD Re, Rs are $0.75 \text{ g}\cdot\text{m}^{-2}\cdot\text{h}^{-1}$, $0.55 \text{ g}\cdot\text{m}^{-2}\cdot\text{h}^{-1}$, which are increased by 25.53%, 63.91% compared with ND Re, Rs. There is no significant difference between LD and SD.

The soil microbial respiration rate under the treatment of Rp and Rnr is tested by paired sample t test. The results showed that there is no significant difference in Rp and Rnr at the same degradation stage (Fig. 5). From the comparison of soil temperature, moisture and electrical conductivity of different treatments (Fig. 4), it can be seen that without root treatment can significantly reduce soil moisture ($P < 0.05$). Based on this, Rp is taken as Rm for the next analysis. In the figure, there is significant differences in Rm at different degradation stages ($P < 0.05$). There are no significant difference in Rr and Rv among ND, LD and SD.

As shown in Table 1, there is no significant difference in the proportions of Rvc, Rs and Rr to Re at different degradation stages, but the proportion of Rv to Re decreases significantly with the degradation succession proportion of alpine swamp wetland ($P < 0.05$). The decreasing range of LD and SD are 24.5% and 23.6% respectively. The proportion of the ND, LD, SD soil microbial respiration Rm in ecosystem respiration Re is 19.0%, 38.8% and 38.0%, respectively, where the f(m/s) of LD and SD increase by 104.5% and 100.5% respectively ($P < 0.05$) compared with ND. However, there is no significant difference between LD and SD.

With the degradation of alpine swamp wetland forming into the alpine meadow, the proportion of Rr to Rs decreases, and proportion of Rm to Rs increases (Table 1). Compared with ND, f(r/s) of LD and SD decrease by 35.2% and 30.3% respectively, while f(m/s) increases by 60.1% and 50.1% respectively ($P < 0.05$).

Table 1 Proportion of respiratory components in different degradation stages (%)

Total	Component	Degradation levels		
		None	Light	Severe
Re	Rs	60.1±27.7a	74.0±16.4a	76.2±18.3a
	Rvc	43.1±24.9a	26.0±16.4a	23.8±18.3a
	Rv	81.1±12.7a	61.2±16.9b	62.0±21.7b
	Rr	44.9±27.4a	35.2±23.7a	38.1±25.0a
	Rm	19.0±12.6b	38.8±16.9a	38.0±21.7a
Rs	Rr	69.5±18.3a	45.0±25.2b	48.5±27.6b
	Rm	34.3±21.9b	55.0±25.2a	51.5±27.6a

Note: The data in the table is the mean ± standard deviation, different lowercase letters indicate significant differences ($P < 0.05$), and the same letters indicate not significant differences.

Relationship between ecosystem respiration components and ecosystem respiration

The rate of each component of ecosystem respiration Rv, Rvc, Rs, Rr and Rm are taken as variables respectively to conduct regression analysis with Re. The results are as shown in Fig. 6: there is a significant positive correlation between Rv and Re in different degradation stages, with R^2 of 0.846, 0.674 and 0.343 respectively ($P < 0.05$). There is a significant positive correlation ($P < 0.05$) between Rvc and Re at the stage of ND ($R^2 = 0.625$) and SD ($R^2 = 0.661$). There is almost no significant relationship between them in LD. Rs, Rr and Re show significant positive correlation in LD ($P < 0.05$), but no significant correlation in ND and SD. In addition, there is no significant correlation between Rm and Re.

The rate of soil respiration components Rr, Rm are taken as variables respectively to conduct regression analysis with Rs. Fig. 7 shows that there is a positive correlation between Rr and Rs in ND and LD, with R^2 of 0.813 and 0.758 respectively ($P < 0.01$). However, the relationship between soil microbial respiration and soil respiration is similar to that between microbial respiration and ecosystem respiration without significant correlation.

Quantitative relationship between respiration rate and soil temperature and moisture in each degradation stage

Table 2 shows that there is an exponential correlation between soil temperature and respiration rate of each treatment in different degradation stages of alpine swamp wetland, and the sensitivity of soil respiration to temperature is the highest. In the ND, LD and SD, R^2 are 0.5721, 0.6492 and 0.5627, respectively, and the correlation of other respiratory rates is different in different degradation stages. In the ND, the order of R^2 is $R_s > R_e > R_v > R_r > R_{vc} > R_m$. In the LD, the order of R^2 is $R_s > R_e > R_v > R_m > R_r > R_{vc}$. In the SD, the order of R^2 is $R_s > R_m > R_e > R_{vc} > R_v > R_r$. On the whole, the law of $R_s > R_e > R_v > R_r$ is the common performance in all stages of wetland degradation, but in the process of degradation from alpine swamp wetland to alpine meadow, the correlation of microbial respiration, vegetation canopy respiration and temperature changes.

Linear model is used to analyze the relationship between soil moisture and respiration rate, whose results show that there is a positive linear correlation between respiration rate and soil moisture (Table 2). The coefficient of determination is as follows: In the ND, $R_v > R_s > R_e > R_r > R_m$; In the LD, $R_e > R_s > R_m$; In the SD, $R_m > R_e > R_{vc} > R_s$.

Two factor model is used to analyze the effect of soil temperature and moisture on respiration rate, whose results show that the two factor model has a higher coefficient of determination than the single factor model (Table 2). The R^2 of soil respiration is the highest (0.6926, 0.6929) in ND and LD, and the R^2 of microbial respiration is the highest (0.6625) in SD, followed by ecosystem respiration rate, with R^2 of 0.6558, 0.6768, 0.6004 in three stages respectively.

With the alpine swamp wetland degenerating into alpine meadow, the temperature sensitivity coefficient of ecosystem respiration is 1.41–1.50, that of vegetation respiration is 1.81–1.94, that of canopy respiration is 4.46–6.93, that of soil respiration rate is 1.41–2.40, that of root respiration is 2.84–5.97, and that of soil microorganism respiration is 1.99–3.74 ($R^2 > 0.2$) (Table 2). The temperature sensitivity coefficient is averaged with the order of vegetation canopy, root respiration, microbial respiration, soil respiration, vegetation respiration and ecosystem respiration, explaining that the temperature sensitivity coefficient of vegetation canopy is the highest, and that of ecosystem respiration is the lowest.

Table 2 Relationship between respiration rate and soil temperature

Degree of degeneration	Respiration type	$R=a \times e^{bT}$				$R=a \times W+b$			$R=a+b \times T-c \times W$			
		a	b	R^2	Q_{10}	a	b	R^2	a	b	c	R^2
Non-degradation	Re	0.3516	0.0404	0.5309*	1.50	0.0351	-1.5188	0.3226*	-0.7310	0.0245	-0.0176	0.6558*
	Rv	0.2352	0.0594	0.4986*	1.81	0.0511	-2.5672	0.4357*	-1.4458	0.0213	-0.0283	0.6451*
	Rvc	0.0192	0.1936	0.4338*	6.93	0.0395	-2.0971	0.1780	-0.2877	0.0344	-0.0026	0.5504*
	Rs	0.1230	0.0874	0.5721*	2.40	0.0382	-1.8963	0.3835*	-0.7884	0.0232	-0.0150	0.6926*
	Rr	0.0700	0.1044	0.4530*	2.84	0.0418	-2.2171	0.3131*	-1.1126	0.0232	-0.0187	0.5228*
	Rm	0.0194	0.1318	0.3952*	3.74	0.0162	-0.8622	0.2840*	-0.3427	0.0105	-0.0056	0.5747*
Light degradation	Re	0.4941	0.0346	0.5448*	1.41	0.0753	-3.6782	0.4236*	-1.7697	0.0198	-0.0389	0.6768*
	Rv	0.1997	0.0661	0.3432*	1.94	0.0424	-2.0234	0.0754	0.9011	0.0300	0.0132	0.3967*
	Rvc	0.2110	-0.0190	0.0135*	0.83	0.0120	-0.5147	0.0158	-0.5569	<0.0001	-0.0129	0.0152
	Rs	0.2542	0.0623	0.6492*	1.86	0.0608	-3.0488	0.2955*	-0.6728	0.0327	-0.0142	0.6929*
	Rr	0.0525	0.1187	0.2874*	5.97	0.0635	-3.4915	0.2165	-0.6858	0.0389	-0.0085	0.5888*
	Rm	0.1105	0.0689	0.3124*	1.99	0.0465	-2.3976	0.2266*	-1.6370	0.0155	-0.0301	0.5350*
Severe degradation	Re	0.4234	0.0371	0.4876*	1.45	0.0536	-2.2953	0.3104*	-1.2165	0.0226	-0.0287	0.6004*
	Rv	0.2095	0.0459	0.1030*	1.58	0.0500	-2.3704	0.1832	-1.9211	0.0095	-0.0396	0.2192
	Rvc	0.0115	0.1496	0.2077*	4.46	0.0562	-2.9957	0.2694*	-2.0577	0.0189	-0.0348	0.4250*
	Rs	0.3250	0.0341	0.5627*	1.41	0.0162	-0.3599	0.2569*	0.0069	0.0169	-0.0052	0.5585*
	Rr	0.1078	0.0446	0.0515*	1.56	-0.0019	0.3759	0.0014	0.8480	0.0213	0.0160	0.1862
	Rm	0.0367	0.1229	0.5281*	3.42	0.0551	-2.7811	0.3681*	-1.3792	0.0257	-0.0230	0.6625*

Note: * in the table indicates $P < 0.05$.

Discussion

Effects of alpine swamp wetland degradation on ecosystem respiration components

For a long time, the research results on the effects of glyphosate on soil microorganisms are mainly divided into two categories. On the one hand, it is believed that glyphosate has little effect on soil microbial individuals and groups, and in soil ecosystem, there is self balance between soil and microorganism. On the other hand, it is regarded that glyphosate plays an important role in soil microorganisms and affects natural ecology (Liang et al., 2021). On the effect study of glyphosate on soil respiration rate, some scholars believe that the relationship between glyphosate content and soil respiration rate does not reach a significant level (Hu et al., 2010), indicating that the effect of glyphosate concentration on soil respiration is not significant. The results show that glyphosate spraying has no significant effect on soil microbial respiration rate in alpine grassland. Based on the above results, this study showed that soil microbial respiration and soil respiration are close to each other in degraded alpine swamp ecosystem (including light and severe degradation), significantly higher than those before degradation. Grassland degradation plays an important role in soil respiration. For example, Lai et al (2019) analyzed the soil respiration of alpine meadow in the process of degradation in order to explore the effect of alpine meadow degradation on soil respiration, discovering that soil respiration increased at first and then decreased with the degradation of meadow in growing season. Wen et al (2014) measured soil respiration in alpine steppe with different degradation degree to find that the average soil respiration rate in the growing season increased first and then decreased during the degradation process, where the respiration of moderately degraded soil is significantly higher than that of non degraded and severely degraded soil without no significant difference in light degeneration. Silvola et al (1996) found that the decline of wetland water level made the peatland rapidly turn into carbon source or have no obvious effect on soil respiration. Mkiranta et al (2009) found that the decrease of wetland water level inhibited soil respiration and emission. However, some studies have shown that surface water in alpine wetlands significantly inhibited soil respiration and improved soil carbon stability (Hu et al., 2016), which is similar to our results. The reason is that the surface waterlogging environment and high water level will reduce the dissolved oxygen content and soil redox potential, and prevent O_2 from entering the soil, forming an anaerobic environment (Oorschot et al., 2000), so as to reduce the decomposition rate of soil animal and plant residues and organic matter, which further reduces the amount of CO_2 emitted from soil environment and inhibits soil respiration (Kraigher et al., 2006). The soil respiration rate in non degradation stage is significantly lower than that in light degradation and severe degradation stage, indicating that the soil conditions of alpine swamp wetland significantly inhibit soil respiration. The intensity and direction of the response of soil respiration to grassland degradation depend on the response of vegetation root respiration and soil microbial respiration. In this study, there is a positive correlation between root respiration and soil respiration at different degradation stages, but the degradation of alpine swamp significantly increases soil microbial respiration with no significant effect on root respiration, which is closely related to biomass allocation of degraded vegetation and soil environment. After all, in the severe degradation stage, the relationship between microbial respiration and soil temperature and moisture has a higher coefficient of determination.

Effect of alpine swamp wetland degradation on the proportion of each component of ecosystem respiration

Ecosystem respiration is divided into autotrophic respiration consumption and heterotrophic respiration consumption. There was a significant difference between the non degradation stage with higher $f(v/e)$ and lower $f(m/e)$ and the light and severe degradation stage with lower $f(v/e)$ and higher $f(m/e)$. In the three degradation stages, the proportions of non-degradation $f(v/e)$ and $f(m/e)$ are 81.1% and 19.0% respectively. In the latter two stages, $f(v/e)$ is about 62% and $f(m/e)$ is about 38%. Under different degradation stages of alpine swamp wetland, higher biomass will produce more autotrophic respiration (Cao et al., 2004), so that the $f(v/e)$ of non-degraded alpine swamp wetland is higher. There is a significant positive correlation between vegetation respiration and ecosystem respiration. Therefore, higher $f(v/e)$ ratio plays a leading role in ecosystem respiration at the same degradation stage. Ecosystem respiration is divided by space, and the proportion of vegetation canopy respiration and soil respiration in ecosystem respiration has no significant difference in different degradation stages with the proportion of $f(s/e)$ more than 60%, and $f(vc/e)$ less than 45% in three communities. In different ecosystems, the proportion of respiratory components is different. Soil respiration accounts for 70% of ecosystem respiration in forest ecosystem (Janssens et al., 2004), and in subalpine meadow, the proportion of soil respiration in ecosystem respiration is about 70% in perennial grazing meadow and seasonal grazing meadow, and the proportion of aboveground vegetation respiration is about 30% in July and August growth peak (Wang et al., 2008). In terms of absolute quantity and proportion, the aboveground vegetation respiration plays a certain role in ecosystem respiration in alpine swamp wetland and its degradation stage, but not a dominant role. Soil respiration plays a greater role in ecosystem respiration. In soil respiration, the correlation between root respiration and soil respiration is stronger than that of microbial respiration and the alpine swamp wetland and its degradation stage have high underground biomass. Therefore, it contributes a lot to soil respiration and vegetation respiration. The degradation of alpine swamp wetland leads to the decrease of biomass (Li et al., 2020), resulting in the decrease of canopy respiration, vegetation respiration and root respiration rate. In addition, the correlation between canopy respiration, soil respiration, root respiration and ecosystem respiration is different in different degradation stages. In the non degradation and severe degradation stages, canopy respiration and ecosystem respiration are significantly positively correlated, while in the light degradation stage, soil respiration, root respiration and ecosystem respiration are significantly positively correlated. The ecological process of ecosystem respiration is very complex, and the alpine swamp wetland in different degradation stages is the result of long-term climate adaptation. The reasons for the differences in the correlation between respiration components and ecosystem respiration need to be further studied and analyzed.

Response of respiratory components to soil temperature and moisture in degraded alpine swamp wetland ecosystem

The components of ecosystem respiration are affected by many factors, but most studies show that soil temperature is the most important factor affecting respiration. For example, the ecosystem respiration of alpine swamp meadow in the source region of the Yangtze River is exponentially

correlated with soil temperature (Chen et al., 2020), the ecosystem respiration, soil respiration and microbial respiration of subalpine grassland in the Central Qilian Mountains are exponentially correlated with soil temperature (Xie et al., 2016), and the canopy respiration, root respiration and mineral soil respiration of *Kobresia humilis* meadow are significantly positively correlated with soil temperature (Wu et al., 2005). In this study, the exponential model used by most researchers is used to analyze the relationship between soil temperature and respiration rate, indicating that the exponential model can well fit the relationship between respiration and soil temperature in different degradation stages of alpine swamp wetland, and the fitting effect of soil respiration and temperature is the best.

Q_{10} is an important model parameter to reflect respiratory sensitivity and predict respiratory emissions, and the small change will lead to great error in respiratory estimation. The Q_{10} values of grassland ecosystem respiration and its components are different. Q_{10} values of ecosystem respiration and soil respiration of alpine grazing meadow in northern Tibet are 1.83–3.07 and 1.54–4.13, respectively (Zhou et al., 2010); The Q_{10} of ecosystem respiration and 5 cm soil temperature of alpine meadow and swamp meadow in Fenghuoshan of Qinghai-Tibet Plateau are 2.35 and 2.75, respectively, whose 20 cm soil temperature Q_{10} are 2.35 and 4.90, respectively (Zhang et al., 2018). Q_{10} of 5 cm soil temperature and soil respiration of non degraded alpine meadow in the Sanjiangyuan region of is 2.89 (Wei et al., 2014), respectively; The Q_{10} values of soil respiration, microbial respiration, root respiration and 10 cm ground temperature of alpine meadow in Aba Prefecture of Sichuan Province on the southeast edge of Qinghai-Tibet Plateau are 2.66, 2.12 and 3.46 respectively (Meng et al., 2020). The results show that ecosystem respiration and its component Q_{10} are different in different degradation stages, ecosystem respiration is 1.41–1.50, vegetation respiration is 1.81–1.94, canopy respiration is 4.46–6.93, soil respiration is 1.41–2.40, root respiration is 2.84–5.97, and soil microbial respiration is 1.99–3.74. Q_{10} has great variability in time and space (Kirschbaum, 2000), which is related to temperature, soil moisture, vegetation, climate, litter (Tong et al., 2005), measured soil temperature (Fierer et al., 2003), soil organic carbon quantity and structure (Zhang et al., 2005). Some studies have shown that even in the same study area, the Q_{10} value will change with the temperature, growth stage, phenology and other environmental factors (Davidson & Janssens, 2006). However, most scholars often use a constant Q_{10} value to simulate and predict the interaction between ecosystem and climate system, which will inevitably reduce the accuracy of simulation and prediction (Fang & Wang, 2007). Therefore, Q_{10} may be a value influenced by multiple factors of the audience, and can only correspond to one Q_{10} in one research site and one time period. It should not be regarded as a fixed value and applied to different environments and ecosystems (Xu & Zhang, 2009).

Soil moisture is also one of the main factors affecting respiration rate. Under the condition of sufficient soil moisture to guarantee the activity of roots and microorganisms, the effect of soil temperature on respiration is obvious (Wildung et al., 1975). When the soil is in extreme drought or water logging, soil moisture becomes the dominant factor affecting respiration (Davidson et al., 2000). Water change can affect root growth of grassland plants, soil metabolic activity, soil microbial community structure and activity, soil permeability and gas diffusion (Xu et al., 2004; Chen et al., 2003), so as to influence the changes in respiratory intensity. Regardless of soil temperature, soil moisture can promote the increase of respiration rate in a certain range (Zhang, 2008). The diurnal and monthly variations of grassland ecosystem respiration rate and its components are largely determined by the differences of soil temperature (Wang et al., 2007). The results show that the moisture content in different degradation stages range from 50–65%, and the respiration is positively correlated with soil moisture. However, the correlation between soil moisture and ecosystem respiration and its component respiration rate at different degradation stages of alpine swamp wetland is lower than that of soil temperature, and the water content of alpine swamp wetland is not the main limiting factor.

In fact, the water and heat conditions in the soil do not exist separately. The interaction between soil temperature and water has a significant impact on respiration. A two factor model is used to analyze the effects of soil temperature and moisture on respiration rate, indicating that the two factor model has a higher coefficient of determination than the single factor model, which is consistent with the results obtained by Hu (2016) and Yu (2014). Therefore, it is better to simulate the effect of soil temperature and moisture on respiration by using composite model.

In the future research on the respiratory components of alpine swamp wetland ecosystem, the soil microbial respiration rate can be determined by spraying herbicides. Meanwhile, our previous research results show that the carbon sink loss caused by the degradation of alpine swamp wetland is $193.44 \pm 47.01 \text{ g} \cdot \text{m}^{-2}$ at the peak of plant growth (Li et al., 2020), emphasizing the importance of classified protection and rational utilization of alpine wetlands in different degradation stages. For example, it is strictly forbidden to open ditches and drain water for non degraded or slightly degraded alpine wetlands, so as to reduce grazing pressure, and carry out zonal management for degraded alpine wetlands (Fu et al., 2017), and promote the function of alpine wetlands as an important carbon sink.

Conclusion

There are significant differences in ecosystem respiration and its components (soil respiration and microbial respiration) among different degradation stages. The proportion of vegetation respiration and microbial respiration in ecosystem respiration changes a lot. There is a significant positive correlation between vegetation respiration and ecosystem respiration (non-degradation, light degradation, severe degradation). There is a significant positive correlation between canopy respiration and ecosystem respiration (non-degradation and severe degradation). There is a significant positive correlation among soil respiration, root respiration and ecosystem respiration (light degradation). In addition, the effect of soil temperature and moisture on respiration rate has a high coefficient of determination. In the degradation stage of alpine swamp wetland, the ecosystem respiration and its component Q_{10} are vegetation canopy > root respiration > microbial respiration > soil respiration > vegetation respiration > ecosystem respiration.

Statements And Declarations

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Competing Interests

The authors have no relevant financial or non-financial interests to disclose.

Author Contributions

Xilai Li and Chengyi Li contributed to the study conception and design. Material preparation, data collection and analysis were performed by Chengyi Li, Pengnian Yang and Chengwei Duan. The first draft of the manuscript was written by Chengyi Li and all authors commented on previous versions of the manuscript. All authors read and approved the final manuscript.

Data Availability

The datasets generated during and/or analysed during the current study are available from the corresponding author or the first author on reasonable request

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Figures

Figure 1

Plots and sampling points distribution

Figure 2

Respiratory composition of ecosystem

Figure 3

Test treatment and effect display

Figure 4

Changes of soil temperature, moisture and electrical conductivity under different treatments

Note: Different lowercase letters in the figure indicate that the difference in respiratory components has reached a significant level ($P < 0.05$); ND—No degradation, LD—Light degradation and SD—Severe degradation. Re—Ecosystem respiration, Rvc—Vegetation canopy respiration, Rs—Soil respiration, Rp—Pesticide-treated soil microbial respiration, Rr—Root respiration, Rnr—Soil microbial respiration without root treatment. The same as below

Figure 5

Changes of respiratory components in different degradation stages

Note: Different lowercase letters in the figure indicate that the difference in respiratory components has reached a significant level ($P < 0.05$); different capital letters in the yellow box indicate the same and different degeneration stage paired sample t-test results ($P < 0.05$). Re—Ecosystem respiration, Rnr—Soil microbial respiration without root treatment, Rp—Pesticide-treated soil microbial respiration, Rr—Root respiration, Rs—Soil respiration, Rv—Vegetation respiration, Rvc—Vegetation canopy respiration

Figure 6

The relationship between ecosystem respiration components and ecosystem respiration

Note: * in the figure indicates $0.01 < P < 0.05$, ** indicates $P < 0.01$. The same as below

Figure 7

The relationship between soil respiration components and soil respiration