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Nitrogen and Warming Control the Vegetation in Inner Mongolia Tourist Area

Qiong Sun(1), Xiaobing Hu(2), Chi Zhang(1,3)

(1) Tourism Institute of Beijing Union University, Beijing, 100101, China

(2) School of Engineering, University of Warwick, Coventry, CV4 7AL, United Kingdom.

(3) Centre for Creative Computing, Bath Spa University, Corsham SN13 0BZ, UK

ABSTRACT

The global warming and atmospheric nitrogen deposition problem has become more and more serious under the influence of human activities, and it has become one of the hot issues in this field, which will have far-reaching impact on all kinds of vegetation, thus the functioning of the ecosystem will be changed, which will be reflected in climate warming process. Inner Mongolia Autonomous Region is mainly composed of desert grasslands, so the development and protection of vegetation has considerable significance on the region. However, in the current environment of global warming, few studies have been carried out on desert grassland plants. In this paper, an in-depth study was carried out on the impact of warming and nitrogen addition on soil temperature, vegetation reproductive phenology and vegetation community seed rain under natural conditions during five-year period from 2011 to 2015. During the experimental period, we found that soil temperature and soil moisture decreased with the increase of soil layer, and warming obviously shortened the time of budding, flowering and fruiting of vegetation. However, no significant effect was found on nitrogen addition. Meanwhile, the impact of interaction effect of warming and nitrogen addition on seed rain was not obvious, but the year difference of all relevant indicators was significant.

Key words: Inner Mongolia; desert grassland; warming; nitrogen addition; vegetation

INTRODUCTION

Since 2000, with the increase in population, rapid economic development and increasing human activities, there appear global environmental changes, including global warming, carbon dioxide concentration increase, global nitrogen deposition (Zaldívar & Sanz, 2014; Oliva et al., 2014), which to some extent, affected the original ecosystem of various species (Buendia et al., 2015; Liu et al., 2014). The United Nations Intergovernmental Panel on Climate Change summarized on its fourth work report in 2007 that in the past few decades, earth's surface temperature increased by about 0.6 degrees Celsius. Meanwhile, it was estimated that average global temperature would increase by a minimum of 1.8 degrees Celsius in the next 2100 years. With the harsh temperature changes, nitrogen settlement of the Earth's surface is also facing a grim situation, which increased by at least 1 time. Moreover, estimated based on the model of Elisabeth, in the next few decades, with the increase of various nitrogen complexes with different activities, nitrogen settlement amount will continue to increase (Lin et al., 2011). The rising temperature and nitrogen settlement has great impact on the growth of plants. It will change the relationship between the various species, and thus affect the vegetation. Apart from the impact on

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community, reproductive phenology and seeds of vegetation, it will also cause indirect effects on plants through changing soil temperature, soil moisture and spring snowmelt time. There are many scholars who had studied in these areas, and these to some extent appeal to human to get the warning that we should protect the environment. For example, Xiaocheng Wen and Guangxin Lu put forward that warming and nitrogen addition and interaction effect of the two changed the height of alpine grassland plant communities and the fresh weight of aboveground biomass (Wen & Lu, 2015). Hongyu Guo, Wei Wang and Guangxin Lu (2015) studied on how plant growth was influenced by warming and nitrogen precipitation increase. While Jianan Cui, Yuexi Chen and Hui Sun (2015) studied on how warming and nitrogen addition affected the mineral elements release of sequoia fresh litter. As one of the necessary nutrients for the growth of plants and a kind of important fertilizer in the earth, nitrogen has drawn extensive attention from experts. Abbasi et al. performed a study to determine the nitrogen-release potential of residues added to soil and indicated that nitrogen concentration was an indicator for the mineralization of organic residues (Abbasi et al., 2015). Yu and Jia observed the increase of soil organic carbon (SOC) and total nitrogen (TN) in the soil and revealed that root biomass could increase SOC and TN (Yu & Jia, 2014). Scharenbroch et al. proved that nitrogen availability of soil could promote the growth of trees (Scharenbroch et al., 2013).

This paper carries out an in-depth analysis on three aspects of soil temperature, vegetation reproductive phenology and vegetation seed rain based on the results obtained from the experiments during 2011 - 2015. It analyzes what impact will be brought by man-made warming and nitrogen addition to plants under natural conditions, so as to estimate the crisis which Inner Mongolia grassland ecosystem may face when there is natural environmental warming and increase of amount of nitrogen precipitation. Also, it can be taken as a warning to call upon humans that we should protect the environment.

MATERIALS AND METHODS

In this experiment, we selected a base located in south central part of Inner Mongolia Ordos Grassland, with a total area of 33,000 acres and a large part of the base are natural grasslands (Johansson et al., 2008). Then we chose an area of desert grasslands and farming-grazing zone as the base of this experiment since this region is relatively local with regional characteristics. The desert grasslands in that region belong to the grassland vegetation subtype with strongest xerophytism among temperate grassland vegetation (Urano et al., 2000), so it is a very suitable base for this experiment.

We carried out a five-year experiment on Inner Mongolia Ordos Grassland from March 2011 to March 2015. Firstly, a warming control device was set up for the quadrat. In the five consecutive years, we conducted a soil warming and nitrogen addition process. Take the soil with 10 cm, 20 cm and 30 cm surface layer as samples and make comparison. Meanwhile, record the relevant data on vegetation reproductive phenology changes during 2011- 2013. Also, analyze the seeds obtained by the 64 seed rain collectors in the five years, and the following can be concluded based on the analysis on its temperature and humidity.

According to the test project, a control test on simulated warming and nitrogen addition under wild natural conditions was carried out. In this test, warming was taken as a simulated global climate change factor and nitrogen addition was taken as a man-made interference factor of global nitrogen settlement. The design was divided into four kinds of treatment experiments which were warming treatment (W), nitrogen fertilizer treatment (F), warming and nitrogen fertilizer treatment (WF) and control treatment (

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without warming or nitrogen fertilizer treatment, C) respectively. Each treatment was repeated six times and 24 treatment plots were included. The designed area of each plot was 8 m^2 (4m×2 m) and the total area of the test was 192 m^2. All treatment groups in the plot were equally distributed in order to avoid the influence of direction and orientation on test results. Infrared heating method was adopted for simulated warming in the test. The infrared radiator, with a length 1.5 m and a width of 18 cm, was hung 2.75 m high above the ground through a steel pipe with a diameter of 4.6 cm. The maximum power of the infrared radiator was 2250 watt and the gear was adjusted to 8-speed when used. In order to avoid test errors caused by shade effect of infrared radiator as well as block effect of infrared ray on rainfall, false radiators of the same shape and size were installed at the same position of the same height as the real ones for treatment groups which didn't require warming. Ammonium nitrate, whose chemical name is NH_4NO_3, was selected as the nitrogen fertilizer, with a nitrogen content of 33.7%. The application time of nitrogen fertilizer was during the end of June and beginning of July when the rainy season approaches annually.

The test project began from March 2011 and the infrared heating test never stopped or was interrupted for even a single day all year round from the beginning to the duration of this test.

RESULTS

When only soil warming was conducted, temperature increased respectively by 1.29 °C, 0.83 °C, 0.80 °C and 0.71 °C; when only nitrogen addition was conducted, the temperature of the surface layer decreased by 0.18 °C, soil temperature decreased by 0.05 °C, 0.03 °C and 0.01 °C respectively at 10 cm, 20 cm and 30 cm layer. However, when both warming and nitrogen addition were conducted, soil temperature of each layer increased respectively by 1.11 °C, 0.78 °C, 0.77 °C and 0.70 °C.

Through repeated variance measurement, it is found that all of the four dominant species were affected by warming and nitrogen addition in the three growing seasons during 2011-2013 in the experiment. And for the time of duration of budding, flowering, fructification and reproductive growth of vegetation, the shortening of average time is more obvious under the warming situation (figure 1); while the shortening of average time under nitrogen addition situation is not obvious (figure 1). When under both warming and nitrogen addition situation, the shortening of average time is less obvious than that under mere warming situation (figure 1).

Through the observation on data results of the impact of warming and nitrogen addition and the interaction of the two on budding time of various species during the three growing seasons from 2011 to 2013, it is found that impact of warming varies on different vegetation species, i.e. there exists the specificity; while for the same vegetation, there presents the difference on impact of warming in different years. Seen from table 1, the budding time of breviflora griseb, convolvulus ammannii and bassia prostrate was shortened significantly due to warming process in 2011. While in 2012, the budding time of breviflora griseb and allium tenuissimum was shortened significantly under warming treatment condition. And in 2013, the budding time of allium tenuissimum and bassia prostrate was shortened significantly due to warming treatment.

At the same time, we also analyzed the experimental data of flowering time of each species in each growing season under both warming and nitrogen addition treatment during 2011-2013. The results show that the response of flowering time of each species to warming is similar with that of budding time;

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there is also specificity in response of each species to warming. For example, in 2011, the flowering time of stipa breviflora and bassia prostrate was significantly reduced under the influence of warming, but no obvious effect was found on the flowering time of convolvulus ammannii and allium tenuissimum. In 2012, only the flowering time of allium tenuissimum was shortened obviously under the influence of warming. While according to the data of 2013, warming has no significant effect on the flowering time of all the species (table 2). Therefore, interaction effect of nitrogen addition and warming has little impact on the flowering time of various species.

From the analysis of data results of fructification time of various species under both warming and nitrogen addition treatment in the three growing seasons during 2011-2013, each species' response to warming has the specificity, that is to say, in the same year, the results affected by warming have different performance in different species. Similarly, for the vegetation itself, its response to warming varies from year to year. In 2011, under the man-made warming treatment, the fructification time of stipa breviflora, convolvulus ammannii and bassia prostrate was significantly shortened. In 2012, there was significant shortening in fructification time of allium tenuissimum due to warming treatment; while seen from table 3, fructification time of stipa breviflora was significantly shortened only by warming in 2013. The response of each species to nitrogen addition conforms to the same law. There is no significant effect on each species in each year.

From the analysis of data results of duration of reproductive growth of various species under both man-made war ming and nitrogen addition treatment in the three growing seasons during 2011-2013, we find that no matter what year it is, there is no significant effect of warming and nitrogen addition on reproductive growth duration of convolvulus ammannii and allium tenuissimum. However, there is a year difference on the effect of warming on the reproductive growth duration of stipa breviflora and bassia prostrate. As can be seen from the table, in 2011 and 2012, the reproductive growth duration of stipa breviflora was significantly shortened under the influence of warming; while in 2012, no significant effect was found on the reproductive growth duration of stipa breviflora and bassia prostrate under the influence of warming; in 2013, a significant shortening of the reproductive growth duration of bassia prostrate was found, as seen in table 4.

During the five year period of growing seasons from 2011 to 2015, the 72 seed rain collectors on the base collected altogether 147,757.19 seeds. The average density of the seed rain is 1229.6 ± 145.8 grains (Mean±SE), and all the seeds belong to 6 families, 8 genera and 8 species. In table 5, there is detailed record of the seed rain information, including stipa breviflora, cleistogenes songorica and wheatgrass, which are perennial bunch grass belonging to grass family. And stipa breviflora and cleistogenes songorica are the vegetation which contribute most to seed rain with rate of contribution of 22.37 ± 2% and 13.11 ± 1% respectively. There are 2 families, 2 genuses and 2 species of perennial herbs which are called allium tenuissimum and convolvulus ammannii. Among all the observed species, allium tenuissimum (its contribution rate is 37.92 ± 2%) makes the greatest contribution to the quantity of seeds rain, and the contribution rate of subshrub bassia prostrate is 14.86 ± 3%. As for annual herbs and biennial herbs, their contribution rates are lower compared with those of the former ones and appear randomly in different years.

Figure 2~6 show the impact of warming and nitrogen addition on seed rain density of cleistogenes songorica, allium tenuissimum, bassia prostrate, stipa breviflora and plant community .

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DISCUSSION

Under the circumstances of global warming, in order to study the functional mechanism between ecosystem and climate warming, various climate warming simulation tests were adopted, including resistance heating, far-infrared irradiation, top-open and top-close field greenhouse (Choi et al., 2012), intercross transplantation etc. In this study, warming through infrared radiation was carried out under wild natural conditions. Through the test, we found that soil temperature increased while soil humidity decreased after warming, suggesting that the warming test had a warming effect. However, the warming effect and amplitude of this study is lower than that of the top-open warming method, which is mainly due to the difference of warming methods. Far infrared warming method can keep the climatic factors of sample plot such as natural air, wind speed, rainfall, temperature and humidity basically the same as the natural climate conditions of the desert steppe, which minimizes the interference of human factors caused by the warming method based on short-term control of air flow (Murakami et al., 2000), thus can truly and objectively reflect and simulate the influence of climate warming on desert steppe.

Soil respiration (Nordgren et al., 2001) is a very complex soil ecological process. To some extent, temperature is considered as the most important factor which influences total soil respiration rate. However, in this study, no significant difference was found on soil respiration rate between warming group and control group, no matter on seasonal change or on daily variation. For small area of sample plot, the response of soil respiration to soil temperature changes showed great uncertainty, which may be related to the spatial difference of water conditions, soil nutrient (Drechsel et al., 2001), biomass of plants and microorganisms, etc, in addition to the short experimental time and low increasing extent of temperature. Soil respiration is a very complicated biogeochemical process and not only the above factors can affect directly or indirectly the generation and emissions of carbon dioxide in soil but also the status and role of these factors will have corresponding changes with the change of temperature. Under certain conditions, they may have modification, correction, and even cover-up effect on the effect of temperature.

The far infrared warming test caused changes in dominant species and composition of the community instead of changes of plant community. This may be because that far infrared warming effect, to some extent, meets the demand for heat of the plant and changes the microclimate environment of plant community and therefore influences the growth and development of plant to a certain degree (Hu et al., 2015). Besides, warming has also changed the content of moisture in soil and influenced moisture absorbing of plant. The growth and biomass of the plant are also affected to varying degrees. The results showed that, for any kind of plant community under the environment of global warming, there are always some species whose response to temperature rises are more sensitive, so as to destroy the interspecific competition and cause changes in community dominant species and composition.

According to some experts, soil moisture decrease caused by warming can prevent the growth of superficial roots, increase root mortality and enhance plant respiration, thus lower the net primary productivity of plants. Warming changed the distribution of the underground biomass (Singh et al., 2014). Compared with the control sample plot, underground biomass decreased in 0 ~ 10 cm soil layer of the warming sample plot while that in 10 ~ 20 cm soil layer increased slightly and the underground biomass

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increased significantly in 20 ~ 30 cm soil layer, which is also related to soil moisture decrease caused by warming. Since warming reduces soil moisture, water becomes the most key factor limiting plant growth. In order to better adapt to the environment, plant roots extend to a deeper level for water, thus the underground biomass transfers to deep soil.

Nitrogen is one of the most needed nutrients (Parras-Alcántara et al., 2013) for plant growth in terrestrial ecosystem. The addition of nitrogen increases soil mineral nutrients and improves carbon nitrogen ratio in soil. Moreover, it can improve microbial activity and increase supply of soil respiration, so as to promote the soil respiration. The result showed that soil respiration rate of nitrogen fertilizer sample plot was higher than that of the control sample plot. However, statistics showed that the difference was not significant, indicating no effect of nitrogen in soil respiration.

Though the addition of nitrogen changed the height, density, coverage and frequency as well as important value of some species of plants, it increased the above-ground biomass of plant species and plant functional groups, suggesting that the increase of above-ground biomass is not related with the addition of nitrogen, instead, it may be related to water conditions, soil environment and affinity interaction of the environment of the year.

Seed rain density of the four main species which make major contribution to plant community was analyzed. From the perspective the plant community level, we conclude that the seed rain density will not be significantly affected due to the warming and nitrogen addition process. However, there is significant difference in years, which is mainly reflected in 2012, 2013 and 2015. From the perspective of species level, these plants were not significantly affected (expect bassia prostrate), but difference between years of the four species are significant. For different species, their response to years is different from each other. The largest seed rain of stipa breviflora occurred in 2014 and 2015 while that of cleistogenes songorica occurred in 2011, 2013 and 2015. The largest seed rain of allium tenuissimum occurred during 2011-2013 while that of bassia prostrate occurred in 2012, 2013 and 2015. Take the year as the statistic unit and analyze the impact of interaction effect of warming and nitrogen addition on seed rain density from 2011 to 2015 (figure 2). Under the condition of warming and nitrogen addition, the seed rain density of cleistogenes songorica and plant community was not affected. But a significant influence can be found on allium tenuissimum, bassia prostrate and stipa breviflora in some years. Besides, significant effect can also be found on the seed rain of allium tenuissimum and bassia prostrate. In addition, when comparing the impact of warming and nitrogen addition on seed rain of stipa breviflora respectively, a significant difference is found.

Through the comparison on seed rain of plant community and the fastigium species number of aboveground vegetation and the analysis of the similarity index applying three-factor analysis of variance, the results show that aboveground vegetation species number decreased significantly under the warming condition. However, from the perspective of seed rain species number and shared species number, there is no significant impact. Still there are significant differences between years (Stott et al., 2014). The maximum and minimum species number of aboveground vegetation was found in 2012 and 2014 and there is significant difference between them. Besides, there is no significant difference in the similarity index of Sorense and Jaccard under both warming and nitrogen addition conditions.

CONCLUSION

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This study takes the stipa breviflora desert grassland in Siziwang Banner, Inner Mongolia as the object of study, carried out a five-year research by applying the method of man-made warming and artificial simulation of atmospheric nitrogen settlement, combined with field survey and ecosystem control test. And an in-depth understanding was obtained through the aspect of soil temperature and humidity, reproductive phenology of vegetation, as well as seed rain. However, because desert steppe ecosystem response to climate change involves many aspects and is a process of multi-channel interaction, there exist some flaws in the results of the research, and there are some factors of uncertainty and ambiguity as well in the study, which still needs further improvement in future researches.

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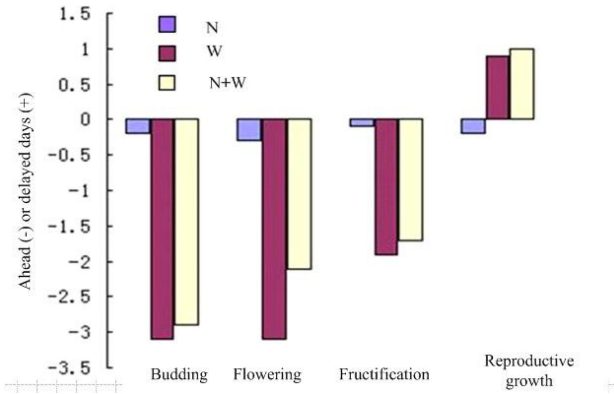

Fig. 1 Impact of warming (W), nitrogen addition (N) and the interaction effect of the two (W+N) on average time of duration of budding, flowering, fructification and reproductive growth of four dominant species in the three growing seasons during 2011-2013

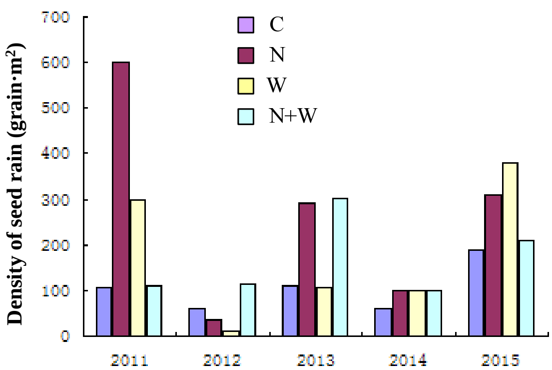

Fig. 2 Impact of warming and nitrogen addition on seed rain density of cleistogenes songorica

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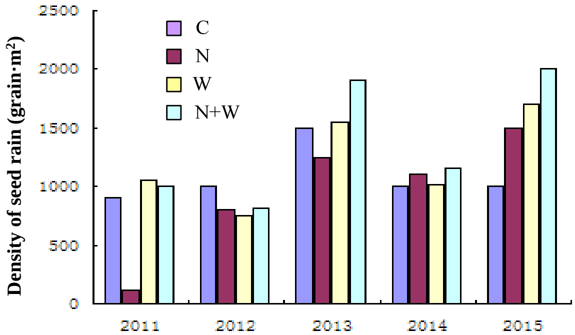

Fig. 3 Impact of warming and nitrogen addition on seed rain density of allium tenuissimum

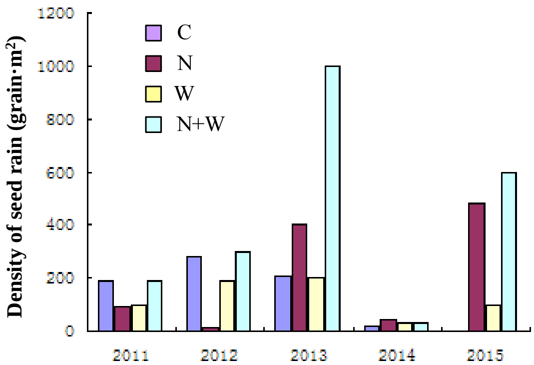

Fig. 4 Impact of warming and nitrogen addition on seed rain density of bassia prostrate

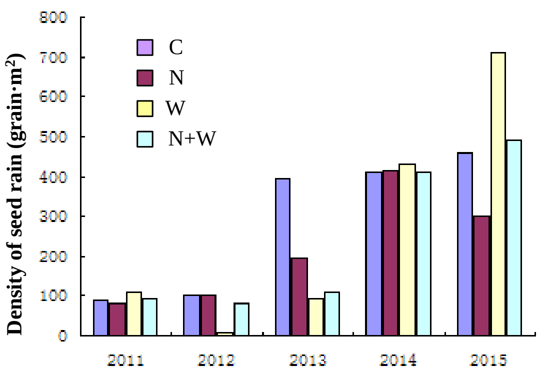

Fig. 5 Impact of warming and nitrogen addition on seed rain density of stipa breviflora

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Fig. 6 Impact of warming and nitrogen addition on seed rain density of plant community

Table 1 Two-factor variance analysis results of budding time of the four main species under nitrogen addtion, warming treatment and the intereaction effect of the two in growing seasons from 2011 to 2013

Year	**Source of variation**	**plant species**			
		Sb	**Ca**	**At**	**Kp**
2011	Warming	0.005	0.031	0.148	<0.001
	Nitrogen	0.159	0.588	0.262	0.459
	W*N	0.309	0.194	0.062	0.153
2012	W	0.008	0.231	0.004	0.166
	N	0.666	0.546	0.474	0.959
	W*N	0.619	0.816	0.125	0.815
2013	W	0.210	0.132	0.035	<0.001
	N	0.704	0.731	0.120	0.431
	W*N	0.634	0.977	0.680	0.537

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Table 2 Two-factor variance analysis results of flowering time of four main species under interaction effect of nitrogen addition and warming in three growing seasons during 2011-2013

year	Source of variation	plant species			
		Sb	Ca	At	Kp
2010	Warming	0.007	0.054	0.121	<0.001
	Nitrogen	0.148	0.783	0.411	0.126
	W*N	0.950	0.204	0.091	0.118
2011	W	0.213	0.289	0.003	0.116
	N	0.471	0.229	0.512	0.485
	W*N	0.192	0.575	0.191	0.761
2012	W	0.089	0.123	0.081	0.059
	N	0.845	0.286	0.671	0.163
	W*N	0.630	0.436	0.829	0.487

Table 3 Two-factor variance analysis results of fructification time of four main species under the interaction effect of warming and nitrogen addition in three growing seasons during 2011 to 2013

Year	Source of variation	Plant species			
		Sb	Ca	At	Kp
2011	Warming	0.015	0.023	0.101	<0.001
	Nitrogen	0.122	0.653	0.734	0.091
	W*N	0.343	0.262	0.172	0.112
2012	W	0.983	0.556	0.012	0.240
	N	0.389	0.156	0.550	0.117
	W*N	0.083	0.923	0.520	0.013
2013	W	0.015	0.811	0.089	0.632
	N	0.623	0.980	0.158	0.801
	W*N	0.711	0.836	0.739	0.881

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Table 4 Two-factor variance analysis results of reproductive growth duration of four main species under the interaction effect of warming and nitrogen addition in three growing seasons during 2011-2013

year	**Source of variation**	**Plant species**			
		Sb	**Ca**	**At**	**Kp**
2011	Warming	0.003	0.405	0.139	0.736
	Nitrogen	0.374	0.385	0.189	0.965
	W*N	0.054	0.959	0.871	0.545
2012	W	0.009	0.269	0.359	0.291
	N	0.989	0.112	0.605	0.831
	W*N	0.379	0.602	0.125	0.511
2013	W	0.105	0.037	0.653	<0.001
	N	0.022	0.146	0.027	0.931
	W*N	0.604	0.545	0.222	0.139

Table 5 The basic information of plant species and seed rain percentage

Species name	**Latin name**	**Life form**	**Seed percentage（%）**
Cleistogenes songorica	Cleistogenes songorica	Perennial hydrophobic cluster grass	13.11±1
allium tenuissimum	Allium tenuissimum	perennial herb	37.92±2
Bassia prostrata	Kochia prostrata	subshrub	14.86±3
Stipa breviflora	Stipabreiflora	Perennial bunch grass	22.37±2
Neopallasia pectinata	Neopallasiapectinata	Annual and biennial	2.11±1
Agropyron cristatum	Agropyron cristatum	Perennial clustered	0.98±0.5
Common Russianthistle	Salsola collina	Annual herb	7.96±0.3
Convolvulus ammannii	Convoivuius ammannii	perennial herb	1.12±0.1