Chapter 1

The Plant Functional Traits of Arid and Semiarid Grassland Plants under Warming and Precipitation Change

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Additional information is available at the end of the chapter

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Abstract

In recent years, climate change has produced a trend of temperature rising and fluctuation of annual precipitation in arid and semiarid grassland ecosystem, which has an impact on grassland plant functional traits including plant morphology, photosynthesis, and respiration efficiency. The dominant species in China's arid and semiarid grassland are *Stipa krylovii*, *Stipa breviflora*, *Leymus chinensis*, and other common steppe species. This study summarized the results of temperature and precipitation change test in the growing season in China's arid and semiarid grassland and analyzed the change rule of plant functional traits of typical species. According to several test results, the plant functional traits generally changed as follows: (1) plant height showed declined trend under warming and dry condition, but plant total leaf number and leaf area increased, and root-top ratio decreased as temperature and precipitation went up. (2) Chlorophyll content and plant photosynthesis and respiration efficiency grew under warming and high precipitation. (3) Hydrothermal conditions had synergistic effect on plant functional traits; increased precipitation helped grassland species to resist high-temperature stress. This study contributed to an understanding of plant morphology and physiological response to climate change of dominant species in China's arid and semiarid grassland.

Keywords: grassland plants, plant functional traits, plant morphology, photosynthesis and respiration efficiency, climate change

1. Introduction

Greenhouse gases such as CO_2 released by human activities contribute to the increase of atmospheric temperature [1, 2]. Sea level rise [3] and global precipitation fluctuation [4, 5] caused by global climate change have great impacts on terrestrial ecosystem. Forest, grassland, and farmland ecosystems show their responses to temperature and precipitation change on microscale, appearing as the relationship between plant morphology and physiological characteristics and climate factors [6–9]. As an important basic part of the ecosystem, plants become an ideal indicator in climate change simulation research. Plant functional traits refer to a series of plant physiological and ecological indicators reflecting plants absorb, use, and maintain resources [10]. Plant functional traits show the functional characteristics of the ecosystem and the change of the environment [11]. In this chapter, plant functional traits include plant morphology, plant photosynthesis, and respiration indicators. Summarizing plant functional traits change rules under warming and precipitation changes contributes to the indication analysis of grassland plants on global climate change and provides scientific basis to explore the response of grassland ecosystem to climate change on microscale.

Grassland is the largest terrestrial ecosystem in China, accounting for 41.7% of China's land area [12]. It is an important ecosystem in northern and northwestern China. The constructive species in China's arid and semiarid grassland are mostly *Stipa krylovii*, *Stipa breviflora*, *Leymus chinensis*, and dozens of other xerophyte grassland plant species. They have curled leaves, inside porosity, narrow leaf area, and strong root system to help them to be resistant to dry climate. In spring, summer, and autumn, the grass leaves are perfect forage for livestock. According to research, since the 1980s, the average temperature in China's Inner Mongolia grassland region experienced an obvious increasing trend; the rate of warming was 0.4°C/10a, which was far more than the average warming rate of mainland China. In addition, the average annual precipitation of Inner Mongolia grassland region in the last 50 years continually decreased with a rate of 4.5 mm/10a [13].

As an important environmental factor of grassland ecosystem, the effects of climate change on the physiological and ecological characteristics of grassland plants are significant. The change of the key environmental factors such as temperature and precipitation will influence the grassland ecosystem dominant species through disturbing their physiological and ecological processes, such as plant morphology, evapotranspiration, decomposition, photosynthesis, respiration, etc. The increase of the concentration of CO_2 in the atmosphere causes warming and precipitation change and has a significant impact on plant functional traits and causes grassland ecosystem adaptations in different scales, grassland communities' productivity, composition, and ecological system change with climate change [14].

The response of grassland ecosystem to climate change is summarized in three scales: species, community, and ecosystem (**Figure 1**). A large number of research focus on the community structure [15], community productivity [16, 17], and the assessment biodiversity of different grassland ecological systems [18, 19]. Most of the plant photosynthesis and respiration research also provide results on ecosystem scale, which discuss the contribution of photosynthesis and respiration to carbon balance [20]. However, there is less research in species scale, focusing on the dominant species of Chinese grassland such as *Stipa* and *Leymus* in the face of the temperature increase and rainfall decrease condition, analyzing the plant morphology,

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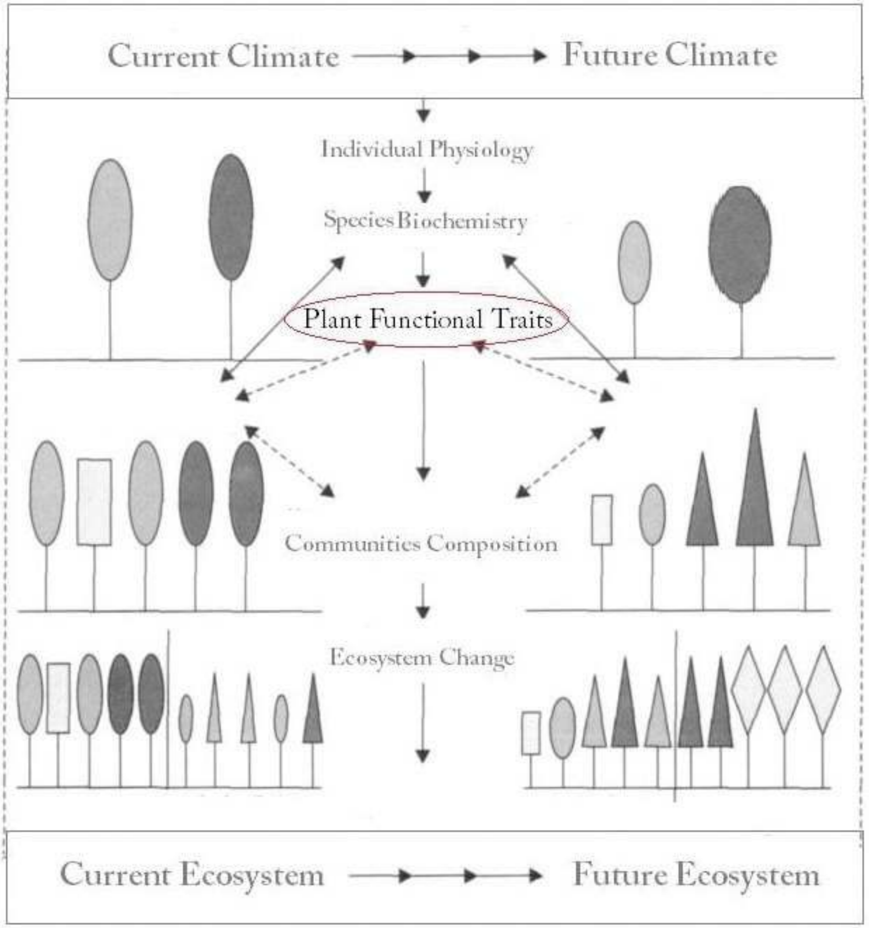

Figure 1. Influence of climate change on ecosystem in different scales.

photosynthesis, and respiration efficiency and other physiological-ecological responses and the adaptive strategies. Therefore, this chapter summarized plant morphology and photosynthetic and respiratory efficiency changes of typical arid and semiarid grassland under different warming and precipitation conditions, showed the response mechanism of typical grassland plant functional traits to climate change, and explained the adaption of China's arid and semiarid grassland ecosystems to climate change on microspecies scale.

2. The influence of warming and precipitation change on plant morphology

Plant morphology refers to the change of plant appearance and structure, including ground parts (leaf, flower, and seed) and underground parts (roots). Environmental changes may result in different structures of plants with the same genes, such as different plant height and leaf area. The expression of plant physiological changes affected by the environment is shown in the form of plant structure. Therefore, it is helpful to understand the adaptation mechanism of plant morphology under temperature and precipitation change. The responses of plant morphology to temperature and precipitation change were summarized in **Table 1**.

2.1. Effects of warming

The ground part of plant morphology includes plant height, branch, canopy, etc. These characteristics play an important role in the obtaining and use of sunlight energy. The influence of warming on plant structure shows indeterminacy in different species and regions. The herbaceous species in arid region may increase individual growth rate under warming condition, which leads to a shorter growth cycle. As a result, the time for "carbon fixed" and biomass accumulation before seed production is reduced, leading to the formation of shorter individuals by the plant [21].

Leaves are the main plant photosynthetic organs; among all of the plant organs, the leaves have the largest morphological diversity and flexibility under environmental change. The influence of temperature on leaf morphology is indefinitely according to different grassland species [22]. Han et al. [23] found that the leaf thickness of C4 plant such as *Leymus* increased with temperature rise, but the leaf thickness of C3 plant such as *Stipa* did not show the same trend. The influence of temperature on plant total leaf area also indicates a large variability. In general, plant leaf area increases with temperature rise [24]. Under the same temperature range, the increasing rate of annual herb SLA on grassland is larger than woody plant SLA.

The root morphology is the spatial distribution structure of root system. It shows the dynamic response to temporal and spatial variation of nutrient supply and other related constraints

Plant morphology	**Warming**	**Precipitation increased**
Plant height	↓	↑
Leaf thickness	C4↑, C3→	Uncertain
Total leaf area	↑	↑
Single leaf area	Uncertain	→
Leaf number	Uncertain	↑
Leaf nitrogen	Uncertain	↓
Root length	↑	↓
Root diameter	↑	Uncertain
Root-top ratio	↑	↓

↑ means positive correlation, ↓ means negative correlation, → means invariability, "uncertain" means insufficient research evidence.

Table 1. The change rule of plant morphology under warming and precipitation change.

[25, 26]. Plant root system has an important role in plants' life course. However, there is little research that focus on root structure and morphological characteristics, and most of them are qualitative description rather than quantitative measurement. In general, warming condition increases the root length and activity, improves the nutrient obtained and rate of the unit root length, and thus affects the growth and morphology of the whole plant root system [27]. The present research suggested that with sufficient nutrition and sunlight conditions, when plants grew below the optimum temperature, warming would promote the expansion of the root, increased the diameter of the fine root, and changed the root branching pattern [28]. When the temperature is higher than optimum, the increase of temperature will limit the growth of plants. The effect of warming on root-top ratio of different grassland species is different. Research on the grassland plants in an arid area showed that the temperature rise had no significant effect on the root-top ratio of herbaceous plant [29, 30], but Hou et al. [31] made a conclusion from the study of four herbaceous plants in grassland that *Stipa* and *Carex* species root-top ratio decreased as temperature rise.

2.2. Effects of precipitation

Water and precipitation are the main limiting factors affecting plant growth and survival in arid and semiarid regions. The adaptation characteristics of desert plants are all related to the use of water resources. Limited precipitation directly restricts the expression of grassland plant morphology, and plants are confronted with the balance of resource allocation in growth, reproduction, and maintenance [32, 33]. The response of grassland plant morphology to precipitation is the results of plants' long-term adaptation to drought.

Precipitation has positive correlations with plant height, total leaf area, plant tiller number, and leaf number but has no obvious influence on single leaf area [34]. The change of total leaf area is mainly because of leaf number change. Leaf nitrogen content and chlorophyll content are positively correlated with precipitation. In China temperate grassland, the *Stipa* and *Leymus* species' leaf nitrogen apparently increases in low precipitation condition, which is the strategy of plant to tolerate water limitation [35], but severe drought decreases wheat nitrogen content [36]. The influences of precipitation on plants have a great extent and depth. Grassland plants have several sensitivity and variable indicator response to precipitation change. Research showed that under less rainfall, *Stipa* plant height, biomass, and seed weight decreased, and leaf length and root-top ratio increased. The *Stipa* species improved water use efficiency by reducing leaf number, spending more on root system to absorb moisture from soil as much as possible [37, 38]. *Stipa* becomes a dominant species in the drought environment in China's Inner Mongolia arid and semiarid grassland. Due to long-term adaptation to the drought environment, *Stipa* adapts to low precipitation by increasing root-top ratio in greater degree, reducing the growth of plant organs—for example, lessen plant height and leaf number—and giving priority in maintaining the growth of root system to ensure the moisture absorption. It is proved that grassland plants have strong drought tolerance ability [39].

Generally speaking, under abundant precipitation, grassland plants have larger total leaf area, plant height, tiller number, and leaf number. However, in the drought environment, plants adapt to drought conditions with a number of growth strategies, including reducing the ground biomass, plant height, and leaf number, slowing down growth rate, and increasing root-top ratio [40].

3. The influence of warming and precipitation change on plant photosynthesis

Photosynthesis is the process of plant absorbing light energy and compounding organic matter through CO_2 and water (H_2O) synthesis and releasing O_2 at the same time. It is the basis of material circulation and energy flow of land ecosystem. Photosynthesis is easily affected by the growth of plants [41–43] and environmental conditions (such as illumination, temperature, and moisture) [44, 45]. Temperature and precipitation are the most important climatic factors affecting plant photosynthesis. The responses of plant photosynthesis to temperature and precipitation change were summarized in **Table 2**.

3.1. Effect of Warming

Plant photosynthesis is a chemical reaction consisting of a series of enzymatic reactions. Photosynthesis has the highest efficiency under optimum temperature range; temperatures fall too far below or above this range will make photosynthesis efficiency decrease. And the decrease rate shows differences between different species [46]. On the one hand, cold climate inhibits photosynthesis because the low temperature leads to membrane lipid phase change, chloroplast ultrastructure damage, and the passivation of enzymes. On the other hand, high temperature causes thermal denaturation of membrane lipid and enzyme protein and enhances plant light respiration and dark respiration which reduce the net photosynthetic efficiency. C4 plants' optimum temperature of photosynthesis is 40°C, and C3 plants' optimum temperature of photosynthesis was around 25°C [47] (**Figure 2**). Moderate warming could increase photosynthetic efficiency and water use efficiency and raise other photosynthetic parameters of plants [48, 49], but excessive warming will repress photosynthetic efficiency [50].

Temperature affects plant leaf photosynthesis in many ways, such as the influence of temperature on stomatal conductance, chlorophyll content, intercellular CO_2 concentration, thylakoid

Plant photosynthesis	Warming	Precipitation increased
Leaf stomatal conductance	↓	↑
Chlorophyll content	↑	↑
Intercellular CO_2 concentration	↑	↑
Water use efficiency	↓	↓
Photosynthesis efficiency	Uncertain	↑

↑ means positive correlation, ↓ means negative correlation, "uncertain" means insufficient research evidence.

Table 2. The change rule of plant photosynthesis under warming and precipitation change.

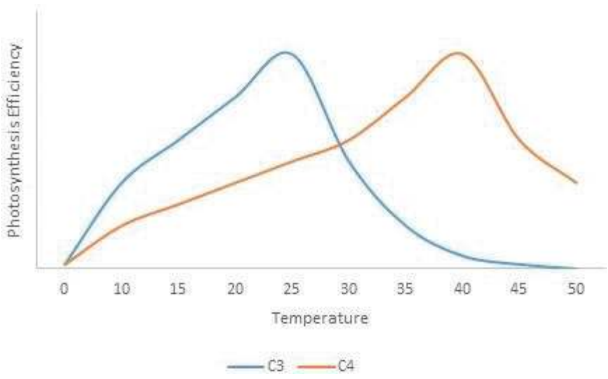

Figure 2. Correlation between temperature and photosynthesis efficiency [47].

membrane, electron transfer, and rubisco activity. It is generally believed that as the temperature increases, leaves' stomatal conductance and transpiration decrease, whereas saturated vapor pressure difference and water use efficiency increase [51, 52]. Hikosaka [53] compared the main parameters of photosynthesis affected by temperature, including the intercellular CO_2 concentration, the maximum rate activation energy of ribulose-1,5-bisphosphate(RuBP) catalyzes (Eav), and maximum rate activation energy of RuBP regeneration ability (Eaj). He pointed out that the Eav and Eaj were the most sensitive parameters to temperature changes and dominant factors to determine the optimal temperature of photosynthesis. At present, the influence of temperature on photosynthetic efficiency of plants is still controversial. The increase of temperature is conducive to plant photosynthesis [54, 55], or inhibitive [56], or no significant effect [57, 58]. This may relate to different geographical locations, vegetation types, and different temperatures, which need to be verified by field simulation results in specific regions.

3.2. Effect of precipitation

Water is an important ecological factor to maintain plant growth and reproduction. Water is not only an important component of plant and metabolism reaction substance but also the solvent of material absorption and transport for plant. However, water consumed by plant photosynthesis only accounts for a small percentage of the plant's absorption from the soil (about 1%), most of the rest is lost by transpiration [59].

In arid and semiarid regions, the influence of precipitation change on photosynthesis is larger than warming [60], because water in this area is the main restrictive environmental factor affecting plant growth and productivity [61, 62]. Research showed that increasing precipitation promoted the photosynthetic rate, stomatal conductance, and transpiration rate of plants but led to the decrease of plant water use efficiency [63, 64], while water stress had the opposite influence [65]. Plant leaf chlorophyll content and photosynthetic rate decrease significantly after precipitation reduces. Even if rainfall increases again, it still could not reverse the downward trend of chlorophyll content at the beginning [66]. The effect of soil water increased and high temperature together has compensated effects on plant photosynthesis [56]. However, excessive soil moisture content leads to the decrease of soil aeration, interferes with the root activity, and indirectly reduces photosynthesis efficiency.

4. The influence of warming and precipitation change on plant respiration

Respiration is the process by which the organic matter in cells is oxidized and decomposed under the action of a series of enzymes. Respiration provides most of the energy needed for plant life. Part of the energy released during respiration is stored in the form of high-energy compound adenosine triphosphate (ATP). The energy released by ATP hydrolysis process is supporting plant life and activities in the body, such as cell division, plant growth, the absorption of mineral elements, etc. Other energies convert into heat energy and lose in the air. The intermediate product of oxidation provides raw materials for many biosynthesis processes. The emission of CO_2 in respiration is an important physiological process, which affects the carbon balance of plants and ecosystem. The responses of plant respiration to temperature and precipitation change were summarized in **Table 3**.

4.1. Effect of warming

Since respiration is an enzymatic reaction, the factors that affect the activity of enzymes also affect respiration. According to the correlation curve of temperature and enzyme activity, plant respiration has three temperature basis points, the highest, the optimum, and the lowest point (**Figure 3**). Exceeding the lowest and highest temperature point causes the destruction of the cell protoplasmic structure and eventually causes the plant death. The optimum temperature for respiration refers to a temperature range which can maintain a high level of respiration efficiency. For most of the grassland plants, the lowest respiration temperature is about −10 to approx. −20°C. Some cold-resistant plants can survive as low as −25°C. The highest respiration temperature is around 45°C. According to *Stipa* grassland control experiments, the largest respiration rate appears in 40°C, but the duration is very short and quickly decreases. However, at 25°C, although the respiration rate is lower than the rate of 40°C at the beginning, it can maintain a high level for a relatively long time [67, 68]. In addition,

Plant respiration	Warming	Precipitation increased
Leaf stomatal density	*Stipa*, *Leymus*↑ *Carex*→	Uncertain
Metabolic heat release rate	↑	Uncertain
CO_2 output rate	↑	Uncertain
Respiration efficiency	Optimum range↑	Generally ↑, soil moisture saturated or below 60%↓

↑ means positive correlation, ↓ means negative correlation, "uncertain" means insufficient research evidence.

Table 3. The change rule of plant respiration under warming and precipitation change.

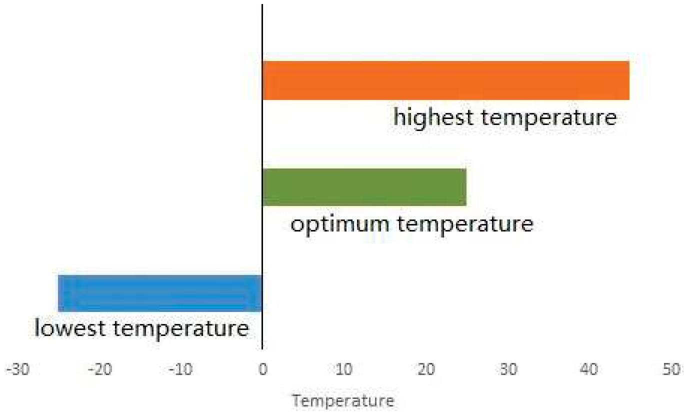

Figure 3. The three basis points of respiration temperature.

the effect of temperature on the respiration efficiency depends on the coordination of other climate conditions. With different conditions, the optimum temperature range of respiration also changes. The plant physiological activity change is the combined contribution of many climate factors. For example, the increasing temperature will improve transpiration of plants and evaporation of soil moisture, promote the mineralization of nitrogen, and cause changes in the activity of enzymes associated with respiration [69, 70].

Some studies confirmed that moderate increase in temperature could promote respiration efficiency [71, 72]. High temperature might cause total leaf area increase [68], and the added leaf stomata increases the cell oxygen partial pressure and therefore promotes the respiration efficiency [73]. The stomatal density of *Leymus* and *Stipa* leaves increases with the high temperature, while the stomatal density of *Carex* does not change with temperature [74]. Under the rising temperature, the metabolic heat release rate (Rq) and CO_2 output rate (RCO_2) of *Ceratoides* are gradually increasing. The differences of Rq and RCO_2 between various *Ceratoides* species increase gradually above 25°C. Compare with the species in Inner Mongolia cold regions, the increasing rate of *Ceratoides* species in relatively warm regions such as Xinjiang, China, shows a greater increase. However, after more than 35°C, the respiratory metabolism of *Ceratoides* is restrained under high-temperature stress.

4.2. Effect of precipitation

Plant respiration is less sensitive to desiccation than photosynthesis. However, the response to desiccation of photosynthesis efficiency and respiration efficiency is roughly the same. In a wide range of moisture in soil from 70 to 90%, the respiration rate maintains relatively stable. But in the range of lower moisture in soil below 60%, the respiration rate decreases with the soil water content [75].

Precipitation can affect the water filling degree of plant cells, and the water saturation degree of protoplasmic cells also has a strong influence on respiration. For plants in the seed stage, the respiration efficiency increases with the increase of water content. For plant in the growth stage, water and respiration rates are also positively correlated. Nevertheless, when water shortage causes plant leaves to become yellow, their respiration rate will also be extremely active for a short time. It is explained from the perspective of plant material and biological characteristics that swelling of dry seeds and fresh tissue dehydration both can cause enzyme activity transfer to hydrolysis and greatly increase the number of respiratory substrate and reinforce respiration [76]. High-grass steppe experiences plant respiration stagnation when the soil moisture content is saturated or grassland plants are wilted for a long time [77]. In arid and semiarid grassland regions, precipitation is the main limiting factor affecting plant growth and reproduction and also has a great influence on respiration efficiency.

5. Synergistic effects of warming and precipitation on plant functional traits

Temperature and precipitation are important ecological factors of plant growth [78]. Their exclusive or composite change has important effects on plant. Plant functional traits' sensitivity and adaptability to warming and precipitation change determine the degree of the climate change impact on their ecosystem.

In the future climate change scenario, temperature and precipitation are co-changing, and the multifactor effect is significantly different with the simple combination of single-factor effect [41]. The existing simulation experiments on the effects of climate change on plants are mostly isolated temperature or precipitation changes [42], and the range of temperature and precipitation is relatively small. Generally, precipitation is divided into different degrees of drought [79], and the temperature change refers to 2–3°C of warming [13]. Research showed that plant growth has an optimum range for temperature and water changes and growth is inhibited if it exceeds or below the optimum range [80, 81]. If hydrothermal range set in the research is too small or deviated from the optimum range, it is unable to gain a comprehensive understanding of the process of plant responses to hydrothermal change and limits the threshold value and adaptation range of plant response to hydrothermal change. Thus, it has a disadvantage in understanding the adaptation mechanisms of plants to warming and precipitation changes.

5.1. Synergistic effects on plant morphology

Higher temperature promotes plant growth and increases plant productivity [82]. Raising temperature at 3°C can make the mixed grassland underground biomass increase by 11.6% [83], and the increase of water content can promote the net primary productivity of high-grass grasslands [84] and increase the total leaf area [85]. Mild drought does not affect plant growth, while excessive drought inhibits plant growth [86]. The simultaneous increase of temperature and precipitation will significantly increase net primary productivity (NPP) of terrestrial ecosystems, while temperature and precipitation decrease at the same time will significantly reduce NPP [84]. The above ground net primary production (ANPP) of grassland plant responds to the annual average temperature in logistic relations [87], and the response to precipitation is linear [88].

The effect of precipitation on the *Stipa* plant height is greater than that of temperature, but the effect of temperature on the total leaf area is greater than that of precipitation. The plant morphology response of *Stipa* under synergistic effects of warming and precipitation is different from the exclusive effects. Synergistic effects do not show a significant effect on *Stipa* leaf number but has a significant influence on root length. The synergistic effects have no significant effect on *Stipa* plant height [89], while it has a significant effect on the plant height of *Leymus* [90]. It is showed that the response of different plant morphologic characteristics to hydrothermal synergy is different. The influence of hydrothermal synergy to different plant functional traits should be taken into account, and sensitivity indicators are selected to indicate the response of grassland dominant species to hydrothermal synergistic effects.

5.2. Synergistic effects on plant photosynthesis

Plant photosynthesis is susceptible to internal rhythms and external environmental factors (sunlight, temperature, water, etc.). When temperature changes within the optimum range for plant photosynthesis, the effect of temperature on photosynthesis is positive [91]. Most plants' photosynthesis optimum temperature has a great difference in different environmental conditions. In high-latitude and high-elevation grassland ecological system, the low temperature is often the key limited factor of the plant growth, and warming can promote the plant photosynthesis efficiency in that area [92].

However, the increase temperature causes changes in other environmental factors such as soil moisture. These growing environment changes together with increased temperature will jointly affect plant photosynthesis. In the arid and semiarid grassland, precipitation is the main limiting factor of plant growth [62]. Increasing temperature will reduce plant photosynthesis [52]. The possible reason is that in the whole growing season, daytime air temperature largely increases, and warming causes increasing plant transpiration rate and reduces the soil moisture [58], even leading to dry land. According to the research by Chaves et al. [93], plants under drought stress usually reduced carbon assimilation which consequently limited plant growth. In addition, soil drought after warming is often the main reason that affects photosynthetic physiology of plants. Farquhar and Sharkey [94] believed that factors influencing plant photosynthesis were not only stomatal opening or closing but also other non-stomatal factors. For example, increasing temperature reduces soil moisture and chlorophyll content of *Stipa krylovii*; these changes lead to the decline of photosynthesis efficiency.

In typical arid and semiarid grasslands, effective water is the most important factor controlling plant functional traits. The photosynthesis efficiency of plants decreases under drought condition. According to research by Niu et al. [64], increased precipitation significantly promoted the photosynthetic efficiency of *Stipa krylovii*, especially under soil moisture deficiency caused by temperature increasing. Precipitation may raise phosphorus regeneration ability in photosynthetic phosphorylation process and the chlorophyll content.

5.3. Synergistic effects on plant respiration

The respiration rate is not only related to the environment but also related to plant growth. Under environmental conditions, respiration rate of the same plant varies with its age and growth stage. For example, the young organ with strong activity of meristem has the strongest respiration rate. As plants grow, respiration rate slows down. There are two peaks of respiration during the growth of individual plants: one is the germination period; the other is the flowering period. In the arid and semiarid grassland, the highest respiration rate of *Stipa* appeared in the late spring, with a slight dropped in summer and a rise in fall, until the lowest in winter [95].

The daily change of plant respiration efficiency is mainly affected by temperature, which is the highest in the afternoon and lowest in the night [95]. Seasonal variation is mainly affected by the interaction between temperature and rainfall, and it is related to the limiting factors of the ecosystem. Precipitation change in Inner Mongolia grassland is a decisive factor in the change of respiration rate of *Stipa krylovii* [96]. It is found that excessive high temperature can reduce the respiration rate, but increasing precipitation will lead to a higher respiration rate. However, at the high-temperature conditions, increasing precipitation can reverse the respiration inhibition effects caused by warming. It is suggested that the changes of respiration rate depend on the matching relationship between soil moisture and heat factor [97]. In arid and semiarid grassland, there is a significant positive correlation between temperature and plant respiration rate [98], and in spring and summer when the temperature raise above 15°C, soil moisture will replace the temperature and build a strong positive correlation with respiration rate [99, 100].

6. Conclusion

Under the background of climate change, the response of plant functional traits to temperature and precipitation change directly affects the function and stability of the ecosystem. Plant morphology, photosynthesis, and respiration process have an optimum temperature range, below or above which the growth of photosynthetic and respiration rates will be inhibited. Precipitation change also plays an important role on plant growth and physiological and ecological process. Water is the main limiting factor affecting plant growth in arid and semiarid grassland. In arid and semiarid grasslands, the proper ratio of warming and precipitation is the key factor to regulate the plant functional traits, including plant morphology, photosynthesis, and respiration characteristics.

Drought is an important factor that results in the decrease of grassland ecosystem productivity, biodiversity loss, and ecosystem degradation. In particular, the increase in temperature leads to further aggravation of drought, which seriously affects the growth of grassland plants. Enhanced precipitation could increase the grassland plants' optimum growth temperature, which means that improving precipitation could contribute to resist high-temperature stress. Temperature and precipitation increased synergistic effects have positive effect on plant growth.

In the past 40 years, the annual mean temperature and annual precipitation change increased in arid and semiarid grassland in China, and precipitation suffered reduction. In the future, the temperature will rise in China grassland area, and precipitation will have a weakly reducing trend. A slight increase in temperature and decrease in precipitation will probably promote the growth of underground part of grassland plants. However, if precipitation decreases by more than 30%, the increase in temperature may inhibit the growth of grassland plants. Therefore, climate change in the future will be mainly manifested as temperature rise, and it would make arid and semiarid grasslands in China develop further drought trend, which will be detrimental to the carbon budget and ecological health of grasslands.

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