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Chapter

Responses of Community Structure, Productivity and Turnover Traits to Long-Term Grazing Exclusion in a Semiarid Grassland on the Loess Plateau of Northern China

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Abstract

Grazing exclusion has been widely used for restoration of degraded grassland all over the world. Based on over a 30-year (from 1982 to 2011) vegetation survey and a 2-year (from 2013 to 2014) field decomposition experiment in Yunwu Mountain Grassland Nature Reserve on the Loess Plateau of China, responses of community structure and productivity and decomposition traits of dominant Stipa species (Stipa bungeana, Stipa grandis and Stipa przewalskyi) litters were determined to reveal the ecosystem cyclic process. Results showed that grassland coverage, plant density, Shannon-Wiener index and aboveground productivity changed in a hump pattern with peaks in 2002. Productivity was significantly positively correlated with mean annual temperature. The direction and magnitude about effects of climatic changes on productivity depended on phonological stages of plant community. Warming in early stage of growing season (April–May) contributed the increase of productivity, while temperature rise after the growing season (September–March in the next following year) was negatively correlated with productivity in the following year. Leaf litters of three Stipa species (S. bungeana, S. grandis and S. przewalskyi) had higher decomposition rates in the growing season than that in the nongrowing season. Nutrient-releasing pattern in litters of three Stipa species followed a different pattern: S. bungeana > S.grandis>S. przewalskyi. Considering productivity and decomposition traits, grazing exclusion promotes carbon sequestration of semiarid grassland, while adjustments in nutrient cycling might explain fluctuations of community structure.

Keywords: yunwu mountain, loess plateau, grazing exclusion, climate variation, decomposition, *Stipa*

1. Introduction

As one of the most important and largest terrestrial ecosystems in the world, grasslands cover 30% of the land surface and are mainly distributed in arid and semiarid regions [1]. Due to global climate change and human activity, such as heavy grazing, grasslands in this area have undergone desertification and even virtually disappeared in recent decades [2, 3], making restoration process urgent for degraded grasslands [4, 5]. Current studies about grassland restoration mainly focus on several key components: community composition and structure, species diversity, soil properties and vegetation succession process [6–10]. Grassland is considered very sensitive to climate changes [11–14] and also is influenced by soil resource availability [15, 16].

Compared with forest ecosystem and cropland ecosystem, aboveground net primary productivity (ANPP) of grasslands is highly temporally variable [16, 17]. Specifically, climate-driven variability in grassland productivity has important effects on the global carbon balance, ecosystem service delivery, profitability of pastoral livelihoods and the sustainability of grassland resources [11, 18, 19]. Many ecologists have analysed the impacts of annual precipitation and temperature on ANPP at regional and continental scales [17, 20–23], while numerous site-specific reports have indicated that interannual variability in ANPP is poorly or even not at all correlated with annual climate conditions [19, 24, 25]. Changes in precipitation or temperature during certain parts of the year have been proven to be more relevant drivers of ANPP than annual changes [26–29], and the impacts on vegetation production varied with seasons [13, 28, 30, 31]. For instance, warming in early spring increased grassland productivity by ameliorating cold temperature constraints on plant growth in northern mid- and high latitudes [32, 33] and advancing spring greening phenology [34–36]. Temperature increases in summer; however, it can depress productivity by reducing soil moisture and intensifying physiological stress [13].

The Loess Plateau of China has a total area of about 52 million hectares and is widely known for its fragile ecological environment, frequent severe droughts and problems with water runoff and soil erosion [37]. In recent years, the complicated landscape, frequent droughts and severe soil erosion have attracted worldwide attention and caused sustained deterioration of the ecosystem of this region. In contrast to numerous studies in the temperate grasslands of Inner Mongolia and the alpine grasslands of the Tibetan Plateau, very few reports are available on responses of grassland productivity to climate variability on the more arid Loess Plateau in China [3], especially with respect to responses to seasonal climatic variability. Restoration of the natural vegetation is regarded as the most effective method for changing the ecological environment of the Loess Plateau [7, 8, 38].

As a major determinant of nutrient cycling, litter decomposition is a fundamental process of grassland ecosystem functioning [39]. Decomposition traits of plant litters are affected by a number of factors, including litter quality, abiotic environment and soil organisms [40]. In general, plant litters with high C:N ratio and lignin concentration are supposed to have slow decomposition and nutrient immobilisation processes, whereas low C:N ratio and low lignin concentration contribute to fast decomposition and nutrient mineralisation processes. Decomposition traits of plant materials may vary with succession stages. For example, late-seral dominant grasses normally had high tissue N concentrations, low C:N ratios and lignin concentrations, which result into fast decomposition rate and enhanced nutrient mineralisation.

Most previous studies have focused on plant species richness and diversity in abandoned croplands following short-term grazing exclusion in China [8, 41, 42]. Few studies

have reported on the restoration succession of typical natural steppe under long-term grazing exclusion [19, 43]. In the present study, *Stipa* steppe has been fenced from 1982 to the present at Yunwu Mountain National Nature Reserve, and long-term grassland ecological characteristics, productivity and weather records have been collected.

The community in the study area consists of 313 plant species, covering 56 families and 165 genera, with five main families being Compositae, Gramineae, Leguminosae, Rosaceae and Labiatae [44]. The dominant *Stipa* plants include *S. bungeana*, *S. grandis* and *S. przewalskyi*, and main forbs are *Thymus mongolicus*, *Artemisia sacrorum* and *Potentilla acaulis* [45]. Genus-specific morphological and functional traits contributed the dominance of *Stipa* plants in temperate, subtropical and tropical steppe in semiarid areas worldwide [46]. Meanwhile, *Stipa* species showed various adaptabilities to environmental changes, presenting an ecological distribution pattern along the climate gradients [47]. There are 32 species, 1 subspecies and 3 variations in genus *Stipa* plants in China, mainly distributed in western and northeastern area, and 5 *Stipa* species are found in our study area. As the constructive species, *S. bungeana* mainly distributed on the Loess Plateau [48]. Noticeably, replacement of dominant *Stipa* species occurred during the long-term restoration process, with *Stipa bungeana* being replaced by *S. grandis* and *S. przewalskyi* [49]. The three *Stipa* species differentiated in their phenotypic traits. In detail, *S. grandis* owns higher plant height, and *S. przewalskyi* possesses more tillers. Besides, *S. bungeana* and *S. przewalskyi* consistently flower and produce seeds earlier than *S. grandis* [49].

The temperature and precipitation variability during 1982–2011 were assessed in this study; the ecological characteristics during long-term grazing exclusion were examined; the relationship between grassland productivity and variation in climate variables were explored; and the variations in decomposition traits of three *Stipa* dominant species (*S. bungeana*, *S. grandis* and *S. przewalskyi*) were determined.

2. Material and method

2.1 Study site

This study was conducted in Yunwu Mountain National Nature Reserve on the Loess Plateau (106°24′–106°28′ E, 36°13′–36°19′ N) (**Figure 1**) [45, 50].

Figure 1.
Location of experimental site.

Grassland in this area was restored from grazing as a long-term ecological monitoring station since 1982. The elevation of this study area is 1800–2180 m and has a total area of 6660 hm². The mean annual temperature is 7.01°C, and there are on average 137 frost-free days per year [49]. The mean annual precipitation is 425 mm, with 60–75% of rainfall falling during July–September. The mean annual evaporation is 1017–1739 mm. Snow cover depth in winters averaged 1.2 cm during the dormancy period. The vegetation type is typical steppe. *Gentianaceae*, *Stipa* and *Potentilla* are important plant components, and the main dominant species include *S. bungeana*, *Stipa grandis*, *S. przewalskyi*, *Thymus mongolicus*, *Artemisia sacrorum*, *Potentilla acaulis* and *Androsace erecta* [45]. Soil type is montane grey-cinnamon soil [45].

2.2 Experimental design and sampling

2.2.1 Grassland ecological survey

The grassland sites have been restored from grazing exclusion since 1982, and consequently goat grazing was excluded [45, 49, 50]. Three equal-sized transect of 300 × 100 m was established at the top, middle and down positions of the same slope, respectively. And, 15 quadrats (1 × 1 m) were established within each transect. The vegetation survey was carried out in mid- or late August each year during 1982–2011. Plant coverage, height, species abundance and plant density in each quadrat were measured. Aboveground parts of grassland plants were clipped and dried at 65°C for 48 h to determine aboveground biomass [43]. Plant roots of 0–120 cm soil layers were collected with a soil auger of 9 cm diameter, then were washed and dried to determine belowground biomass.

Important value (IV) was used to describe the importance of species in grassland community during the restoration process. Shannon-Wiener index was used to indicate diversity and evenness of plant community [50]. All indices were calculated according to 8 and 43.

Important value (IV)

$$IV = \frac{RH + RC + RA + RF}{4} \qquad (1)$$

where IV is the important value, RH is the relative height, RC is the relative coverage, RA is the relative abundance and RF is the relative frequency.

Diversity index (H), using Shannon-Wiener index

$$H = -\sum_{i=1}^{S} P_i \ln P_i \qquad (2)$$

where S is the total species number of a quadrat and P_i is the relative importance value of species i.

2.2.2 Litter decomposition experiment

Considering the difficulty of gathering sufficient senesced leaves, leaves of three *Stipa* species (*S. bungeana*, *S. grandis* and *S. przewalskyi*) were collected in August of 2013 and then dried at 40°C as decomposition materials, according to other decomposition studies [51–53]. Leaf litters were cut into pieces of 10 cm in length and enclosed in nylon bag (15 g bag⁻¹, 15 × 10 cm, 0.15 mm mesh).

In early October of 2013, the leaf litterbags of three *Stipa* species were transferred to grassland site restored for 23 years. Four plots of 10 × 10 m were established, and seven leaf litterbags of each *Stipa* species were placed on the soil surface and secured in place with iron nails on each of four plots. Four leaf litterbags of each *Stipa* species were harvested after 1, 3, 6, 9, 12, 18 and 24 months of incubation.

In the laboratory, leaf litters were removed from bags, cleaned to remove any extraneous material and weighed after drying at 65°C for 48 h. Leaf litters were analysed for carbon (C), nitrogen (N) and phosphorus (P). C was determined by oxidation with potassium dichromate in a heated oil bath. N was determined by the semimicro Kjeldahl method. P was determined by Olsen method [54].

According to [55], decomposition rate (k) of leaf litters was estimated by the negative exponential decay function:

$$\frac{X}{X_0} = e^{-kt} \tag{3}$$

where X is the remaining mass, X_0 is the initial mass and t is the decaying time (year).

Based on the nutrient concentration and remaining mass, we further calculated nutrient accumulation index (NAI) for C, N and P of leaf litters during decomposition process [56, 57]:

$$NAI = \frac{X_t \times C_t}{X_0 \times C_0} \times 100\% \tag{4}$$

where X_0 and C_0 indicate initial leaf litter mass and chemical element concentration, respectively. X_t and C_t indicate remaining leaf litter mass and chemical element concentration after a period of time t (year), respectively.

2.3 Data analyses

All data in the paper are presented as mean ± standard error. A two-way analysis of variance was conducted to determine the effects of decomposition time, species and their interaction on decomposition rate, nutrient concentration and NAI of leaf litters. A linear mixed model was used to examine correlations of vegetative indices with restoration time, productivity with climate variables and remaining mass with decomposition time. Significant differences of all statistical tests were estimated at a significance level of $P < 0.05$. All statistical analyses were performed using SPSS 18.0 (SPSS Inc., Chicago, IL, USA).

Partial least squares (PLS) regression was used to analyse the responses of grassland productivity to variation in daily temperature and precipitation during all 365 days of the year based on data for 1992–2011 [58, 59]. The two major outputs of PLS analysis are the variable importance in the projection (VIP) and standardised model coefficients. The VIP threshold for considering variables as important is often set to 0.8 [60]. The standardised model coefficients indicate the strength and direction of the impacts of each variable in the PLS model. The root-mean-square errors (RMSE) of the regression analyses were calculated to determine the accuracy of the PLS model. In the PLS analyses, periods with VIP greater than 0.8 and high absolute values of model coefficients represent the relevant phases influencing grassland productivity. Positive model coefficients indicate that increasing temperature or precipitation during the respective period should increase ANPP, while negative model coefficients imply negative impacts on productivity.

3. Results

3.1 Temperature and precipitation changes

The annual mean air temperature had an increasing trend and increased by 1.17°C from 1982 to 2011(**Figure 2A**). In contrast with mean annual temperature, mean annual precipitation showed a decreasing trend and larger intra- and interannual variations in our study, indicating the warmer and drier climate. The mean annual precipitation from 1982 to 2011 was 425.42 mm, with markedly lower values in 1986, 1991 and 1999 and with higher values in 2003 (**Figure 2B**).
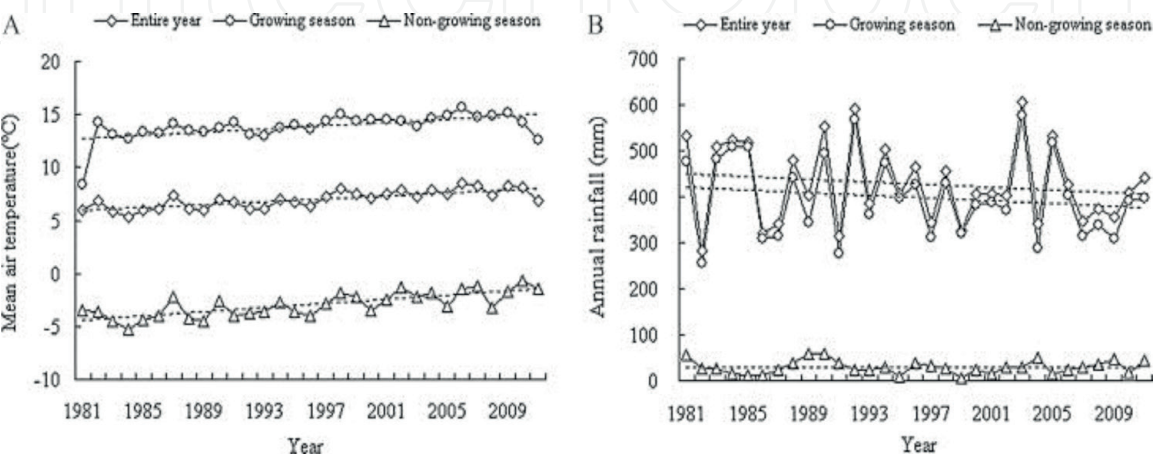
Figure 2.
Mean annual air temperature (a) and mean annual rainfall (B) of growing season, nongrowing season and entire year at Yunwu Mountain during 1982–2011.
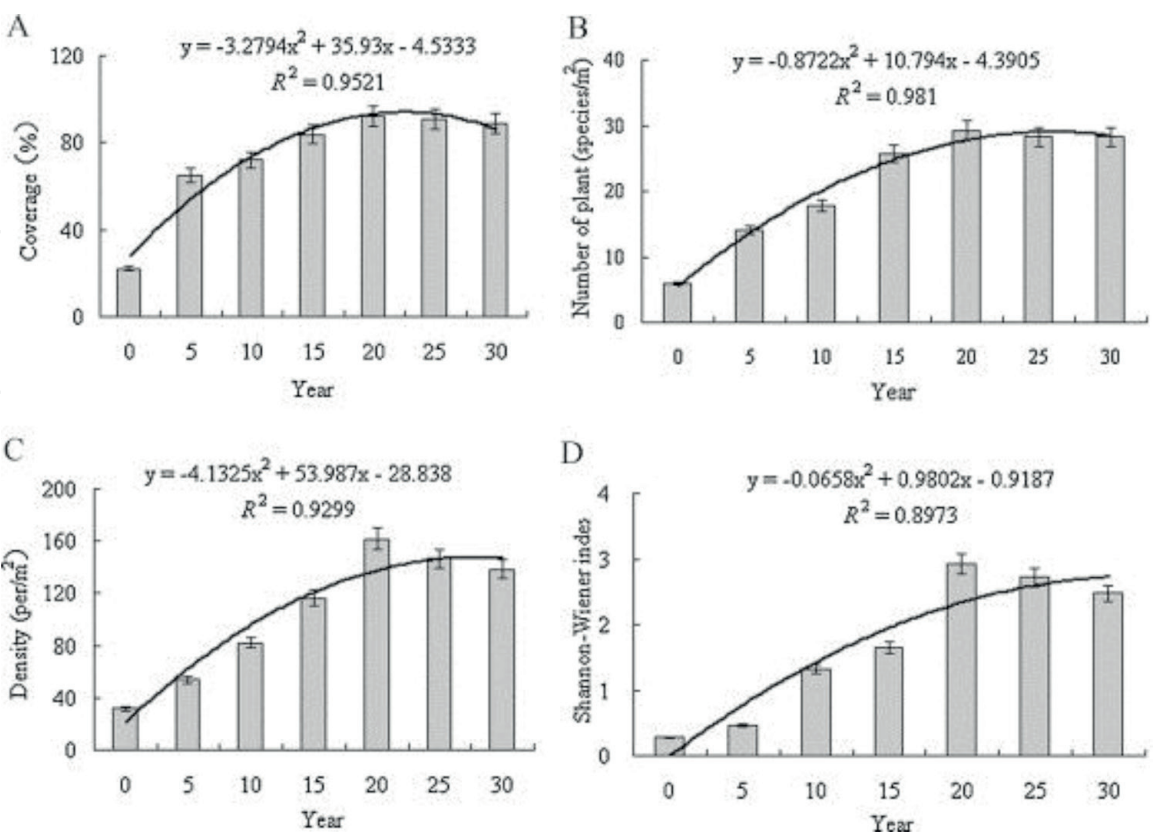

Figure 3.
Changes of coverage (a), number of plants (B), plant density (C) and Shannon-wiener index (D) of grassland with grazing exclusion time at 5, 10, 15, 20, 25 and 30 years.

3.2 Vegetative ecological characteristics after grazing exclusion

Grassland coverage, plant species richness (number of plant species), plant density (number of plant individuals) and Shannon-Wiener index had similar variation tendencies during the three-decade restoration process (**Figure 3**). Initially, the coverage, plant richness, plant density and Shannon-Wiener index significantly increased. After 20 years' restoration, they reached peak values of 92.47%, 29.33 species m^{-2}, 161.8 individuals m^{-2} and 2.93, respectively. With grazing exclusion process continuing, the four indices' values decreased to 88.73%, 28.2 species m^{-2}, 138.7 individuals m^{-2} and 2.47, respectively (**Figure 3**).

3.3 Biomass changes in grassland community after grazing exclusion

There were significant differences in aboveground biomass between four groups and between total aboveground biomass and total belowground biomass (**Figure 4**).
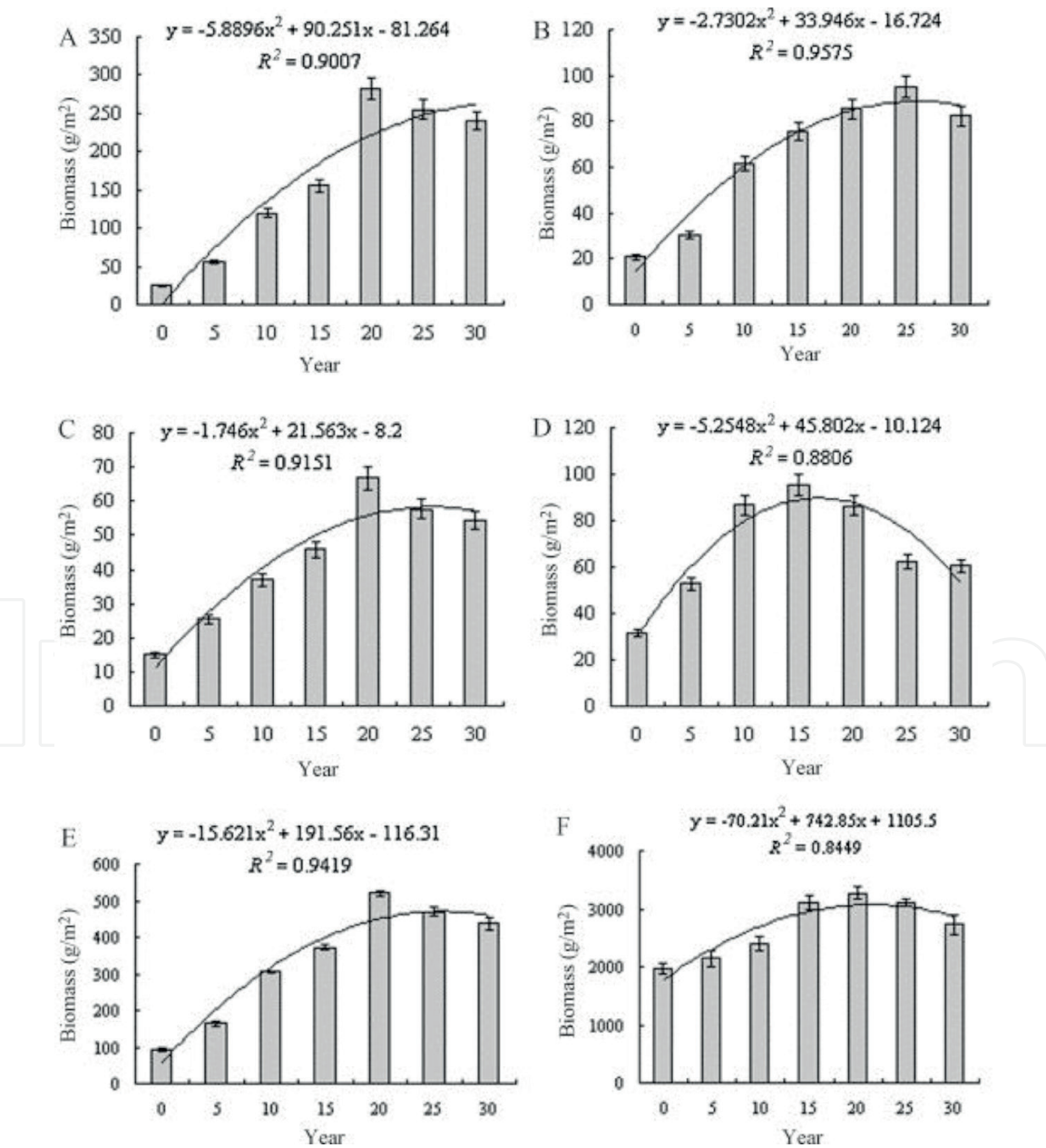

Figure 4.
Biomass changes of Gramineae (a), Leguminosae (B), Compositae (C), weeds (D), aboveground community (E) and belowground community (F) of grassland with grazing exclusion time at 5, 10, 15, 20, 25 and 30 years.

Aboveground biomasses of four plant groups increased with restoration time after grazing exclusion. Aboveground biomass of Gramineae and Compositae peaked at the 20th year, while that of Leguminosae peaked at the 25th year, and that of Weeds families peaked at the 15th year during restoration process after grazing exclusion. Considering the reduced biomasses of weed families, long-term grazing exclusion improved forage quality of grassland. Meanwhile, aboveground and belowground community biomasses were both increased by grazing exclusion. Since grassland mainly consisted of plants belonging to Gramineae and Compositae, peaks of the total above- and belowground community biomass both occurred at the 20th year, with aboveground community biomass of 520.5 g m^{-2} and belowground community biomass of 3240.2 g m^{-2} (**Figure 4**).

3.4 Responses of aboveground productivity to climate variation

Regression analysis showed that ANPP was significantly correlated with MAT (**Figure 5b**) but was little influenced by AP variations (**Figure 5a**).

The VIP and standardised model coefficients of the PLS analysis showed that impacts of warming on grassland productivity varied with season periods (**Figure 6a**). Different with the clear-cut impacts of temperature on ANPP, precipitation showed more complex impacts (**Figure 6b**).

3.5 Decomposition traits of leaf litters of three dominant *Stipa* species

The remaining mass of leaf litters decreased with decomposition time and showed significant differences among three *Stipa* species (**Figure 7**). At the end of decomposition experiment, the remaining masses of leaf litters of *S. bungeana*, *S. grandis* and *S. przewalskyi* were 64.47%, 61.53% and 65.78%, respectively (**Table 1**).

Different lowercase letters in the same column indicate significant differences ($P < 0.05$).

During 2 years' decomposition process, variations of nutrient concentration were affected by the nutrient type (**Figure 8**). In detail, concentrations of carbon and nitrogen showed species-specific fluctuations with decreasing tendency among three *Stipa* species. In contrast, phosphorus concentrations in leaf litters were averaged doubled. There were significant differences in C:N ratio and nutrient accumulation index (NAI) of leaf litters among three *Stipa* species (**Table 2**).
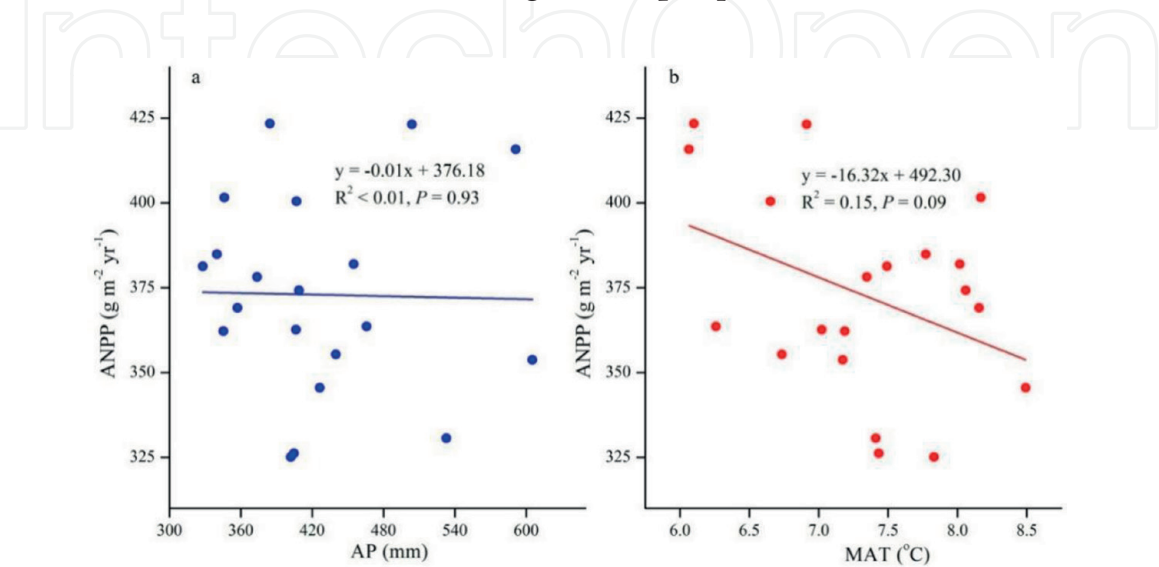

Figure 5.
Correlations between ANPP and annual precipitation (a) and mean annual temperature (b) during 1992–2011 at Yunwushan. AP means annual precipitation and MAT represents mean annual temperature.
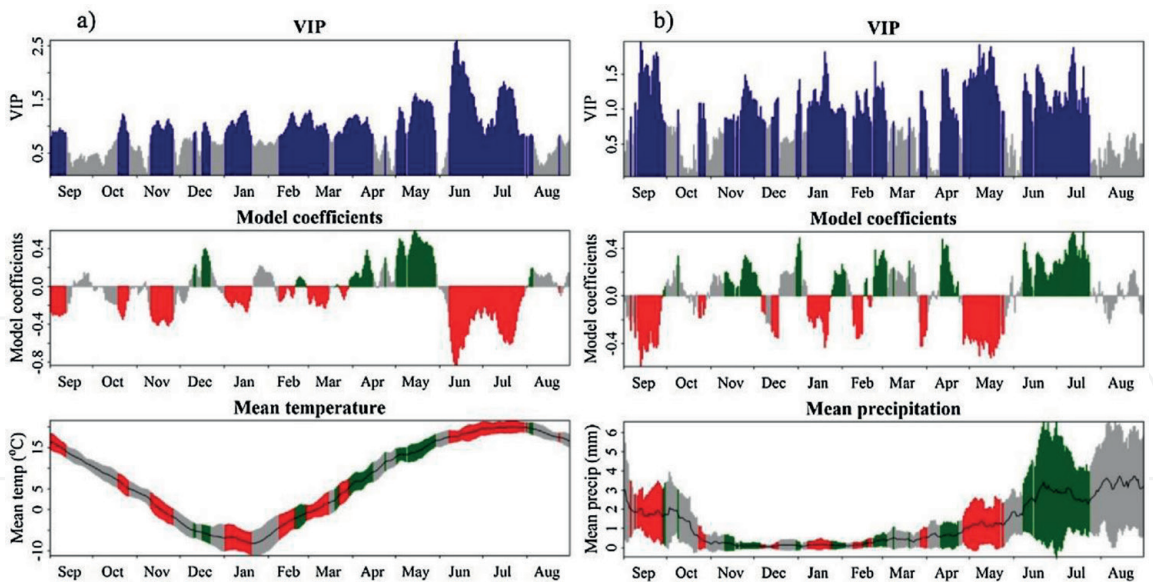
Figure 6.
Results of partial least squares (PLS) regression correlating grassland productivity at Yunwu Mountain during 1992–2011 with 15-day running means of (a) daily mean temperature and (b) daily precipitation previously from September to august. Blue bars in the top row indicate that VIP values are greater than 0.8, the threshold for variable importance. In the middle row, red colour means model coefficients are negative and important, while green colour indicates important positive relationships between grassland productivity and climate variables. The black lines in the bottom panel stand for daily mean temperature and precipitation, while grey, green and red areas represent the standard deviation of daily climate variables.
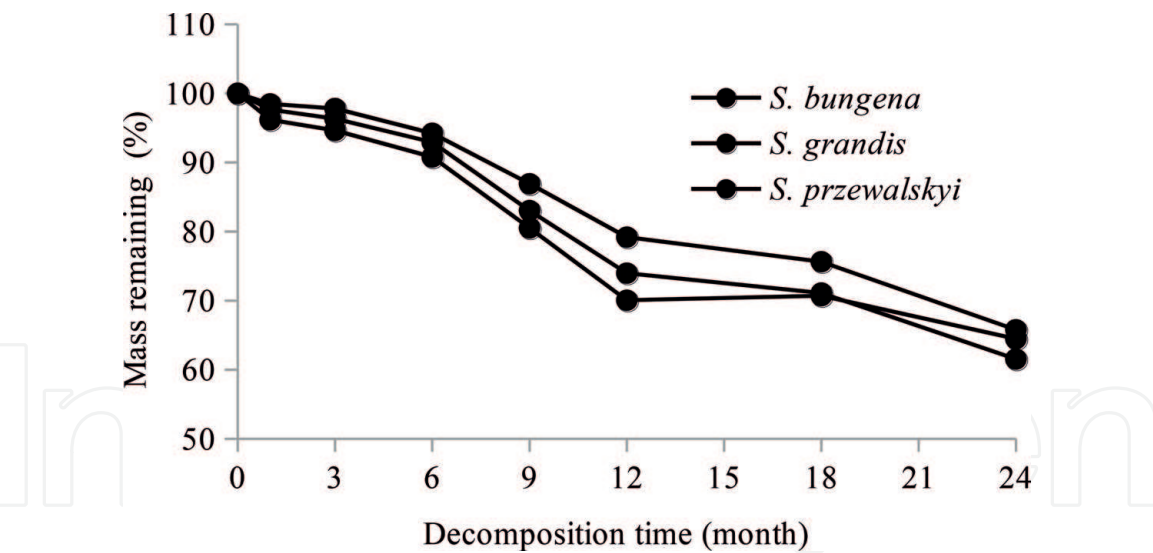

Figure 7.
The remaining mass dynamics of leaf litters of three Stipa species during 2 years' field decomposition process.

Species	Remaining mass		k-Value	
	First year	Second year	First year	Second year
S. bungeana	70.05 ± 3.91 b	64.47 ± 3.66 ab	0.360	0.236
S. grandis	73.97 ± 1.81 ab	61.53 ± 5.24 b	0.320	0.242
S. przewalskyi	79.18 ± 1.49 a	65.77 ± 1.80 a	0.237	0.225

Table 1.
Comparisons of litter decomposition traits after 1 and 2 years' decomposition between three Stipa species.
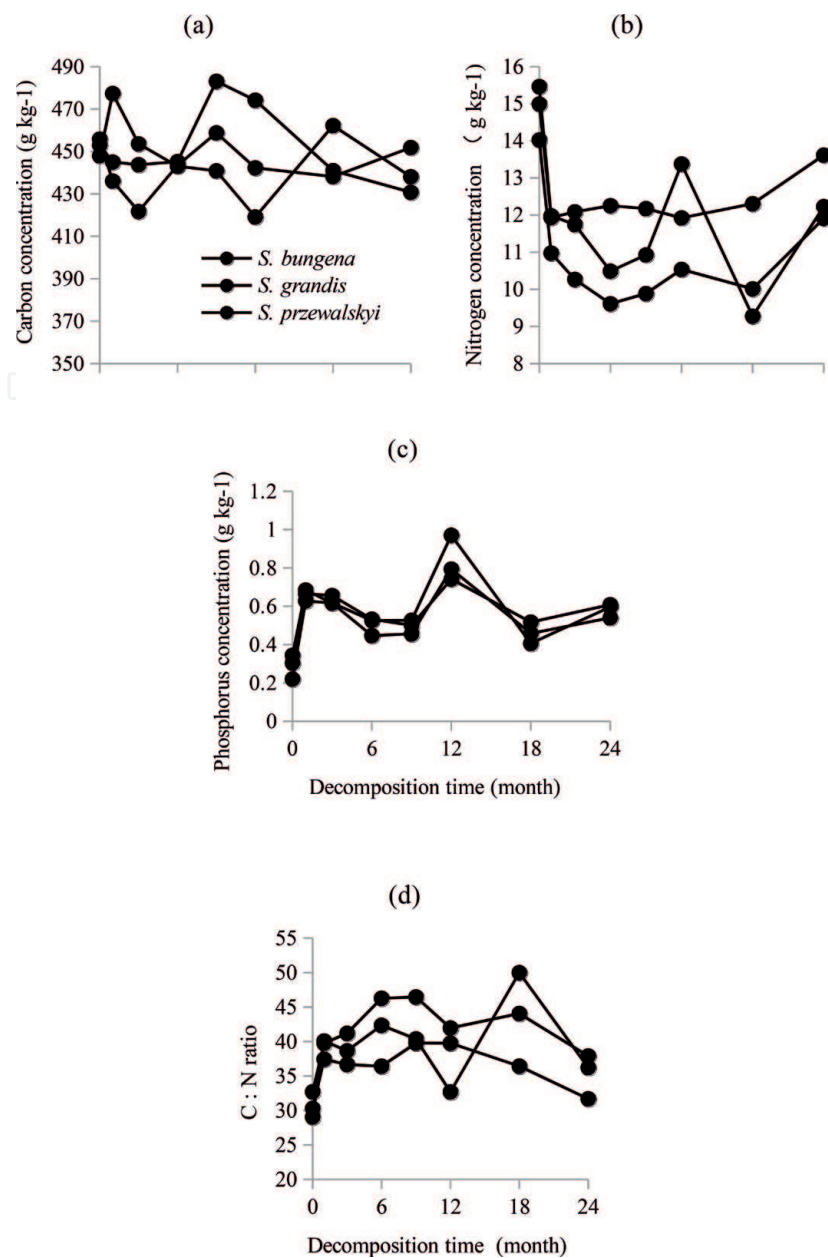
Figure 8.
Dynamic of carbon (a), nitrogen (b), phosphorus (c), concentrations and C:N ratio (d) of leaf litters of three Stipa species during 2 years' field decomposition process.

| Variables | df | Concentration (g·kg⁻¹) | | | C/N | | NAI | |
		C	N	P		C	N	P
Time	6	0.575 ns	4.701 **	39.564 ***	3.877**	49.738 ***	23.944 ***	53.070 ***
Species	2	0.613 ns	18.860 ***	2.991 ns	9.074**	0.560 ns	11.026 ***	50.008 ***
Time× Species	12	1.163 ns	1.843 ns	1.224 ns	1.889 ns	1.663 ns	1.014 ns	1.185 ns

Table 2.
Analysis of variance of decomposition time, species for nutrient concentration, C:N ratio and NAI.

NAI, nutrient accumulation index; ns indicates no significant effects ($P > 0.05$). ** and *** indicate significant effects at $P < 0.01$ and $P < 0.001$ level, respectively.

Different with nutrient concentrations, nutrient accumulation indices in **Figure 9** indicated that C, N and P were all mineralised into soils during the decomposition process. There was no significant difference between species for carbon-releasing pattern (**Figure 9**).
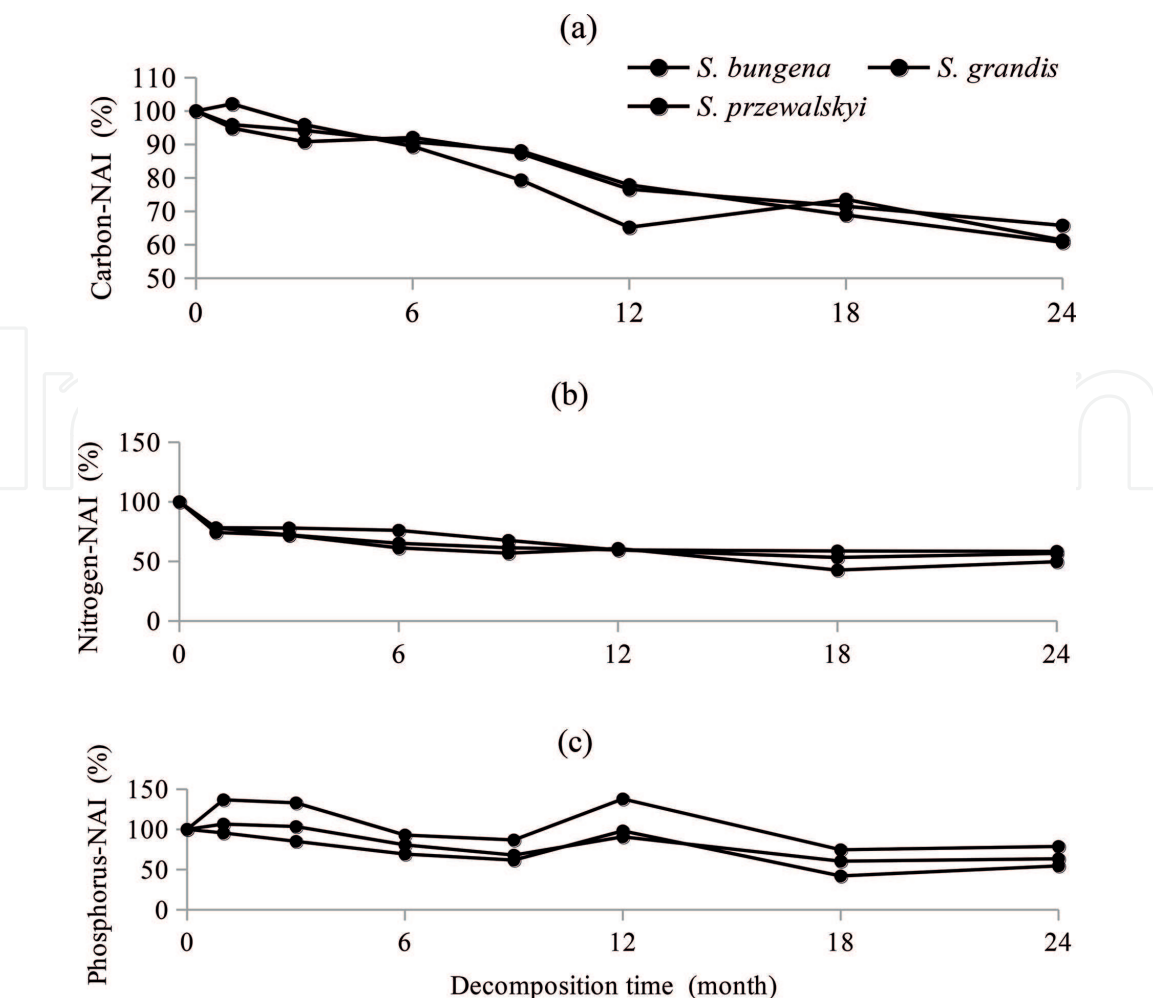
Figure 9.
NAI dynamics for carbon (a), nitrogen (b), phosphorus (c) of leaf litters of three Stipa species during 2 years' field decomposition process.

4. Discussion

Anthropogenic activities and climate changes have made important impacts on terrestrial ecosystem structure and functions in the last century [30]. Global surface temperatures during the twentieth century was increased by 0.56–0.92°C, while temperatures are predicted to have an increment of 2.0–4.5°C in the twenty-first century [61]. Annual mean air temperature was increased by 1.17°C from 1982 to 2011 in this study, having similar temperature changing trends with study in Xilingol steppe of Inner Mongolia [61]. In detail, temperature rises differentiated with seasons, with temperature rises of 1.01°C and 1.68°C in growing season and nongrowing season, respectively. Thus, the nongrowing season experienced a higher temperature rise than the growing season. In contrast with mean annual temperature, mean annual precipitation showed a decreasing trend and larger intra- and interannual variations in our study, indicating the warmer and drier climate. Previous researches have shown that vegetation characteristics could be improved using grazing exclusion in the degraded sandy grasslands, alpine meadow and wetlands in China [5, 62]. However, many of these restoration studies were based on a relatively short-term scale and the research strategy focusing on the spatial series substitute for temporal series methods [5, 63]. In this study, community coverage, plant species richness, plant density and Shannon-Wiener index had similar variation tendencies during the three-decade restoration process. After 20 years' restoration, they reached peak values, but these four index values

decreased in the following years. These decreases mainly resulted from accumulation of litter, which reduced the access to light for plant seedlings [64, 65]. Overall, 30 years' restoration made plant species richness increase from 9.5 species m^{-2} to 28 species m^{-2} and make grassland coverage increase from 25 to 85%. In addition, plants were categorised into four groups: Gramineae, Leguminosae, Compositae and weeds. Considering the reduced biomasses of weeds, long-term grazing exclusion improved forage quality of grassland. Meanwhile, aboveground and belowground community biomasses were both increased by grazing exclusion.

The rapid recovery due to grazing exclusion played a more important role than climatic variations in regulating grassland ecosystem. Therefore, datasets of aboveground grassland biomass and climate variables during 1992–2011 were used to examine the impacts of climate variations on aboveground net primary productivity (ANPP). Regression analysis showed that ANPP was significantly correlated with MAT and was little influenced by AP variations, while precipitation is regarded as the most important determinant of grassland productivity in arid and semiarid regions [19, 21, 66]. Considering the neglected temporal variation of annual climate variables, more attentions should be paid to studies at higher temporal resolution attributing impacts of climate variation on grassland productivity to seasonal or even daily variation in climatic variables rather than to annual variation [26, 27, 28, 29, 31]. A low root-mean-square error (RMSE) of 8.13 g m^{-2} indicated a good fit of the data for the resulting PLS model. The VIP and standardised model coefficients of the PLS analysis showed that impacts of warming on grassland productivity varied with season periods. Since model coefficients in April and May were always positive and VIP values mostly exceeded 0.8, warming in this period had a positive impact on grassland productivity. The positive impacts of warming in spring on grassland productivity may result from increased water absorption, N mineralisation, accelerated snowmelt and advanced spring greening for plants, which may lengthen the growing season and increase photosynthesis and carbon acquisition for plants [13, 67–69].

Warming in summer (June–July) depressed productivity, forming a striking contrast with the impacts of spring warming. The results can be explained by physiological stress for plant growth generated by warming in summer coinciding with drought [70]. Moreover, warming in summer may reduce soil moisture by increasing evapotranspiration [71]. It is believed that climate variations make impacts on grassland productivity through changes of soil moisture [24, 72, 73]. Furthermore, continuous warming and drought in summer reduced productivity by limiting soil resource availability [74, 75]. And, temperature variation in August had no apparent impacts on grassland productivity.

The majority of published studies have focused on productivity responses to climate variability during the growing season. However, the importance of winter climate is getting more and more attentions [76–80]. Considering the majority of model coefficients during September–March, high temperature at that time was unfavourable for productivity of the following year. Temperature increases during September–October delay the senescence of grassland, which may increase soil nutrient and water depletion, inhibiting biomass production in the following year [36, 69, 81]. Our results were similar with warming experiments in two limestone grasslands in the UK, which showed that winter heating combined with drought reduced the biomass of both communities [11]. Besides, warmer winter can accelerate snowmelt, resulting in declines of snow cover accompanied with increases of frequency of freezing events, which exerted negative impacts on plant growth [76, 82]. Also, warming in winter may delay the fulfilment of chilling requirements of plants for resuming growth in the following spring or even delay onset of spring phenology [58, 59, 77–79, 83].

Interestingly, some short intervals with positive coefficients during 1 November–29 March were detected during 1992–2011, indicating a complex physiological and ecological process in dormancy period of grassland. Taking a broader view at model coefficients and aiming at consistency with established phenological phases, we interpreted the entire period (November–March) as another relevant period during which temperature increases appeared to reduce grassland productivity. Therefore, we recommend that more scientific attention should be paid to impacts of winter warming on grassland productivity and the timing of spring phenology events.

The daily precipitation values between the previous September and August were also used as independent variables in the PLS analysis. The resulting model still proved to be a good fit for the data, with an RMSE of 6.53 g m^{-2}. Different with the clear-cut impacts of temperature on ANPP, precipitation showed more complex impacts. Precipitation increases in June and July had positive impacts on productivity, while increasing precipitation during the senescence period (September–October) and the early growing season (April–May) was correlated with low productivity. In contrast to studies reporting the positive impacts of precipitation during April–May on grassland productivity [29, 30], results in the present study can be explained by the site hydrology, with frequent winter snow providing sufficient soil water for plant growth, making sporadic precipitation during April–May (with an average of 59.5 mm during 1992–2011) which has less important direct impacts on grassland productivity. Similarly, there was also no significant relationship between grassland ANPP and precipitation in August. Similar results have also been reported for grasslands in Kansas, USA [13]. During the dormancy period, positive impacts of precipitation were almost offset by negative ones; thus, precipitation seemed to have little impacts on grassland productivity during this period.

Investigating the decomposition traits of dominant *Stipa* species' (*S. bungeana*, *S. grandis* and *S. przewalskyi*) litters can reveal the ecosystem cyclic process under grazing exclusion and climatic changes. The remaining mass of leaf litters decreased with decomposition time and showed significant differences among three *Stipa* species. At the end of decomposition experiment, the remaining mass of leaf litters of *S. bungeana*, *S. grandis* and *S. przewalskyi* were 64.47%, 61.53% and 65.78%, respectively. Therefore, *S. grandis* decomposed fast, and *S. przewalskyi* had a slow decomposition rate. Additionally, leaf litters decomposed faster in growing season (6–12 month and 18–24 month) than in nongrowing season (0–6 month and 12–18 month). The decomposition rate (k) was calculated based on the regression of negative exponential decay function, with k-values of 0.360, 0.320 and 0.237 after 1 year's decomposition for *S. bungeana*, *S. grandis* and *S. przewalskyi*, respectively. Similarly, k-values after 2 years' decomposition of *S. bungeana*, *S. grandis* and *S. przewalskyi* were 0.236, 0.242 and 0.225, respectively. Since higher k-values indicate higher decomposition rates, we concluded that litter's decaying progress became difficult as decomposition time increases, mainly due to the depletion of soluble compounds and easily decayed parts at the beginning of decomposition process, leaving hard parts such as lignin to decay slowly [39].

The variations of nutrient concentration were affected by nutrient type during 2 years' decomposition process during 2013–2014(**Figure 8** and **Table 2**). In detail, concentrations of carbon and nitrogen showed species-specific fluctuations with decreasing tendency among three *Stipa* species (**Figure 8a** and **b**). In contrast, phosphorus concentrations in leaf litters were averaged doubled (**Figure 8c**), indicating immobilisation of P in the leaf litters, possibly due to microbial immobilisation through the uptake of P from soil solution and translocation of P from fungal hyphae [84]. There were significant differences in C:N ratio of leaf litters among three *Stipa* species (**Figure 8d**). *S. przewalskyi* had higher C:N ratio than *S. bungeana*, which

explained the differences of decomposition rates between them. As the dominant species in late succession stage of grassland, C:N ratio of *S. przewalskyi* litters did not show a lower value as predicted from other studies [51], possibly due to the divergences of climate and species between two regions. C:N ratio has been proven to be negatively correlated with decomposition rate. Besides, the lower k-value after 2 years' decomposition process could be explained by the increased C:N ratio of leaf litters. Compared with nutrient concentrations, nutrient accumulation indices indicated that C, N and P were all mineralised into soils during the decomposition process. There was no significant difference between species for carbon-releasing pattern. Still, NAI value for C of *S. przewalskyi* was higher than two other *Stipa* species after 2 years' decomposition (**Figure 9**). The lower NAI values for N and P of *S. bungeana* indicated that *S. bungeana* released more N and P to soil than the two other *Stipa* species. From this perspective, replacement of *Stipa* species after long-term grazing exclusion might inhibit nutrient cycling of grassland ecosystem, due to the lower nutrient mineralisation in leaf litters of two *Stipa* species at middle and late succession stage.

5. Conclusion

The present study indicated that grazing exclusion induced positive effects on grassland vegetative characteristics, with peak values in the 20th year (2002), and long-term grazing exclusion led to decreased species diversity and biomass and can inhibit grassland renewing due to the litter accumulation. Besides, nutrient cycling in grassland might be slowed down through replacement of dominant species during long-term grazing exclusion. Grassland productivity was more influenced by temperature than precipitation. Results indicated that analysis of productivity responses should account not only for the magnitude of climate variation but also for its timing. Climate warming might prolong/shorten growing season by advancing/delaying onset of greenness of plant community. Warmer winter further decreases ANPP, and impacts of warming in early spring should also be considered in evaluating ANPP variability. Therefore, more scientific attention should be paid to trends in spring phenology and their impacts on productivity at species and community levels.

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