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Enhanced Community Production rather than Structure Improvement under Nitrogen and Phosphorus Addition in Severely Degraded Alpine Meadows

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Abstract: Fertilization is a common management measure for the restoration of degraded grasslands. In order to investigate whether fertilization can improve the severely degraded alpine meadows, we conducted a fertilization experiment on the Tibetan Plateau that began in 2008. The treatments were nitrogen (N) addition alone (50 kg N ha^{-1} year^{-1}, LN; 100 kg N ha^{-1} year^{-1}, HN) or combined with phosphorus (P) fertilizer [(50 kg N + 50 kg P) ha^{-1} year^{-1}, LN+P; (100 kg N + 50 kg P) ha^{-1} year^{-1}, HN + P] in a severely degraded alpine meadow. Eleven consecutive years of N and P fertilization did not significantly change plant species richness, while fertilization reduced the plant species diversity index, with the most significant reduction in HN and HN + P treatments. LN + P and HN + P treatments greatly increased community coverage and aboveground biomass, while N addition alone, especially the HN treatment, significantly reduced community coverage and aboveground biomass. Fertilization had no effect on edible pastures, while N and P fertilization significantly increased the biomass of forbs. The proportion of forbs to total aboveground biomass was more than 90%, and fertilization had no effect on this proportion. This shows that forbs still have an absolute advantage in the community. In addition, HN, LN + P, and HN + P treatments significantly reduced ecosystem stability. Community aboveground biomass was greatly enhanced in the N and P fertilization treatments, and this was beneficial for the ecosystem quality and soil hydrological functioning. However, fertilization treatments did not improve the community structure with either N addition alone or combined with P fertilizer, which was of little significance in providing forages for the sustainable development of livestock husbandry. To improve the structure of severely degraded alpine grasslands, it is necessary to combine other measures such as cutting the roots of forbs, fencing, or reseeding.

Keywords: community structure; nitrogen and phosphorus fertilization; plant production; severely degraded alpine meadow; ecosystem temporal stability; Tibetan Plateau

1. Introduction

Due to the disturbances of climate change and over-grazing, alpine grasslands on the Tibetan Plateau have been widely degraded. What is more, the structure and function of the alpine ecosystems are impaired, resulting in the decline of the alpine grasslands quality [1,2]. Previous studies have found that scientific grassland management has positive effects on the restoration and improvement of degraded grasslands. Fence enclosure, fertilization, reseeding, rodent control, and other measures have achieved positive effects in the improvement and restoration of degraded alpine meadows [3–6]. Among them, moderate and balanced fertilization is one of the important measures to improve degraded grasslands. Fertilization can increase soil surface fertility, improve plant community structure, and contribute to the restoration of grassland productivity. Therefore, rational fertilization has become an important management measure to protect grassland resources, maintain nutrient balance in grassland ecosystems, and restore degraded grasslands [3,7,8].

Due to the differences in plant community composition and soil properties, the restoration measures of alpine grasslands with different degradation degrees may be quite different [9,10]. However, there are few studies on the restoration of alpine meadows with different level of degradation on the Tibetan Plateau. At present, most studies focus on the importance of nitrogen (N) addition on grassland restoration. Short-term low level N addition indeed could increase community production, while excessive addition of N fertilizer imbalanced soil and plant nutrients, caused soil acidification, and generated toxic effects [11–14]. Excessive single nutrient addition was not conducive to the improvement of community structure and productivity [15]. The combined addition of N and phosphorus (P) was beneficial to the balance of nutrient elements, and many studies have investigated the response of different grasslands to the combined addition of N and P. Although all of the studies found that the combination of N and P could significantly increase aboveground biomass [8,16–19], plant functional groups responded differently in various alpine grasslands. In the dry meadow, N and P addition significantly increased the proportions of graminoid and forb biomass, and there was a decrease in the proportions of community biomass made up by the dominant sedge *Kobresia myosuroides* in the Front Range of the Colorado Rocky Mountains [16]. In the wet meadow in Colorado Rocky Mountains, graminoid biomass increased significantly in N + P plots, and forb biomass significantly decreased [16], and this result was similar to the results conducted in a wet alpine meadow on the eastern side of the Tibetan Plateau [18]. However, both sedge and forb biomass increased significantly under N and P addition, while N and P addition had no effect or even decreased graminoid biomass in a slight degraded alpine meadow in a semiarid region on the Tibetan Plateau [19]. These results showed that the alpine grasslands in different climate regions have different responses to N and P additions. From this, we inferred that even in the same climate zone, different degraded types of grasslands may respond differently to N and P additions, but the research on this balanced nutrient addition to different degraded types of alpine grasslands is currently lacking.

In the alpine environment, soil microbial activity is relatively weak, and soil supply nutrient capacity is poor due to high latitude and low temperature [20]. Therefore, N becomes one of the main elements limiting the production of alpine grasslands [16,21], while the grassland degradation process intensifies the lack of N. Exposed areas in degraded grasslands are subject to erosion, resulting in loss of soil nutrients and accumulation of organic matter [22]. Studies have also shown that the productivity of alpine meadows in semi-arid and semi-humid areas is co-limited by N and P [16,17]. Moreover, excessive N addition can exacerbate P limitation [23,24]. Our previous study found that N and P combined addition could significantly improve the coverage and productivity of the plant community in light degraded plots [19]. However, due to the different grassland community compositions and soil nutrient statuses in different degradation levels, the response of degraded grasslands to nutrient types and addition levels may also be different. Improper fertilization measures not only increase economic costs but also have negative impacts on the plateau environment, causing environmental problems such as soil acidification and water pollution. Therefore, it is of great practical significance to explore restoration measures suitable for alpine grasslands under different degradation degrees.

Alpine meadows are typical vegetation on the Tibetan Plateau and are the representative of the alpine environment in central Asia and alpine regions around the world. At the same time, alpine grasslands are the basis for the economic and husbandry development of the Tibetan Plateau. As an important economic pillar of the Tibetan Plateau, the degradation of alpine grasslands has seriously affected the sustainable development of people's living and livestock husbandry [25,26]. Therefore, the restoration and improvement of degraded grasslands have important practical significance. Generally, high-intensity grazing results in a sharp decline in the predominance of edible pastures, an increase in forbs, and a significant decrease in species diversity, especially for severely degraded grasslands. Due to the low proportion of edible pastures, the value of utilization for animal husbandry is very low. Therefore, for the sustainable development of livestock husbandry, it is of great significance to improve the heavily degraded alpine grasslands. In this study, the heavily degraded alpine meadows of the typical *Kobresia pygeama* C.B. Clarke var. *pygmaea* on the Tibetan Plateau were selected as the research objects, and a long-term exogenous nutrient addition experiment was set up. N addition alone and the combination with P addition were applied to the heavily degraded alpine meadows. Through the assessment of the effects of nutrient enrichment on community structure and production, we aimed at exploring the suitable restoration measures for the heavily degraded alpine meadows and providing scientific guidance for the restoration and management of degraded alpine meadows on the Tibetan Plateau.

2. Materials and Methods

2.1. Site Description

The study site is located in an alpine meadow in the Damxung grassland station, Damxung County, Tibetan Plateau (30°29′ N, 91°05′ E). The mean elevation is 4333 m above sea level. Long-term (1962–2013) mean annual temperature is 1.3 °C. The mean annual precipitation amount is 477 mm, with more than 85% occurring from June to August [27,28]. This site is located in semi-arid areas, with annual potential evapotranspiration of 1725.7 mm and the aridity index of 3.6 (annual potential evapotranspiration divided by precipitation amount). The soil is alpine meadow soil corresponding to Gelic Cambisol. Soil depth is 0.3–0.5 m, and soil total N and P are approximately 0.12% and 0.05%, respectively [29]. Native plant communities in this alpine grassland are dominated by *K. pygmaea* C.B. Clarke var. *pygmaea*, *Carex montis-everestii*, with total community coverage of 30–50%. In recent decades, *Stipa capillacea* Keng and *Anaphalis xylorrhiza* Sch.-BiP. also invaded to this alpine grassland due to overgrazing. The total atmospheric N deposition is approximately 10.0 kg N ha^{-1} $year^{-1}$ [28].

2.2. Experimental Design

In June 2008, a very flat and homogenous 40 m × 40 m severely degraded area was selected for the fertilization experiment with complete randomized block design. This severely degraded condition was mainly due to overgrazing in the last decades [30], and *A. xylorrhiza* Sch.-BiP., *Artemisia wellbyi* Hemsl. et Pears. ex Deasy, and *Heteropappus bowerii* (Hemsl.) Griers. became the dominant species. The proportion of edible pasture is very low. In this area, five blocks were established, and five 5 m × 5 m subplots were set up in each block with 2 m aisles as the buffering zone among the subplots. In total, there were 25 subplots. In each block, five treatments were randomly assigned by 0 (without N addition, coded as control), 50 (coded as LN), and 100 (coded as HN) kg N ha^{-1} $year^{-1}$. In addition, the LN and HN treatments were combined with a constant level of phosphorous (P, 50 kg P ha^{-1} $year^{-1}$) and coded as LN + P and HN + P. In middle June, the granular $CO(NH_2)_2$ and $(NH_4)_2HPO_4$ fertilizers were evenly sprinkled to each subplot, which occurred at the very beginning of each growing season [8,19,31]. Four out of five replicates were randomly selected for the field sampling and measurements for each fertilization treatment.

2.3. Field Sampling and Measurements

Before the establishment of the fertilization experiment, the background of this fertilization area was investigated in the middle of August 2008, including the measurement of community coverage, species richness, and aboveground biomass [32]. From 2012 to 2018, community surveys and measurements were conducted during the peak growing season (middle August) in every year. Four replicates of each fertilization treatments were randomly selected for the investigation and sampling. The subplots of community surveys were 0.5 m × 0.5 m in each fertilization plot, evenly divided into 25 0.1 m × 0.1 m grids by strings to determine the total coverage of the community and the coverage of each plant species. The richness of each plant species was counted manually. After that, the aboveground part of each plant species was manually cut, placed in page bags, and brought back to the laboratory. They were placed in an oven at 65 °C for 48 h to constant weight and calculated as community aboveground biomass (accuracy of 0.001 g).

All species in the community are classified to three functional groups: graminoids, sedges, and other inedible forbs. In this alpine grassland, graminoids consist of *S. capillacea* Keng, *Stipa purpurea*, and *Poa crymophila* Keng. Sedges consist of *K. pygmaea* C.B. Clarke var. *pygmaea* and *C. montis-everestii*. The edible pastures were mainly composed of graminoids and sedges. Compositae, Rosaceae, Chenopodiaceae plants, and other families are all classified into other inedible forbs.

2.4. Data Calculation

We used the following Equations (1) through (3) to calculate community species α diversity index, including the Simpson index (D), the Shannon-Weiner index (H'), and the Pielou index (E) [33,34].

$$D = 1 - \sum_{i=1}^{s} (P_i)^2 \quad (1)$$

$$H' = -\sum_{i=1}^{s} (P_i)(\log_2 P_i) \quad (2)$$

$$E = \frac{H'}{H_{\max}} = \frac{H'}{\ln(S)} \quad (3)$$

where P_i represents the ratio of the number of i-th species to the total number of plant species in the community, and S represents the total number of species in each plot.

The importance value (IV) of different plant species was calculated by averaging the relative abundance (RA), relative coverage (RC), and relative biomass (RB) as follows [19,35].

$$IV = (RA + RC + RB)/3 \times 100\%. \quad (4)$$

The temporal ecosystem stability in each plot was defined as μ/σ [36], where μ and σ are the inter-annual mean and standard deviation of the community aboveground biomass, respectively.

2.5. Statistical Analysis

A repeated-measure ANOVA was applied to assess the effects of fertilization on species richness, the Simpson index, the Shannon-Weiner index, the Pielou index, community coverage, total aboveground biomass, aboveground biomass of graminoids, sedges, and forbs, and the proportion of forbs to total biomass, with the sampling year as the repeated factor. A one-way ANOVA followed by Duncan's multiple comparisons was used to (1) detect the effects of fertilization on each variable; and (2) test the effects of fertilization on the ecosystem temporal stability. All the statistical analyses were performed using the SPSS 16.0 software package (SPSS, Chicago, IL, USA). Statistical significance was $p < 0.05$. All the figures were produced using Origin Pro 8.0 (OriginLab Corporation, Northampton, MA, USA).

3. Results

3.1. Variability of Climatic Data

Figure 1 shows the variabilities of climatic data during the observation period (2012–2018). The mean annual air temperature ranged from 2.6 to 3.5 °C, with the maximum occurring in 2017 (Figure 1A,B). The mean annual precipitation ranged from 376.8 to 667.0 mm, and the maximum and minimum occurred in 2012 and 2018, respectively (Figure 1C,D).

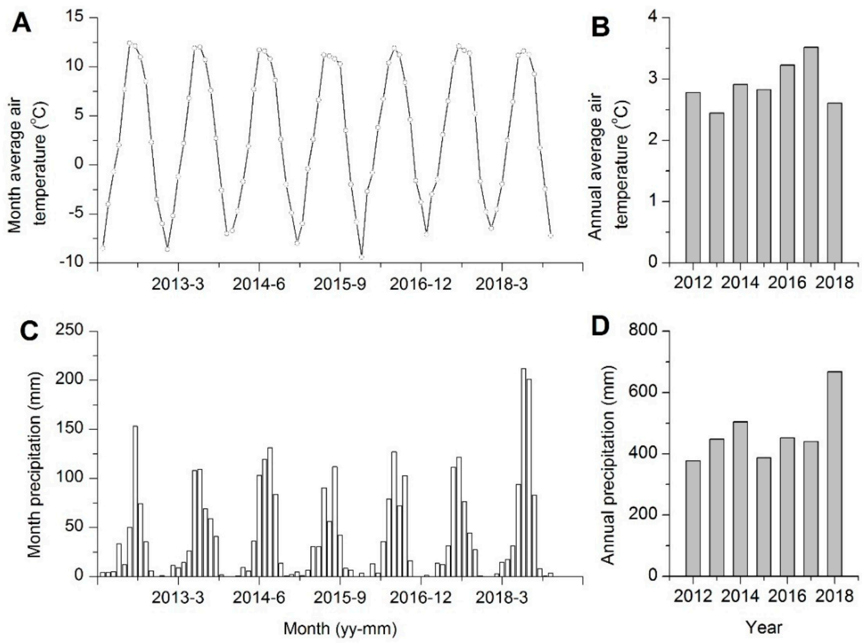

Figure 1. Monthly and annual climatic data during of the observation period (2012–2018). (**A**,**B**) represent monthly and annual air temperature, and (**C**,**D**) represent monthly and annual precipitation, respectively.

3.2. Community Composition, Species Diversity, and Temporal Stability

Statistical analysis found that although there were differences between years, 11 consecutive years of N and P fertilization did not significantly change the richness of plant species (Table 1, Figure 2A). There was no significant effect on the Simpson index in the first few years of fertilization (2012, 2014–2015), and the significant effect of fertilization appeared after 2016 with the extension of time. Fertilization reduced the Simpson index, with the most significant reduction in HN and HN+P treatments (Table 1, Figure 2B). In most fertilization years, N and P fertilization significantly reduced the Shannon-Weiner index, and LN, HN, and HN + P treatments significantly reduced the Shannon-Weiner index (Table 1, Figure 2C). For the Pielou evenness index, the effects of fertilization varied with years. Overall, LN, HN, and HN+P treatments significantly reduced the Pielou index (Table 1, Figure 2D). In 2017, the significant decrease effect mainly occurred in the HN + P treatment.

Table 1. Repeated measure ANOVA analysis on the effects of year (Y) and fertilization (F) on species number, the Simpson index, the Shannon-Weiner index, the Pielou index, community coverage, total aboveground biomass, aboveground biomass of grasses, sedges, and forbs, and the proportion of forbs to total biomass.

	Year (Y)		**Fertilization (F)**		**Y × F**	
	F	***P***	***F***	***P***	***F***	***P***
Species number	14.828	<0.001	2.199	0.118	1.511	0.145
Simpson index	11.216	<0.001	7.210	0.002	3.305	0.001
Shannon-Weiner index	12.471	<0.001	8.796	0.001	2.979	0.002
Pielou index	6.185	<0.001	5.437	0.007	3.093	0.001
Community coverage	35.382	<0.001	54.260	<0.001	5.455	<0.001
Community aboveground biomass	25.563	<0.001	45.254	<0.001	5.844	<0.001
Aboveground biomass of grasses	5.676	0.016	1.809	0.180	1.134	0.375
Aboveground biomass of sedges	2.689	0.066	1.528	0.244	0.490	0.841
Aboveground biomass of forbs	24.900	<0.001	36.998	<0.001	5.839	<0.001
Proportion of forbs to total biomass	2.742	0.017	0.907	0.485	1.333	0.167

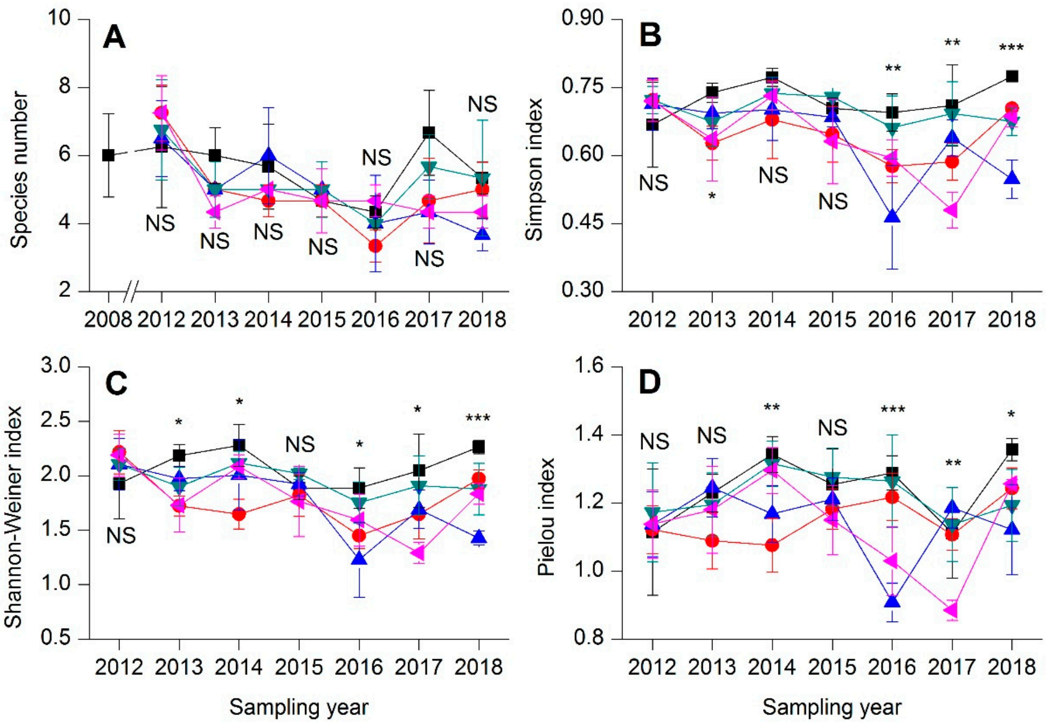

Figure 2. Effects of nitrogen and phosphorus fertilization on plant species richness (**A**), the Simpson index (**B**), the Shannon-Weiner index (**C**), and the Pielou index (**D**). NS, *, **, and *** represent $p \geq 0.05$, $p < 0.05$, $p < 0.01$, $p < 0.001$, respectively. Explanation: control (■); LN (●); HN (▲); LN+P (▼); HN + P (◀).

In the control, the *IV* of *A. xylorrhiza* Sch.-BiP. accounted for 48–65% of the total community in from 2012 to 2018, absolutely dominating in the whole community, while the sub-dominant species changed from *A. wellbyi* Hemsl. et Pears. ex Deasy (2012–2013) to *H. bowerii* (Hemsl.) Griers. (2014–2017) and finally *Chenopodium foetidum* Schrad. (2018) (Figure 3). In LN and HN treatments, the dominant species changed from *A. xylorrhiza* (2012–2015) to *C. foetidum* (2016–2018), similar to the changes in LN + P and HN + P treatments. However, the sub-dominant species *H. bowerii* remained the same in LN + P treatment, while under HN + P treatment, the sub-dominant species shifted from *H. bowerii* (2012–2015) to *Potentilla bifurca* Linn. (2016–2018) (Figure 3).

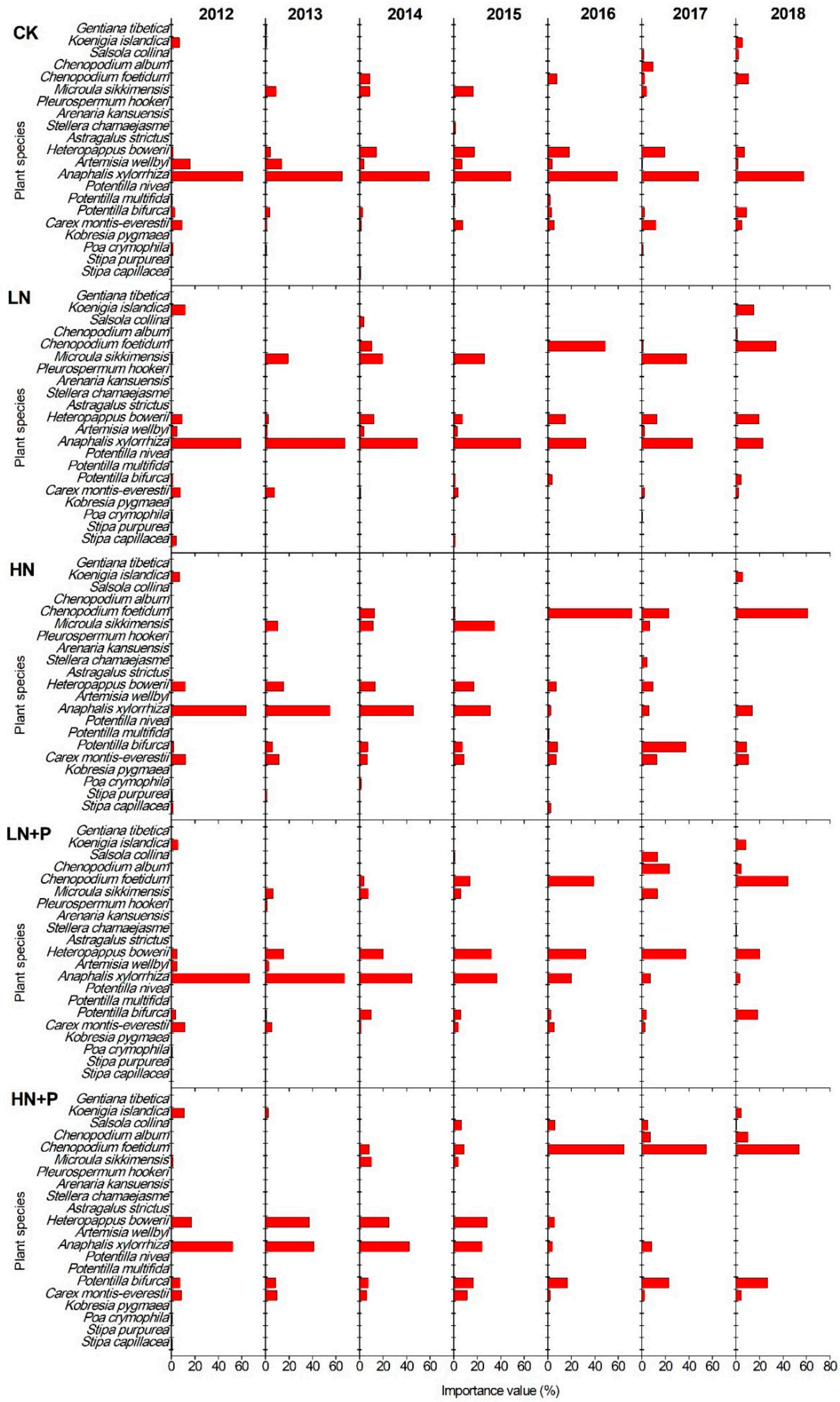

Figure 3. Effects of nitrogen and phosphorus fertilization on the importance value of each plant species in every sampling year.

Further analysis found that fertilization had significant impacts on ecosystem stability (Figure 4, $p = 0.026$). Fertilization treatments had a tendency to reduce the ecosystem stability. Compared with the control, HN, LN + P, and HN + P treatments significantly reduced ecosystem stability.

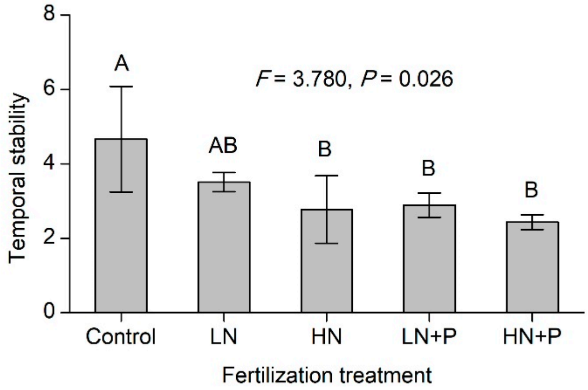

Figure 4. Effects of nitrogen and phosphorus fertilization on temporal stability. Different uppercase letters on the bars represent significant differences among fertilization treatments.

3.3. Community Production

Statistical analysis found that N and P fertilization significantly changed community coverage and aboveground biomass (Table 1, $p < 0.001$), and there were inter-annual differences (Table 1, $p < 0.001$). N and P addition greatly increased the community coverage. Compared with the control, the LN + P and HN + P treatments increased the community coverage by 200% and 202% in 2018, respectively. N addition alone, especially HN treatment, significantly reduced community coverage, and in 2017, it reduced community coverage by 49% (Figure 5A).

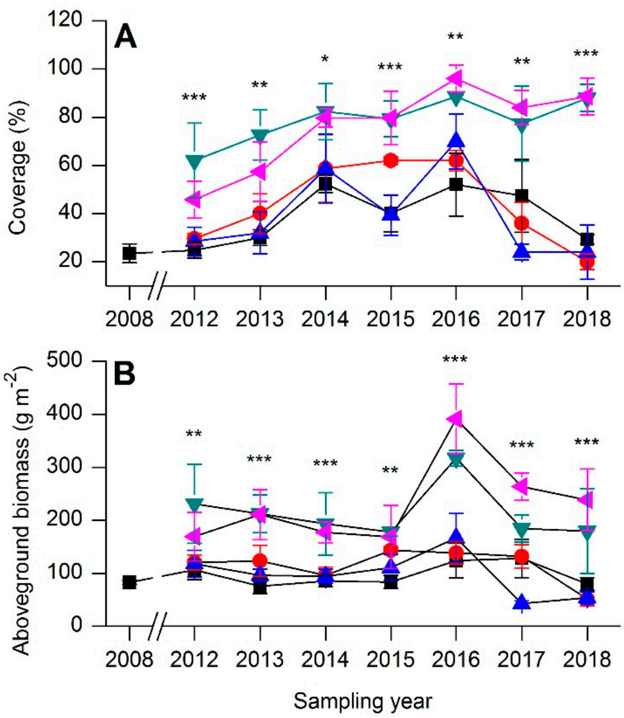

Figure 5. Effects of nitrogen and phosphorus fertilization on community coverage (**A**) and aboveground biomass (**B**). Explanation: control (■); LN (●); HN (▲); LN + P (▼); HN + P (◀).

Consistent with the community coverage, the addition of N and P greatly increased the community aboveground biomass, especially the HN + P treatment with the extension of fertilization time.

Community aboveground biomass in the HN + P treatment was 215%, 106%, and 198% higher than that of the control in 2016, 2017, and 2018, respectively, and the LN + P treatment increased by 156%, 44%, and 125%, respectively. The HN treatment significantly reduced community aboveground biomass by 84% and 26% in 2017 and 2018, respectively (Figure 5B).

3.4. Response of Different Plant Functional Groups to Fertilization Treatments

This study showed that the proportion of edible pastures (graminoids and sedges) was very small, although there were differences between years (Table 1, $p < 0.05$). Fertilization had no significant effect on graminoid biomass (Table 1, $p > 0.05$) and only had a significant impact on sedges in 2013.

Contrary to the edible pastures, N and P fertilization had significant effects on aboveground biomass of other forbs (Table 1, $p < 0.001$), and there were also differences between years. Statistical analysis showed that N and P fertilization significantly increased the biomass of forbs (Figure 6, $p < 0.001$). In the control treatment, the proportion of forbs to total aboveground biomass was more than 96%. Although there were inter-annual differences, fertilization had no significant effects on the proportion of forbs to total aboveground biomass (Figure 6). This indicated that forbs still had an absolute advantage in the community, and the proportion of edible pastures was still low. Fertilization did not significantly improve the community structure of the severely degraded alpine grasslands.

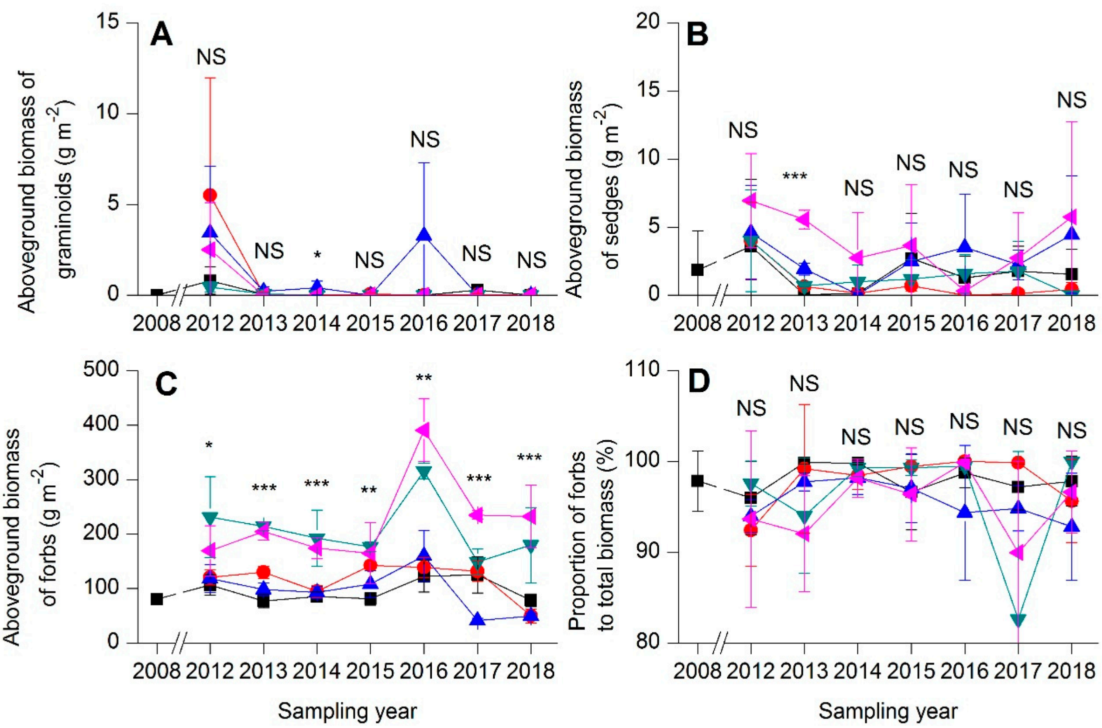

Figure 6. Effects of nitrogen and phosphorus fertilization on aboveground biomass of graminoids (**A**), sedges (**B**), and forbs (**C**), and the proportion of forbs to the total aboveground biomass (**D**). Explanation: control (■); LN (●); HN (▲); LN + P (▼); HN + P (◀).

4. Discussion

Our previous study [19] found that although there was no significant difference in the coverage of light degraded and severely degraded grasslands, the richness and diversity of plant species in severely degraded plots were significantly lower than those in light degraded plots, and the dominant species were gradually replaced by inedible forbs (such as *A. xylorrhiza* and *H. bowerii*). Generally, there are two types of grassland degradation, the quality and quantity degraded types [37]. The quantitative degradation type applies when community coverage and productivity is extremely reduced, resulting in bare lands. In this study, the severe degradation was the quality degradation type. The richness of plant species considerably reduced, and the community composition significantly changed. Forbs such as Compositae have become the main plant functional group, but plant productivity did not decrease significantly, and the grassland quality reduced. Therefore, the recovery and improvement measures were different due to the differences in the causes and manifestations of quality and quantity degradation types.

4.1. Effect of Nitrogen Addition on Alpine Ecosystems

Fertilization is an important management measure to improve grassland production and restore degraded grasslands. Through exogenous supply of soil nutrients, fertilization not only can increase grassland primary productivity but also improve the nutritional quality of grassland plants [38]. This study found that N addition alone had no significant effect on plant species richness in severely degraded plots, and HN treatment reduced the community species diversity index and the community stability in several growing seasons, indicating that HN treatment was not conducive to the maintenance of species diversity and ecosystem stability. This indicates that although the community structure of the heavily degraded plots is relatively simple, and the species diversity is low, its sensitivity to N addition is not high. The community structure did not change significantly after N addition, and it was still dominated by forbs, which has no practical significance from the perspective of grassland utilization.

N addition alone had no effect on the aboveground biomass of the heavily degraded community; it even decreased community biomass in some years. Our previous study also showed that N addition reduced the belowground biomass, resulting in a decrease in root to shoot ratio [19]. Excessive N addition was not conducive to the enhancement of community production, and it also led to negative effects such as soil pollution and acidification. This could be explained by several mechanisms. First, according to Liebig's law of minimum factor, although N addition alleviated the N limitation on plant production, N addition may have caused other factors (such as P) to become the limiting factors [23,39], which was also not conducive to the increase of community biomass. Second, the minimum N addition was 50 kg N ha^{-1} $year^{-1}$ in this study, which may have reached the threshold that the alpine meadow ecosystems could withstand. The saturation threshold of this alpine meadow community occurred at 40–50 kg N ha^{-1} $year^{-1}$ [15,28]. Excessive N addition would not only improve plant production, it would also negatively affect the ecosystem in ways such as soil pH reduction and salt-based ion loss [13,14], which is not conducive to the sustainable development of ecosystems. Subsequently, soil acidification caused by excessive N addition can indirectly modify key ecosystem processes such as N mineralization and N cycling by altering the soil microbes and nematodes [40]. Previous studies indicated that the below-ground microbial and nematode communities were more sensitive to soil acidification than the plant communities, and the changes in plants induced by N addition were mediated by the changes in belowground communities and soil nutrients [13]. Therefore, N fertilizer addition alone is not a good measure to restore alpine severely degraded grasslands.

4.2. Effects of Nitrogen and Phosphorus Addition on Alpine Ecosystems

Previous studies showed that forage production in alpine grasslands was mainly restricted by N availability, but long-term addition of N fertilizer alone can lead to many environmental problems such as soil acidification and cation leaching [13,14]. From the perspective of nutrient balance and grassland management, N combined with P addition were also added to the severely degraded alpine grasslands in this study. Generally, N and P are the most important elements for plant growth and development. Although the alpine meadows have high potential fertility, the low temperature due to the high altitude limits the decomposition activities of soil microorganisms [20]. Therefore, most of the nutrients are in organic forms, and the soil nutrient availability is low [21].

This study found that N combined with P addition significantly increased community coverage and aboveground productivity in heavily degraded plots, consistent with the results in light degraded alpine grasslands [8,31] and other alpine ecosystems [16,18,41]. This indicated that the production of alpine meadows in arid and semi-arid areas was co-limited by N and P availability. Previous studies showed that P addition alone had no effect on community production in wet [16,18,42] and dry [16,41,43] alpine grasslands. The same phenomenon was observed in our experimental areas (unpublished data). The balanced addition of N and P was better than the separate addition of the fertilizer. N addition significantly increased soil inorganic N and total N content while reducing soil available P and total P content, resulting in an increase in N to P ratio [23]. Furthermore, the addition of P could compensate for this reduction and balance soil nutrients. In addition, the combined addition of N and P could not only directly increase the soil active N and P content, but it could also increase soil urease and phosphatase activities, promote the decomposition of organic N and P, and increase the supply potential of soil N and P nutrients [44]. Moreover, N and P addition could enhance the enzyme production and mycorrhizal activity due to the increased acquisition of plant growth on soil nutrients [45].

In this study, HN + P treatment reduced the richness and diversity of the heavily degraded plots and reduced ecosystem temporal stability. Even if N combined with P were added at the same time, the N addition level needed not be too high. N combined with P addition significantly increased aboveground biomass in heavily degraded communities, but the community composition was still dominated by forbs. The proportion of forbs was still higher than 90%, and the proportion of edible pastures (graminoids and sedges) remained very small. This showed that that the combined addition of N and P did not significantly improve the plant community structure. The heavily degraded plots are mainly composed of Compositae and Chenopodiaceae, and there is no seed source of edible pastures. In addition, the proportion of forbs is very high, and they are above the plant community [46]. Soil nutrients and light resources in the community are basically occupied by forbs, and the establishment of new plant species is much more difficult. Therefore, the improvement of such severely degraded alpine grasslands may require additional restoration measures such as shallow tillage, fence enclosures, and reseeding [47–51].

5. Conclusions

Eleven consecutive years of N and P fertilization did not significantly change the richness of plant species, and it reduced the diversity index, especially in HN and HN + P treatments in severely degraded alpine grasslands. N and P addition greatly increased community coverage and aboveground biomass, mainly resulting from the increase in forbs, while none of the fertilization treatments had significant effects on edible pastures (graminoids and sedges). On the contrary, N addition alone, especially high N levels, significantly reduced community coverage. In addition, HN, LN + P, and HN + P treatments significantly reduced ecosystem stability. Forbs still dominated in this community, and the proportion of edible pastures was still extremely low after long-term fertilization. Our results show that N and P addition greatly improved community productivity, and this was benefical for the improvement of the ecosystem quality and soil hydrological functioning. However, fertilization did not significantly improve the community structure of this severely degraded alpine grassland. Therefore, we conclude that fertilization cannot restore the severely degraded alpine grasslands from the perspective of grassland management. In order to provide more edible pastures to livestock and restore this kind of severely degraded alpine grassland, other measures such as fencing and reseeding should be combined with N and P fertilization. However, due to the difference in community composition, the effects of N and P fertilization on light degraded alpine grasslands may be very different, and further study should be conducted.

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