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Changes in Biomass Production, Plant Diversity, and Their Relationship During the Early Establishment of Artificial Alpine Grasslands with Different Species Combinations

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Abstract: The establishment of artificial grasslands is a highly effective strategy for the rapid restoration of degraded grasslands. To investigate the dynamics of biomass production and plant diversity—two critical objectives of grassland restoration—and their relationship during the early stages of artificial grassland establishment, we conducted an experiment in Menyuan County, located in the northeastern region of the Qinghai-Tibet Plateau. The experiment involved sowing different combinations of species (one, three, six, and nine species). Using data collected over three years (2021–2023), we found that biomass production generally increased over time. Specifically, in the second year, biomass production exhibited a unimodal relationship with the number of sown species, while in the third year, it increased linearly with the number of sown species. Plant diversity, which includes both sown and naturally occurring species, initially increased with the number of sown species in the first year but decreased in mixed sown plots in the third year. In the first year, biomass production was not correlated with plant diversity, whereas in the second and third years, biomass production decreased as plant diversity increased. This pattern was primarily driven by the accelerated growth of Gramineae. These results highlight the complex dynamics between biomass production and plant diversity during the early stages of artificial alpine grassland establishment. Our findings suggest that a trade-off between biomass and biodiversity should be carefully considered when designing restoration strategies, as achieving both high productivity and biodiversity may require a more nuanced approach.

Keywords: artificial pasture; functional group; mixed sowing; aboveground biomass; species diversity; Qinghai-Tibet Plateau

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1. Introduction

The Qinghai-Tibetan Plateau, also known as "The Roof of the World" and the "Water Tower in Asia", is a globally important ecological region where alpine grasslands cover

more than 60% of the landscape [1]. This region, defined by its unique geographical location and climate, is acknowledged as a sensitive and vulnerable area for biodiversity [2]. Since the mid-to-late 20th century, alpine grasslands have undergone varying levels of degradation due to increased grazing intensity and climate change [3]. Grassland degradation leads to a series of ecological and environmental problems, including reduced vegetation cover, loss of biodiversity, and decreased productivity [4–6], posing a significant threat to the sustainable development of alpine grasslands. In severely damaged areas, natural restoration is often limited, making the establishment of artificial grasslands one of the most effective approaches for ecological reconstruction [7].

Compared to natural grasslands, artificial grasslands generally exhibit greater community coverage, increased vegetation height, and enhanced productivity. Therefore, they play a crucial role in restoring degraded grasslands. Nonetheless, the ability of seeded species to adapt to environmental conditions may affect future productivity as the years of growth accumulate. They can alleviate grazing pressure on natural grasslands and improve the ecological environment [8]. The dry matter yield of high-quality, high-yielding artificial grasslands can be four to five times greater than that of non-degraded natural grasslands in regions with favorable hydrothermal conditions on the Qinghai-Tibet Plateau [9]. The main methods for establishing artificial grasslands include monoculture sowing and mixed sowing [10]. Numerous studies indicate that artificial grasslands established through mixed sowing generally exhibit higher and more stable productivity, along with superior forage quality, compared to those created through monoculture sowing [11]. On the Qinghai-Tibet Plateau, the main goal of establishing artificial grasslands is to fulfill grazing needs. Most Gramineae species serve as high-quality forages, while Leguminosae contribute to biological nitrogen fixation. As a result, mixed sowing on the plateau typically includes combinations of Gramineae species or blends of Gramineae and Leguminosae species [12]. However, this strategy often limits the diversity of sown species, leaving the potential roles of other functional group species unclear.

Current research on the plant communities of artificial grasslands primarily emphasizes productivity and plant diversity [7,13]. Among all the ecosystem functions and services provided by alpine grasslands, plant biomass production is highly significant because it relates to carbon storage and cycling, as well as the sustainable development of regional animal husbandry [14]. Analyzing the relationship between plant diversity and ecosystem functions can establish a theoretical foundation for sustaining ecosystem services, especially biomass production. The relationship between biodiversity and productivity has been extensively studied and debated in recent decades [14,15]. Commonly discussed patterns include a unimodal relationship, a monotonic relationship (whether positive or negative), and the absence of any relationship [16–20]. The connection between productivity and plant diversity is complex, influenced by the variations in the types of plant communities studied, the environments examined, and the constraints of timescales. While most research has concentrated on natural grasslands, studies involving artificial grasslands often entail the removal of non-sown species, which limits their applicability to artificial grassland establishment [21].

Investigating the dynamics of biomass production and plant diversity and their relationship during the early stages of artificial grassland establishment without removing non-sown species allows for natural succession. Additionally, integrating non-Gramineae and non-Leguminosae species into artificial grassland establishment can enhance plant diversity, which typically correlates positively with the multifunctionality of grasslands. We conducted an artificial grassland establishment experiment by sowing different combinations of species (one, three, six, and nine species) in Menyuan County, Qinghai Province, China. Using data collected over three years (2020–2023), we address the following ob-

jectives: (1) assess changes in biomass productivity and plant diversity during the initial establishment phase of artificial alpine grasslands with varying species combinations. (2) Examine the relationship between productivity and plant diversity. (3) Investigate the dynamics of different functional groups and their impact on biomass productivity and plant diversity during the establishment of artificial grasslands. We predict that both biomass productivity and plant diversity will increase both with the number of sowed species and over the establishment period. The relationship between productivity and plant diversity, along with the dynamics of different functional groups, will vary over time due to the complex growth characteristics of each functional group. Our aim is to provide theoretical insights into the development and management of artificial grasslands in the alpine and cold zones of the Qinghai-Tibet Plateau.

2. Materials and Methods

2.1. Study Sites and Experimental Design

The experimental site of artificial grassland is located near Qingshizui in Menyuan County, Qinghai Province, on the Qinghai-Tibetan Plateau (37°34′ N, 102°26′ E, altitude 3010 m). The climate is a typical continental climate of the plateau, characterized by cold and humid conditions, long sunshine hours, strong solar radiation, and a significant temperature difference between day and night. The annual sunshine hours range from 2264.8 to 2739.8 h, with the longest hours occurring in the summer. The annual average temperature is −1.2 °C, and the annual average precipitation is 569 mm, with over 60% of this precipitation falling from June to October. The grassland type in the study area is classified as an alpine meadow, with dominant species including *Elymus nutans Griseb.*, *Saussurea nigrescens Maxim.*, *Kobresia humilis (C.A.Mey. ex Trautv.) Serg.*, *Gentiana straminea Maxim.*, and *Oxytropis kansuensis Bunge*. The experimental site is flat agricultural land that had been cultivated with *Brassica rapa* L. for over 10 years. Agricultural farmland borders the southern and eastern sides, while alpine meadows are located to the north and west.

The sample site was built in 2021. The experimental plot adopted a random block design, the size of each experimental plot was 2 m × 2 m, and there was a 1 m isolation zone between each plot. Rodent control, ploughing, and raking leveling were carried out before sowing, and then the sample land was enclosed with a wire mesh fence. *B. rapa.* seedlings were manually removed during the growing season to minimize their impact on the experimental data. Grazing was prohibited in the sample area throughout the year, and no fertilization treatment was applied. Cutting treatment was carried out before the growth season (early April each year) to remove litter. Twelve plant species, including those primarily used for establishing artificial grasslands and species commonly found in the study area, were selected to create the artificial grassland communities (*E. nutans*, *Poa pratensis* L., *Lolium perenne* L., *Medicago sativa* L., *Onobrychis viciifolia Scop.*, *Melilotus officinalis* (L.) *Pall.*, *S. nigrescens*, *Gentiana lawrencei Burkill*, *Morina chinensi Diels ex Grüning*, *Pax & K. Hoffm.*, *Descurainia sophi* (L.) *Webb ex Prantl*, *Elsholtzia densa Benth.*, *Thlaspi arvense* L., Table 1). Each species combination consisted of various amounts of species (one, three, six, or nine) and different functional groups (Gramineae, Leguminosae, fast-growing forbs, slow-growing forbs), sown three times, resulting in a total of 147 plots and 3 plots without seed addition (Table S1). The amount of seed sown in each plot was 5 g/m^2, and the species in each combination were mixed and evenly distributed to reach the same seed weight.

Table 1. Information on the selected species.

Species	Family	Functional Group
Elymus nutans Griseb.	Gramineae	Gramineae
Poa pratensis L.	Gramineae	Gramineae
Lolium perenne L.	Gramineae	Gramineae
Medicago sativa L.	Leguminosae	Leguminosae
Onobrychis viciifolia Scop.	Leguminosae	Leguminosae
Melilotus officinalis (L.) *Pall.*	Leguminosae	Leguminosae
Saussurea nigrescens Maxim.	Asteraceae	Slow-growing forbs
Gentiana lawrencei Burkill	Gentianaceae	Slow-growing forbs
Morina chinensi Diels ex Grüning, *Pax & K. Hoffm.*	Dipsacaceae	Slow-growing forbs
Descurainia sophi (L.) *Webb ex Prantl*	Brassicaceae	Fast-growing forbs
Elsholtzia densa Benth.	Lamiaceae	Fast-growing forbs
Thlaspi arvense L.	Brassicaceae	Fast-growing forbs

2.2. Sampling and Aboveground Biomass Measurement

Within each 2 × 2 m treatment plot, a 0.5 × 0.5 m subplot was established to sample plant community characteristics, including species richness and abundance, during August each year. The abundance of each species was counted and recorded. The aboveground part of the plant community within the sample plot was cut and transported to the laboratory to measure aboveground biomass at the species level. This was achieved through oven drying at 65 °C until a constant weight was reached (more than 48 h). The aboveground biomass of the total community is the sum of the aboveground biomass of each species, and the aboveground biomass of each functional group is the sum of the aboveground biomass of each species belonging to a certain functional group. Species richness and the Shannon–Wiener index were applied to describe the plant diversity of the community.

The species richness (R) was calculated as follows:

$$R = S. \quad (1)$$

The Shannon–Wiener index (H) was calculated as follows:

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

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

$$P_i = RB \quad (3)$$

$$RB = (\text{Biomass of a species}/\text{Biomass of all species}) \times 100\%, \quad (4)$$

where RB is the relative biomass.

2.3. Statistical Analysis

In this study, Excel 2019 and SPSS Statistics 22 were used for statistical analysis, and Origin 2022 was used for data plotting. One-way analysis of variance (ANOVA) and least significant difference (LSD) tests were employed to statistically analyze diversity indices and biomass productivity. Regression analysis was used to examine the linear relationships between diversity indices and aboveground biomass, as well as those between the importance values of each functional group and both biodiversity indices and aboveground biomass.

3. Results

3.1. The Effects of Different Species Combinations on Aboveground Biomass

Significant differences were observed in the aboveground biomass of artificial grassland communities among different species combinations, and these differences varied over the planting years. In 2021, the control treatment exhibited the highest aboveground biomass, whereas the three-species mixed sowing treatment showed the lowest aboveground biomass. All sowing treatments showed significantly lower aboveground biomass than the control ($p < 0.05$, Figure 1). In 2022, the six-species mixed sowing treatment achieved the highest aboveground biomass, while the control achieved the lowest. All sowing treatments had higher aboveground biomass than the control, and the three and six-species mixed sowing treatments were significantly higher ($p < 0.05$, Figure 1). In 2023, the nine-species mixed sowing treatment had the highest aboveground biomass, while the control had the lowest, with all mixed sowing treatments significantly exceeding the control ($p < 0.05$, Figure 1). Moreover, biomass exhibited a unimodal response to the number of sown species in the second year, and mixed sowing treatments consistently exhibited greater aboveground biomass than monoculture treatments in the second and third years (Figure 1).

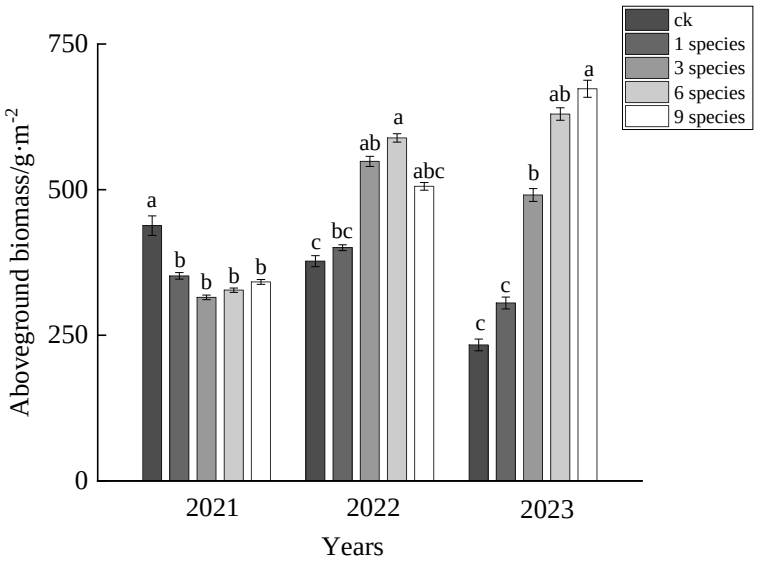


Figure 1. The effects of different species combinations on aboveground biomass. Different lower case letters indicate significant differences between different processing parameters ($p < 0.05$).

3.2. The Effects of Different Species Combinations on Plant Diversity

Species combinations influenced plant diversity differently across the years of the experiment (Figure 2). In 2021, the species richness and Shannon–Wiener diversity index of mixed sowing treatments were significantly higher than those of the control and monoculture treatments ($p < 0.05$, Figure 2). Additionally, plant diversity increased with the number of mixed species in 2021. In 2022, the control exhibited the highest species richness, the species richness of the three mixed sowing treatments was significantly lower than that of the control ($p < 0.05$, Figure 2A), and there was no significant difference in the Shannon–Wiener diversity index across treatments ($p > 0.05$, Figure 2B). In 2023, the control once again had the highest species richness and Shannon–Wiener diversity index. As the number of mixed sowing species increased, plant diversity decreased, with mixed sowing treatments exhibiting lower species richness and Shannon–Wiener diversity than monoculture treatments and significantly lower values than the control ($p < 0.05$, Figure 2).

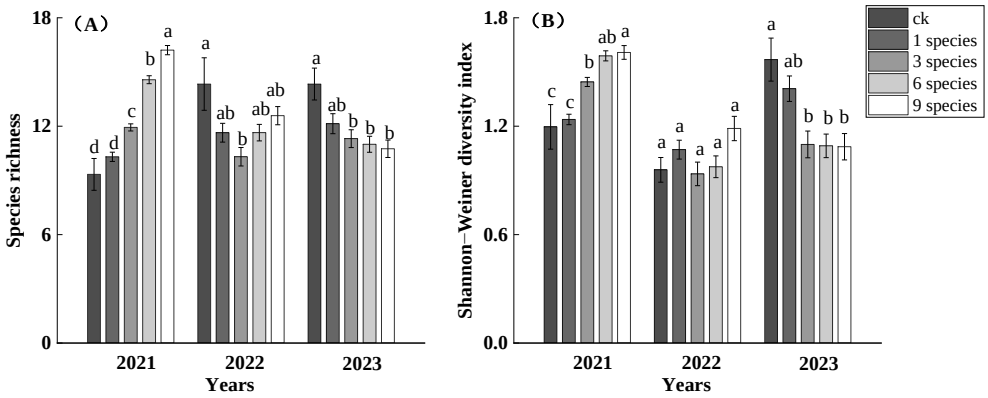


Figure 2. The effects of different species combinations on community plant diversity. (**A**) The effects of different grass species combinations on plant diversity; (**B**) the effects of different species combinations on the Shannon–Wiener index. Different lower case letters indicate significant differences between different processing parameters ($p < 0.05$).

3.3. The Relationship Between Plant Diversity and Biomass Productivity

The relationship between aboveground biomass and plant diversity shifted from non-significant in the first year to a significant negative linear relationship in subsequent years (Figure 3). In 2021, neither species richness nor the Shannon–Wiener index was significantly correlated with aboveground biomass ($p > 0.05$, Figure 3A,D). Conversely, the increase in species richness and the Shannon–Wiener diversity index resulted in a linear decrease in aboveground biomass in 2022 ($R^2 = 0.14$, $p < 0.01$ for species richness and $R^2 = 0.25$, $p < 0.01$ for Shannon–Wiener diversity index, Figure 3B,E) and 2023 ($R^2 = 0.11$, $p < 0.01$ for species richness and $R^2 = 0.28$, $p < 0.01$ for Shannon–Wiener diversity index, Figure 3C,F). The Shannon–Wiener diversity index explained the higher variation in aboveground biomass than species richness.

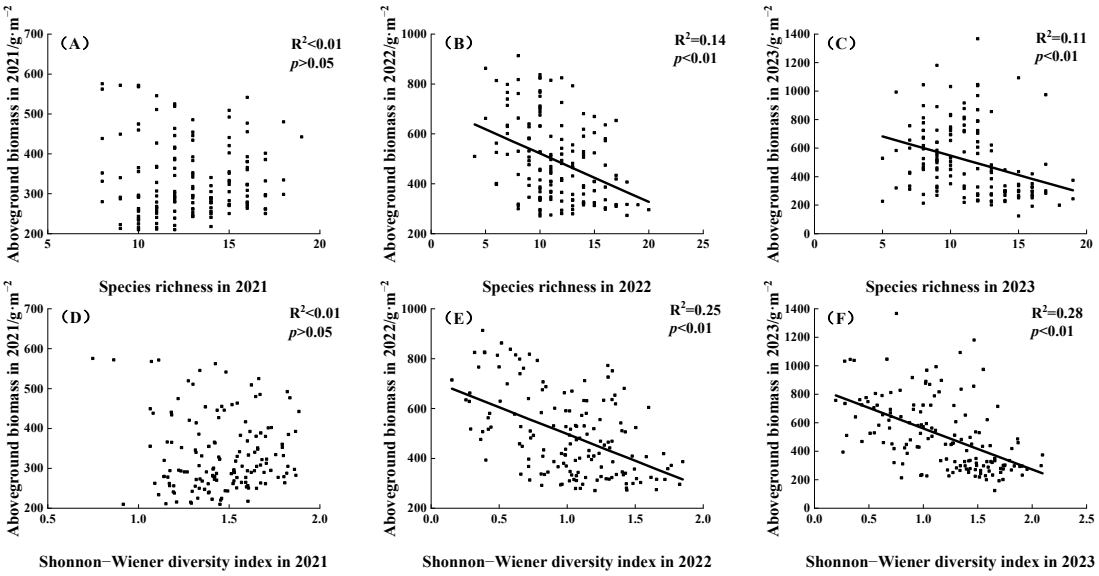


Figure 3. The relationship between the aboveground biomass and plant diversity of different species combinations. (**A**) The relationship between aboveground biomass and species richness in 2021; (**B**) the relationship between aboveground biomass and species richness in 2022; (**C**) the relationship between aboveground biomass and species richness in 2023; (**D**) the relationship between aboveground biomass and Shannon–Wiener index in 2021; (**E**) the relationship between aboveground biomass and Shannon–Wiener index in 2022; (**F**) the relationship between aboveground biomass and Shannon–Wiener index in 2023.

3.4. The Effect of the Importance Value of Each Functional Group on Biomass

An increase in the importance value of Gramineae significantly enhanced aboveground biomass in 2021 (R^2 = 0.19, p < 0.01), 2022 (R^2 = 0.47, p < 0.01), and 2023 (R^2 = 0.42, p < 0.01, Figure 4A). In contrast, the importance value of Leguminosae did not exhibit a significant linear relationship with aboveground biomass (Figure 4B). There was no significant linear relationship between the importance value of slow-growing forbs and aboveground biomass in 2021, but the aboveground biomass decreased significantly with the increase in the importance value of slow-growing forbs in 2022 (R^2 = 0.13, p < 0.01) and 2023 (R^2 = 0.29, p < 0.01, Figure 4C). Similarly, the increased importance value of fast-growing forbs significantly reduced aboveground biomass in 2021 (R^2 = 0.20, p < 0.01), 2022 (R^2 = 0.42, p < 0.01), and 2023 (R^2 = 0.32, p < 0.01, Figure 4D).

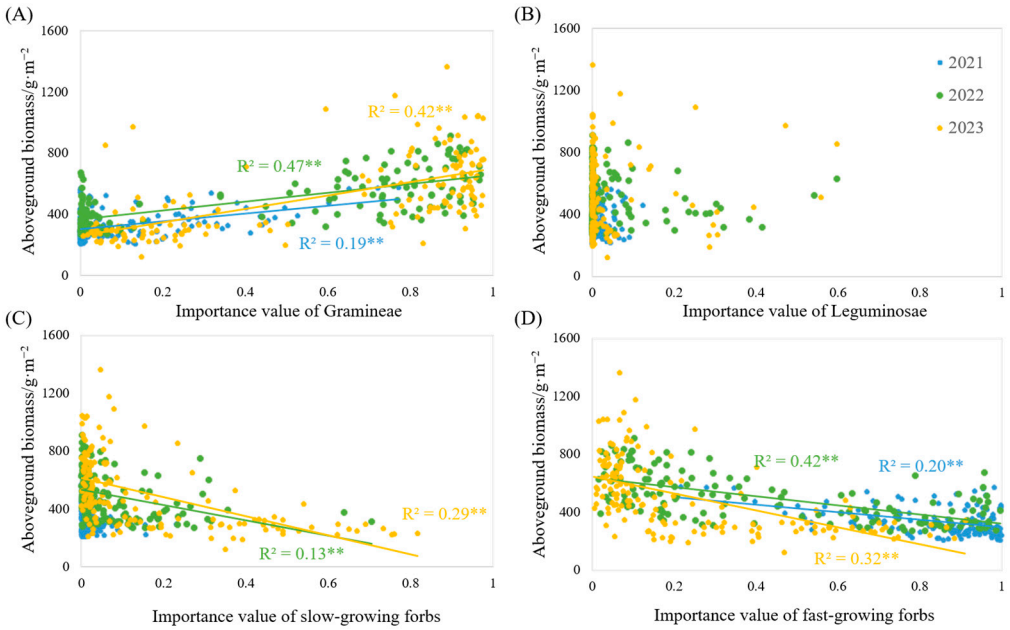


Figure 4. The results of regression analysis between aboveground biomass and the importance values of (**A**) Gramineae, (**B**) Leguminosae, (**C**) slow-growing forbs, and (**D**) fast-growing forbs. ** represent a significant linear relation at the 0.05 and 0.01 levels, respectively.

3.5. The Influence of the Importance Value of Each Functional Group on Diversity

In the first year, no significant linear relationships were detected between species richness and the importance values of Gramineae and Leguminosae. However, species richness decreased with the increase in the importance value of Gramineae in 2022 (R^2 = 0.28, p < 0.01) and 2023 (R^2 = 0.38, p < 0.01; Figure 5A), and increased with the increase in Leguminosae 's importance value in 2022 (R^2 = 0.03, p < 0.05) and 2023 (R^2 = 0.02, p < 0.05; Figure 5B). The species richness index increased with the increase in the importance value of slow-growing forbs only in 2023 (R^2 = 0.13, p < 0.01; Figure 5C). In the first year, there was a negative linear relationship between fast-growing forbs and species richness (R^2 = 0.03, p < 0.05), but it shifted to a positive linear relationship in 2022 (R^2 = 0.27, p < 0.01) and 2023 (R^2 = 0.34, p < 0.01, Figure 5D).

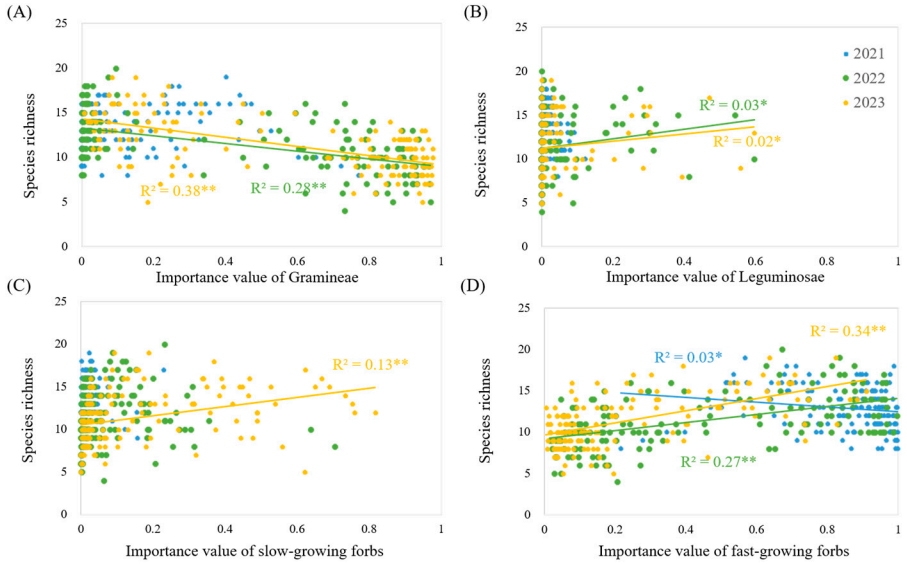


Figure 5. The regression analysis results of species richness and the importance values of (**A**) Gramineae, (**B**) Leguminosae, (**C**) slow-growing forbs, and (**D**) fast-growing forbs. * and ** represent a significant linear relation at the 0.05 and 0.01 levels, respectively.

Regarding the Shannon–Wiener diversity index, it increased with Gramineae's importance value in 2021 ($R^2 = 0.03$, $p < 0.05$), but decreased in 2022 ($R^2 = 0.38$, $p < 0.01$) and 2023 ($R^2 = 0.62$, $p < 0.01$; Figure 6A). A positive linear relationship was observed between the importance value of Leguminosae and the Shannon–Wiener diversity index in 2021 ($R^2 = 0.06$, $p < 0.01$), 2022 ($R^2 = 0.13$, $p < 0.01$), and 2023 ($R^2 = 0.06$, $p < 0.01$; Figure 6B). The Shannon–Wiener diversity index increased with the increase in the importance value of slow-growing forbs in 2022 ($R^2 = 0.12$, $p < 0.01$) and 2023 ($R^2 = 0.26$, $p < 0.01$; Figure 6C). In the first year, the Shannon–Wiener diversity index decreased with the increase in the importance value of fast-growing forbs ($R^2 = 0.06$, $p < 0.05$), while it increased with the increase in the importance value of fast-growing forbs in 2022 ($R^2 = 0.24$, $p < 0.01$) and 2023 ($R^2 = 0.44$, $p < 0.01$; Figure 6D).

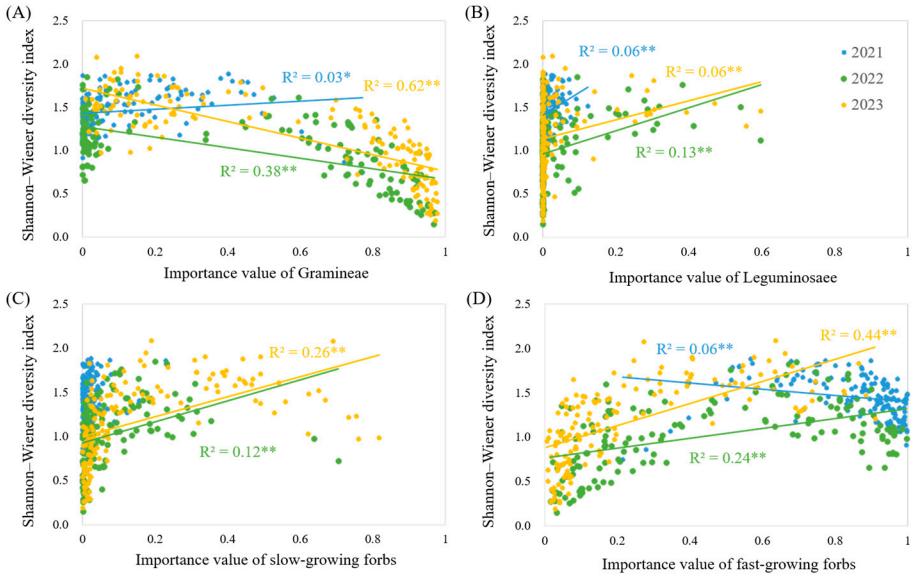


Figure 6. The regression analysis results of the Shannon–Wiener diversity index and the importance values of (**A**) Gramineae, (**B**) Leguminosae, (**C**) slow-growing forbs, and (**D**) fast-growing forbs. * and ** represent a significant linear relation at the 0.05 and 0.01 levels, respectively.

3.6. Community Change of Artificial Grassland

The Sankey diagram illustrates the overall changes in the aboveground biomass structure of the artificial grassland community (Figure 7). In 2021, fast-growing forbs dominated the aboveground biomass, but their proportion decreased annually. Gramineae contributed the largest share of total biomass in 2022 and 2023, while the proportions of Leguminosae and slow-growing forbs increased over time. Specifically, the proportion of Gramineae biomass rose from 12.80% in 2021 to 49.29% in 2022 and 69.69% in 2023. Slow-growing forbs increased from 1.78% in 2021 to 5.97% in 2022 and 9.78% in 2023, whereas fast-growing forbs declined from 84.01% in 2021 to 40.46% in 2022 and 17.00% in 2023.

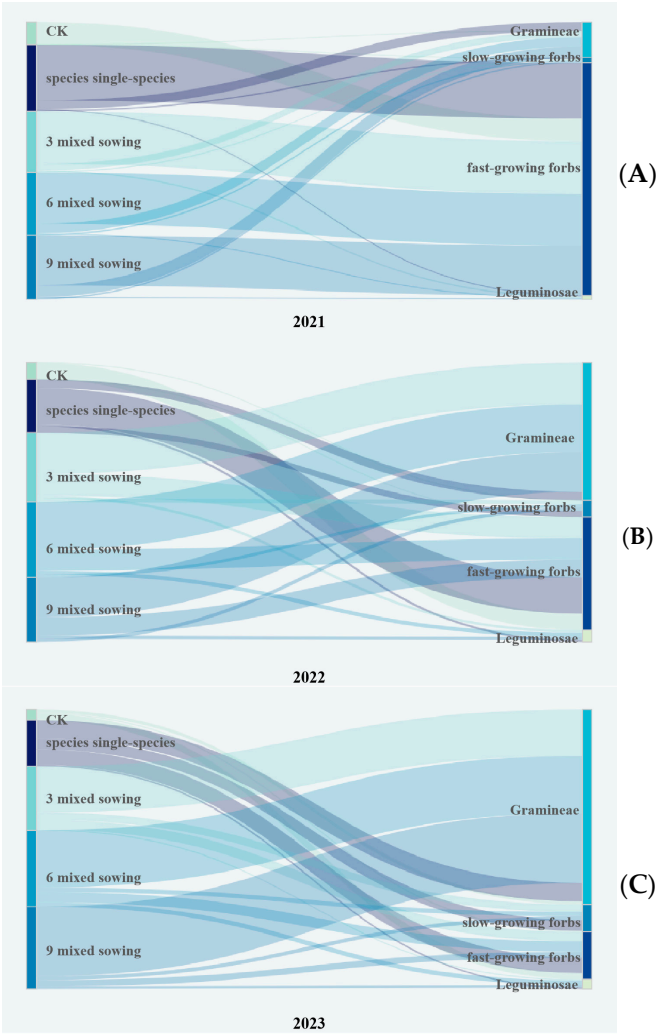


Figure 7. A mulberry base map of each functional group based on their aboveground biomass (**A**) in 2021, (**B**) in 2022, and (**C**) in 2023.

4. Discussion

Artificial grasslands are essential for the rapid restoration of degraded grasslands and for reducing grazing pressure on natural grasslands. Understanding their dynamics in terms of biomass production and plant diversity, along with the relationship between these two statistics, forms the foundation of the management and utilization of artificial grasslands. Using data collected over three years from an experiment involving various combinations of species (one, three, six, and nine species), we observed a general increase in biomass production over time, characterized by two patterns of dynamics and a contrasting

shift in plant diversity along with the relationship between biomass production and plant diversity. Ultimately, these dynamics were primarily driven by the Gramineae. Our findings provide a unique insight into the establishment and management of artificial grassland, referring to biomass productivity and plant diversity in the study area.

During the three-year establishment period, biomass production dynamics shifted significantly and exhibited various patterns with differing numbers of sown species; overall, biomass production generally increased over time. In the second and third years of establishment, most sown species showed more remarkable growth compared to the first year, resulting in an increase in the aboveground biomass of the artificial grassland. Overall, the aboveground biomass of the mixed sowing plots was higher than that of the monoculture plots, which was consistent with the results of previous studies [22–24]. In the first year of establishment, the aboveground biomass of the control plots was greater than that of the sown plots, which contrasts with the findings of a similar study in Henan County, Qinghai [25]. This may be attributed to the initial slow growth of the selected species during the first year, particularly the Leguminosae and slow-growing forbs, while the control plots were dominated by fast-growing forbs that emerged from the soil seed bank, leading to higher biomass production than the other sown plots. The biomass production of the monoculture and three-species mixed sowing plots displayed a unimodal trend with the established year, which aligns with the results of She et al. [26]. The biomass production of the six- and nine-species mixed sowing plots increased linearly with the established year, consistent with the study by Chen et al. [27]. At the same time, the aboveground biomass of the control plots declined annually. This result confirms the effects of the sowing treatments and suggests different utilization strategies for artificial grasslands constructed with a low or high number of species in the study area, such as establishing artificial grasslands with fewer species for short-term use and a higher number of species for long-term use.

Plant diversity serves as a critical indicator of community structure and ecosystem functioning [28]. Moreover, significant shifts in species composition can significantly alter diversity [29]. During the planting period of the artificial grassland, species richness and the Shannon–Wiener diversity index initially increased with the number of sown species but decreased in mixed sown plots in the third year. Each treatment exhibited a "V"-shaped change over three years of planting, consistent with the results of Xue et al. [30] and She et al. [31]. This pattern may result from two factors: the progress of succession and the failure of *Lolium perenne* L. to overwinter. *Lolium perenne* grew rapidly in the first year and suppressed the emergence of other species, while they died out in the second and third years, thereby increasing plant diversity through the invasion of other species. In the early stages of artificial grassland establishment, the plant community primarily consisted of fast-growing forbs and sown species; thus, the plant diversity increased with the number of sown species. As succession progressed, fast-growing forbs were gradually replaced by Gramineae in the later stages. When Gramineae gained an advantage in mixed sown plots, they limited the growth of other species and decreased the species richness and species diversity in subsequent years. We could achieve high biomass productivity in the artificial grassland, but not high plant diversity, even though we sowed more species in the study area.

The relationship between plant diversity and community productivity has been a topic of great interest to ecologists [16], and numerous conclusions have emerged. As with previous studies [17,32–34], there was a positive correlation between plant diversity and productivity in grassland communities, but there were differences in the upward trends between different types of grasslands, and the reasons for the differences may be related to specific environmental factors, spatiotemporal differences between studies, and the research methods adopted. Van Ruijven [34] noted a strengthening positive correlation between

plant diversity and productivity over time. Grime et al. [35] found a positive quadratic relationship between plant community productivity and plant diversity, indicating that community productivity initially increased and then decreased with increasing plant diversity. The results of these experiments suggest that there may not be a simple single-level relationship between plant diversity and productivity in grassland communities, and that changes in productivity are related to many other influencing factors while following changes in plant diversity. In this study, biomass yield showed no correlation with diversity in the first year, while in the second and third years, biomass yield decreased with the increase in plant diversity, indicating that low biodiversity results in high aboveground biomass, which is consistent with the results of Deng et al. [36] and Zhang et al. [37]. This may stem from shifts in community composition, where dominant species, such as *E. nutans*, play a crucial role in shaping the aboveground biomass of the plant community. In the first year, fast-growing forbs dominated the aboveground biomass, while the other sown species enhanced the plant diversity but had little influence on the aboveground biomass. Thus, biomass productivity showed no correlation with plant diversity in the first year. The dominant species of Gramineae replaced the early dominants of fast-growing forbs, and their absolute competitive advantage led to a decrease in plant diversity and an increase in aboveground biomass. The results above show the significant impact of dominant species on the biomass productivity and plant diversity of the artificial grassland.

Functional groups are essential indicators of community-level dynamics, with their roles evolving over time. Fast-growing forbs significantly contributed to aboveground biomass in the first year of construction; however, the aboveground biomass of Gramineae increased substantially in the second and third years (Figure 7). This indicates a rapid shift in dominance from fast-growing forbs to Gramineae, which aligns with the findings of Zhang et al. [38,39]. Plowing the land during the year of construction can loosen the soil and provide good environmental conditions for seed germination, seedling emergence, and later growth, as well as facilitate the growth of fast-growing forbs. This shift may also result from grazing exclusion, which enables the competitively superior Gramineae. The Gramineae exhibited a significant positive effect on biomass productivity, especially in the following two years, while forbs significantly decreased biomass productivity, with an increase in their importance value, and Leguminosae did not show a significant influence on biomass. These results were consistent with our previous study in Henan County, Qinghai [11]. Although the fast-growing forbs dominated the aboveground biomass in the first year, the aboveground biomass productivity decreased as their importance value increased. Gramineae may contribute to greater biomass productivity due to their higher height and density. In conclusion, Gramineae play a central role in enhancing the biomass productivity of artificial alpine grasslands.

As the importance value of Gramineae increased, the trends in species richness and species diversity were consistent, showing a decreasing trend in the second and third years. Consequently, higher proportions of Gramineae led to reduced plant diversity during these years. This aligns with the findings of Zhang et al. [40], and a possible explanation for this phenomenon is that Gramineae possess a significant advantage in interspecific competition. As the number of Gramineae plants increases, they utilize more resources such as light and soil nutrients, resulting in less competitive plants receiving fewer resources, which subsequently impacts the plant diversity of the entire community. With the increasing importance value of Leguminosae and slow-growing forbs, the species richness and species diversity have shown an upward trend. The increase in the importance value of fast-growing forbs led to decreased species richness and species diversity in the first year, but an upward trend in the following two years. Increasing the importance value of fast-growing forbs and slow-growing forbs can help to improve the plant diversity of artificial grassland

plant communities, which is consistent with the work of Pokorny et al. [41]. This may be because forbs possess strong adaptability and resource utilization capabilities, and their increase could promote niche differentiation, allowing different species to utilize various resources and, thus, enhance the plant diversity of the community. This study shows that the significant values of non-Gramineae species promote the plant diversity of artificial grassland.

5. Conclusions

In this study, we found that biomass production in artificial alpine grassland generally increased over time, followed a unimodal pattern, and increased linearly with the number of mixed species in the second and third years, respectively. This indicates that constructing artificial grasslands with fewer species is suitable for short-term use, while a higher number of species is more appropriate for long-term use. Plant diversity initially increased with the number of sown species in the first year but decreased in mixed sown plots by the third year. In the first year, biomass yield was not related to plant diversity, whereas in the second and third years, biomass yield decreased as plant diversity increased. Our findings suggest that while we can achieve high biomass productivity, it is challenging to maintain both high biomass productivity and plant diversity in the study area. These dynamics are primarily driven by the accelerated growth of Gramineae species, while non-Gramineae species, particularly the forbs, contribute to plant diversity. Therefore, when constructing artificial alpine grassland for production purposes, Gramineae should be prioritized, while non-Gramineae species should be included for long-term use and the potential for high plant diversity.

Supplementary Materials: The following supporting information can be downloaded at: https://www.mdpi.com/article/10.3390/d17050341/s1, Table S1: All species combinations.

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