agronomy

Article

Aboveground Biomass in China's Managed Grasslands and Their Responses to Environmental and Management Variations

Huimei Meng [1,†], Jingrui Yang [2,3,†], Wenjuan Sun [4], Liujun Xiao [5] and Guocheng Wang [6,7,*]

1 College of Science, Tibet University, Lhasa 850000, China
2 State Key Laboratory of Soil and Sustainable Agriculture, Institute of Soil Science, Chinese Academy of Sciences, Nanjing 210008, China
3 University of Chinese Academy of Sciences, Beijing 100049, China
4 State Key Laboratory of Vegetation and Environmental Change, Institute of Botany, Chinese Academy of Sciences, Beijing 100093, China
5 Institute of Agriculture Remote Sensing and Information Technology, College of Environmental Resource Sciences, Zhejiang University, Hangzhou 310058, China
6 LAPC, Institute of Atmospheric Physics, Chinese Academy of Sciences, Beijing 100029, China
7 Key Laboratory of Agricultural Remote Sensing and Information System, Hangzhou 310058, China
* Correspondence: wanggc@mail.iap.ac.cn
† These two authors contributed equally to this work.

Abstract: Aboveground biomass (AGB) in managed grasslands can vary across a suite of environmental and management conditions; however, there lacks a quantitative assessment at the national scale of China. Although the potential effects of individual drivers (e.g., species, nutrient fertilization, and water management) have been examined in China's managed grasslands, no attempts have been made to comprehensively assess the effects of multiple variables on AGB. Using a meta-data analysis approach, we created a database composed of AGB and associated attributes of managed grasslands in China. The database was used to assess the responses of AGB to anthropogenic factors, in addition to a suite of natural variables including climate, soil, and topography. The average AGB in managed grasslands of China is approximately 630 g m^{-2} of dry matter, ranging from 55 to 2172 g m^{-2} (95% confidence interval). *Medicago sativa* is the most widely planted species in China's managed grasslands, followed by *Elymus dahuricus* and *Bromus japonicus*. The national average AGB of these three species was around 692, 530, and 856 g m^{-2}, respectively. For each species, AGB shows a large discrepancy across different places. In general, grassland AGB depends substantially on species, environments, and management practices. The dependence can be well described by a linear mixed-effects regression in which a series of biotic and abiotic factors are used as predictors. We highlight that establishing managed grassland can potentially contribute to not only AGB enhancement, but also grassland restoration on degraded natural grasslands.

Keywords: aboveground biomass; managed grasslands; plant species; management; climate; soil; topography

Citation: Meng, H.; Yang, J.; Sun, W.; Xiao, L.; Wang, G. Aboveground Biomass in China's Managed Grasslands and Their Responses to Environmental and Management Variations. *Agronomy* **2022**, *12*, 2913. https://doi.org/10.3390/agronomy12122913

Academic Editors: Kesi Liu and Xinqing Shao

Received: 25 October 2022
Accepted: 21 November 2022
Published: 22 November 2022

1. Introduction

Covering nearly 40% of the Earth's surface, grassland is the world's largest terrestrial ecosystem [1], providing food and ecosystem services and contributing substantively to regulating the global carbon cycle and climate change [2]. Due to either anthropogenic activities (e.g., cultivation and overgrazing) or climate change (e.g., drought), grasslands have been degrading across the world, leading to substantial decreases in the production of forages and livestock [2,3]. To combat terrestrial ecosystem degradation, the United Nations (UN) General Assembly declared 2021–2030 the "UN Decade on Ecosystem Restoration", which outlined the urgent need for global restoration of degraded lands, including grasslands.

China has the world's second largest area of grasslands, a majority of which has been degrading to some extent due to both climate change and/or anthropogenic activities since more than half a century ago [4–6]. Grassland degradation is characterized mainly by decreases in plant species diversity, plant cover, and productivity. Synchronously occurring with degradation, grassland biodiversity and productivity have also been widely declining [7,8]. China's grassland aboveground biomass (AGB) was generally 30–50% lower than that of approximately 60 to 70 years ago [9]. Decreases in grassland AGB pose massive threats to food security and ecosystem health. To address this issue, the establishment of managed grasslands by planting grass species with high quality and quantity forage production and/or supplying additional nutrients and water has widely been recommended [10,11]. However, to date, managed grasslands make up only approximately 3% of China's total grassland area, which is substantially lower than those in developed regions such as Europe and Australia. Overall, to meet the growing needs of forage and livestock production, the establishment of managed grasslands is becoming an increasing trend [11].

Over the past two decades, a number of managed grassland experiments aimed at assessing the responses of plant productivity to environmental and anthropogenic factors have been conducted across China (Appendix B). Specifically, in this study, managed grasslands are defined as the grasslands managed by introducing species with high-quality and high-quantity forage production combined with a series of recommended management practices, such as nutrient fertilization and irrigation [11]. Most existing field-scale managed grassland experiments, however, focused on the effect of a single factor, such as plant species [12,13] and nutrient fertilization [14,15], on AGB. It is well known that grassland productivity is coregulated by both natural and anthropogenic attributes, such as irrigation and climatic, edaphic, and topographic conditions [16–19]. However, the regulating effects of these drivers have seldom been assessed [9], leaving a gap in knowledge on the dynamics of grassland AGB under changing environments and/or management. Moreover, potential forage production through establishing managed grasslands remains unclear at the national scale, which prevents policy makers and local shepherds from projecting the expected benefits from establishing managed grasslands.

In this study, we conducted a data synthesis of 101 publications to collate AGB observations in China's managed grasslands. By employing a suite of environmental and management covariates, we further clarified the regulating effects of these predictors on managed grassland AGB in China.

2. Materials and Methods

2.1. Data Compilation

Using the keywords of *aboveground biomass*, *productivity*, *production*, *China*, and *managed grasslands* (or *managed pasture*), peer-reviewed publications reporting AGB measurements in managed grasslands in China were collected by searching Web of Science (WoS; since the publication year of 1990) to construct a synthesis dataset during October–December 2021. The online datasets used for the literature search in WoS included the WoS Core Collection and Chinese Science Citation Database (articles written in Chinese). We ultimately obtained 101 studies (19 in English and 82 in Chinese) by screening the return publications using the following criteria: (1) managed grasslands were involved; (2) grass species were specified; (3) amount of AGB was reported; (4) experimental locations with precise latitude and longitude coordinates were specified; (5) observation year was directly reported; (6) if fertilization was adopted, type and amount of fertilizers [e.g., nitrogen (N), phosphorus (P) and potassium (K)] were reported; and (7) water management (i.e., rainfed or irrigation) was reported or could be obtained through personal communications. We finally obtained 864 individual AGB measurements widely distributed in China's main grassland areas (Figure 1). In all the managed grassland experiments included in our study (Appendix B), zero-grazing was adopted. In general, the standing tissue of grasses was cut and harvested manually for measuring AGB during its peak amount for a year (e.g., July or August). All other agronomy regarding fertilization and water management for each experiment was summarized in a dataset, which is publicly obtainable via this link: https:

//figshare.com/articles/dataset/AGB_of_managed_grasslands_in_China/19641654 (accessed on 1 July 2022).

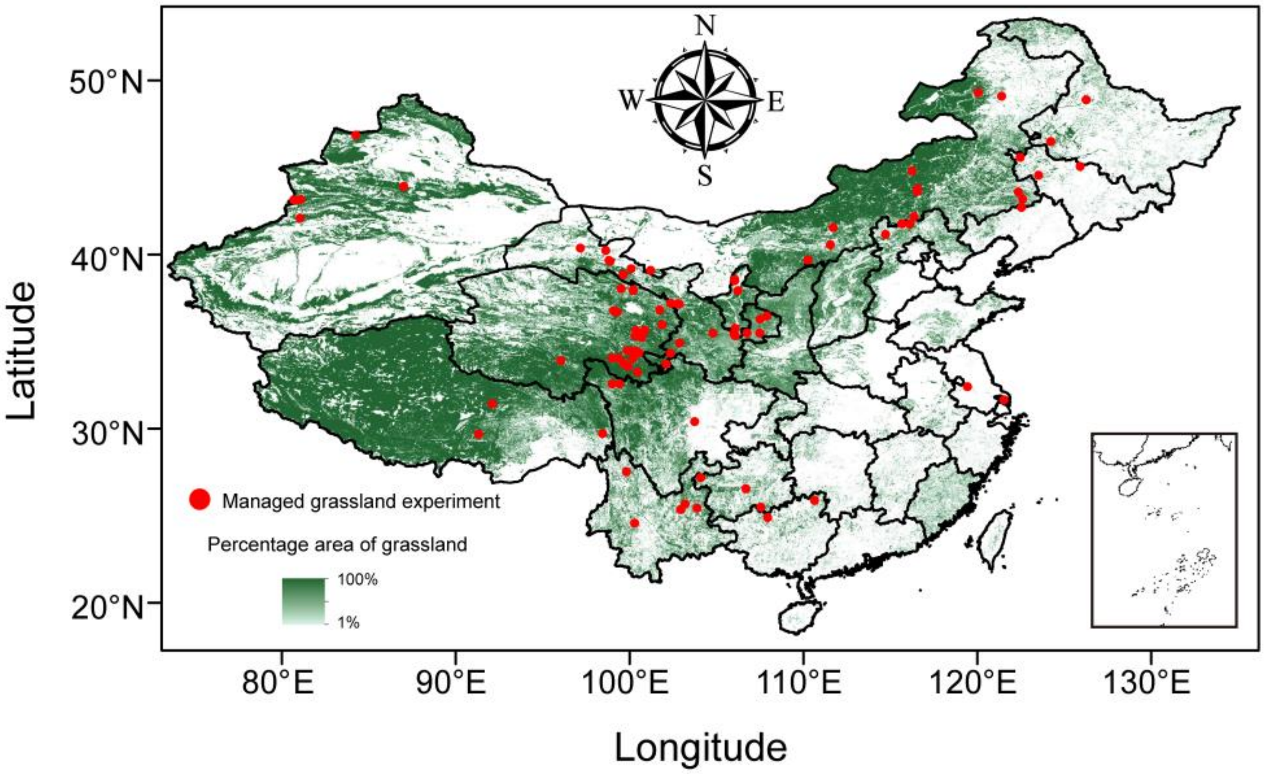

Figure 1. Locations of managed grassland experimental sites collected from literature reviews.

We obtained a set of global and/or national layers of environmental covariates, including edaphic, climatic, and topographic variables (Table A1), as potential predictors of managed grassland AGB. These variables have widely been used to assess the possible regulation effects of environment on changes in grassland aboveground biomass [20] and terrestrial carbon cycles [21]. Here, 10 soil physical and chemical properties (Table A1) were obtained from the ISRIC-WISE soil profile database [22] with a spatial resolution of 1 km^2. We also obtained 16 topographic attributes with the same resolution as the WISE database from Amatulli, et al. [23]. In addition, we determined 19 bioclimatic attributes (T1–T11 and P1–P8; Table A1) quantifying biologically meaningful variables using monthly maximum and minimum temperature and precipitation [24] at each location in the observation year of the experiment. Specifically, for the observation year, we first extracted the monthly maximum and minimum temperature and precipitation from Peng, et al. [25] using the location information of each measurement. Then, the 19 bioclimatic variables (Table A1) were calculated using the *biovars* function in the R package *dismo*. Global gridded rasters of these 19 bioclimatic attributes (representing the period of 1980–2000) with a spatial resolution of 1 km^2 were derived from WorldClim [24]. More details of these global spatial covariate layers are described in Table A1. The collated AGB measurements and their associated predictors are documented and publicly available from: https://figshare.com/articles/dataset/AGB_of_managed_grasslands_in_China/19641654 (accessed on 1 July 2022). The spatial distribution of grasslands was obtained from the National Land Cover DataSets (NLCD) of China developed from Landsat TM digital images [26].

2.2. Drivers of Managed Grassland AGB

We first produced boxplots characterizing the mean, median, and interquartile range of AGB among different groups of environmental and management attributes. Then, we used linear mixed-effects regression (LMER) to examine the relationship of a suite of predicting variables with AGB. We assumed that AGB is potentially associated with soil properties, climatic factors, topographic conditions (Table A1), plant species, and management practices. In fitting the LMER, plant species was treated as a random effect, i.e., the coefficients of other predictor variables were modified by species, and all numerical variables were standardized to unit variance; therefore, the absolute magnitude of the coefficients for the predictor variables reflected their relative importance [27]. A principal component analysis (PCA) was applied to eliminate potential correlations in the 10 edaphic variables, 19 climatic variables, and 16 topographic variables (Table A1). The most important principal components (PCs) with variances greater than 1 were retained for the regression [28]. PCA and LMER were performed using *procomp* in the R package *stats* and *lmer* in the R package *arm*, respectively, in R 4.0.3 [29].

Furthermore, we performed a machine learning-based regression (i.e., a random forest model) to assess the drivers of AGB. Before fitting the regression, the variance inflation factor (VIF) was calculated and used to minimize the multicollinearity of environmental covariates. Specifically, the variables with a VIF value larger than 10 were excluded from further regressions. Treating the remaining covariates together with species, fertilization, and irrigation regimes as independent variables, and AGB as a dependent variable, we then fitted the machine learning-based model, which inherently quantifies the variable importance of predictors using importance scores for each predictor in the regression.

3. Results

3.1. AGB in China's Managed Grasslands

In total, 16 dominant plant species were identified in these studies (Figure A1). In general, the top four species with the highest frequencies identified among the 107 studies, including *Medicago sativa*, *Elymus dahuricus*, and *Bromus japonicus*, were generally more widespread than the remaining species (i.e., *Poa pratensis*, *Leymus chinensis*, *Elymus sibiricus*, *Agropyron cristatum*, *Lolium perenne*, *Onobrychis viciifolia*, *Dactylis glomerata*, *Festuca ovina*, *Trifolium repens*, *Astragalus adsurgens*, and *Phleum pratense*; Figures A1 and A2).

The data synthesis suggested that, by averaging across the 101 sites in China (Figure 1), AGB in managed grasslands was estimated to be 630 g m^{-2} of dry matter (ranging from 55 to 2172 g m^{-2}, lower and upper limit of 95% confidence interval). Among the four most widely distributed species (Figure A1), *Bromus japonicus* had the highest average AGB (856 g m^{-2}), followed by *Medicago sativa* (692 g m^{-2}) and *Elymus dahuricus* (530 g m^{-2}, Figure 2). A large variability existed in the observed AGB (Figure 2). For example, the uncertainty (expressed as CV, i.e., standard deviation divided by mean) of observed AGB for *Medicago sativa* was 96% (data not shown).

Regardless of other factors, such as species and water management, AGB under fertilization (e.g., nitrogen, phosphorus, and potassium) was on average 50% higher than that under zero fertilization (Figure 3a). Similarly, the adoption of irrigation enhanced the average AGB by approximately 100% compared with that under rainfed conditions (Figure 3b). When pooling all data together, we found that AGB was generally higher in regions with higher mean temperatures during the plant growing seasons (i.e., April–October; Figure A3a), while the correlation between AGB and P_G (accumulated precipitation during the growing season) was much weaker (Figure A3b). By excluding the impacts of fertilization and irrigation, we found that the AGB of *Medicago sativa*, for example, was generally higher in regions with a warmer and wetter growing season (Figure 3c,d).

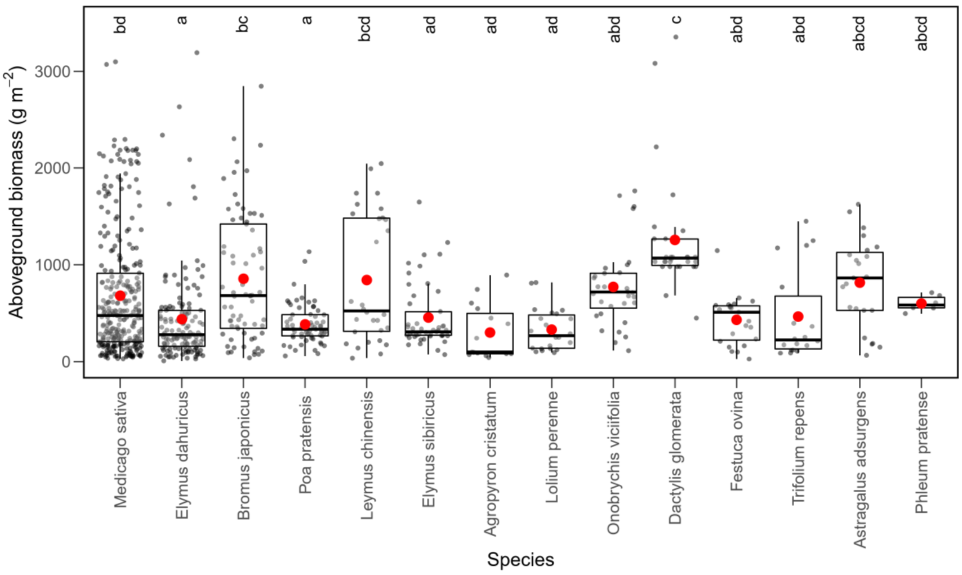

Figure 2. Observed AGB of different grass species planted in managed grasslands. Red dots show the average, and boxplots show the median and interquartile range with whiskers extending to 1.5 times the interquartile range. Different letters above the boxes indicate significant differences ($p < 0.05$) between the AGB of different species.

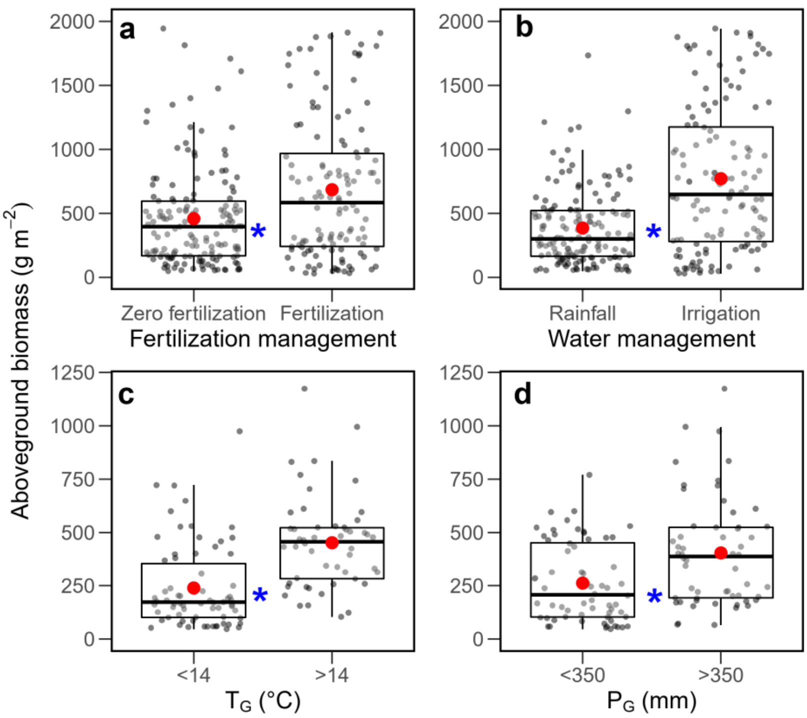

Figure 3. AGB as impacted by management and environmental factors. (**a**): fertilization; (**b**): water management; (**c**): mean temperature during plant growing seasons (April–October; TG); (**d**): accumulated precipitation during plant growing seasons (April–October; PG). Red dots show the average, and the boxplots show the median and interquartile range with whiskers extending to 1.5 times the interquartile range. Blue stars between two boxes of AGB indicate significant differences ($p < 0.05$) between the two groups of data as determined by t test. Observed AGBs of all species were analyzed in (a) and (b), while only AGB of *Medicago sativa* under zero fertilization and rainfall conditions were used in (c) and (d).

3.2. Comprehensive Assessment of Drivers on Managed Grassland AGB

We further introduced three sets of environmental factors, i.e., soil, climate, and topography. Principal component analysis (PCA) suggested that the first two soil principal components (PCs), four climate PCs, and four topography PCs could explain 71% (Figure 4a), 94% (Figure 4c), and 77% (Figure 4e) of the variances in the 10 soil attributes, 19 climate variables, and 16 topography properties (Table A1), respectively. For the first two PCs of soil, the most important contributing variables were ORGC (organic carbon) and CLPC (clay content) (Figures 4b and A4a). For the first four PCs of climate, the most important contributing attributes were P1 (annual precipitation), T10 (mean temperature of warmest quarter), T3 (isothermality), and P4 (precipitation seasonality) (Figures 4d and A4b). For the first four PCs of topography, the most important contributing variables were TRI (topographic position index), Northness, PCURV (profile curvature), and Aspectsine (aspect sine) (Figures 4f and A4c).

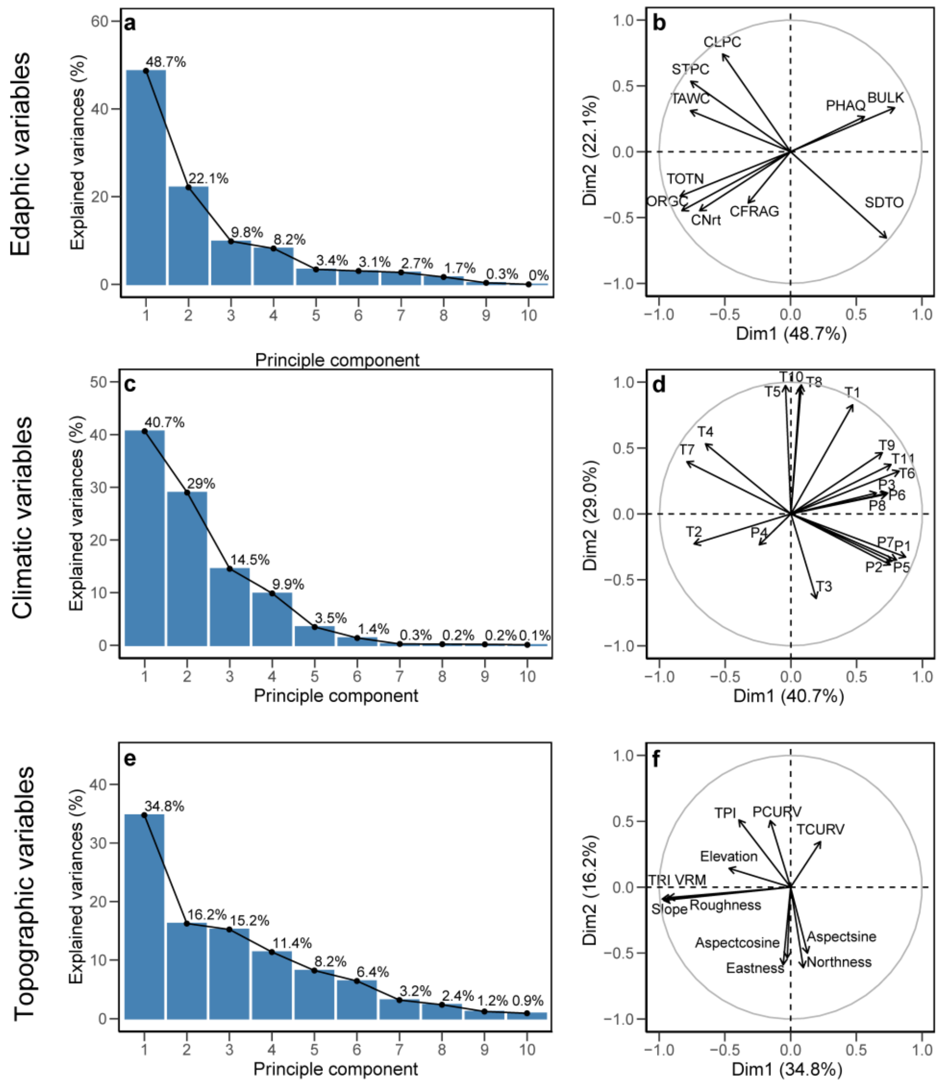

Figure 4. Principal component analysis of edaphic ((**a**) and (**b**); first row), climatic ((**c**) and (**d**); second row) and topographic ((**e**) and (**f**); third row) variables at the managed grassland sites. See Table A1 for detailed descriptions of the variables. The first column shows the loadings of each environmental variable to the top two most important principal components (PCs); the second column shows the percentage of explained variances of the first ten PCs.

Using these PCs as predictors, together with species, which were treated as random effects, and nutrient fertilization attributes as co-predictors, a linear mixed-effects regression (LMER) was fitted to the observed AGB (Figure 5). On average, the fitted LMER explained 68% of the variances in AGB (Figure 5). In general, AGB was significantly and positively correlated with nitrogen fertilization (Figure 5). AGB was also positively and significantly correlated with the first two PCs of climate variables (Figure 5). Thus, annual precipitation (P1, the most contributing variable of PC1 of climate, Figure A4b) and mean temperature of the warmest quarter (T10, the most contributing variable of PC2 of climate, Figure A4b) were generally positively correlated with AGB. The first PC of soil was generally negatively correlated with AGB (Figure 5). Variations in AGB were also regulated by topographic factors, and AGB was significantly correlated with the first three PCs of topography (Figure 5).

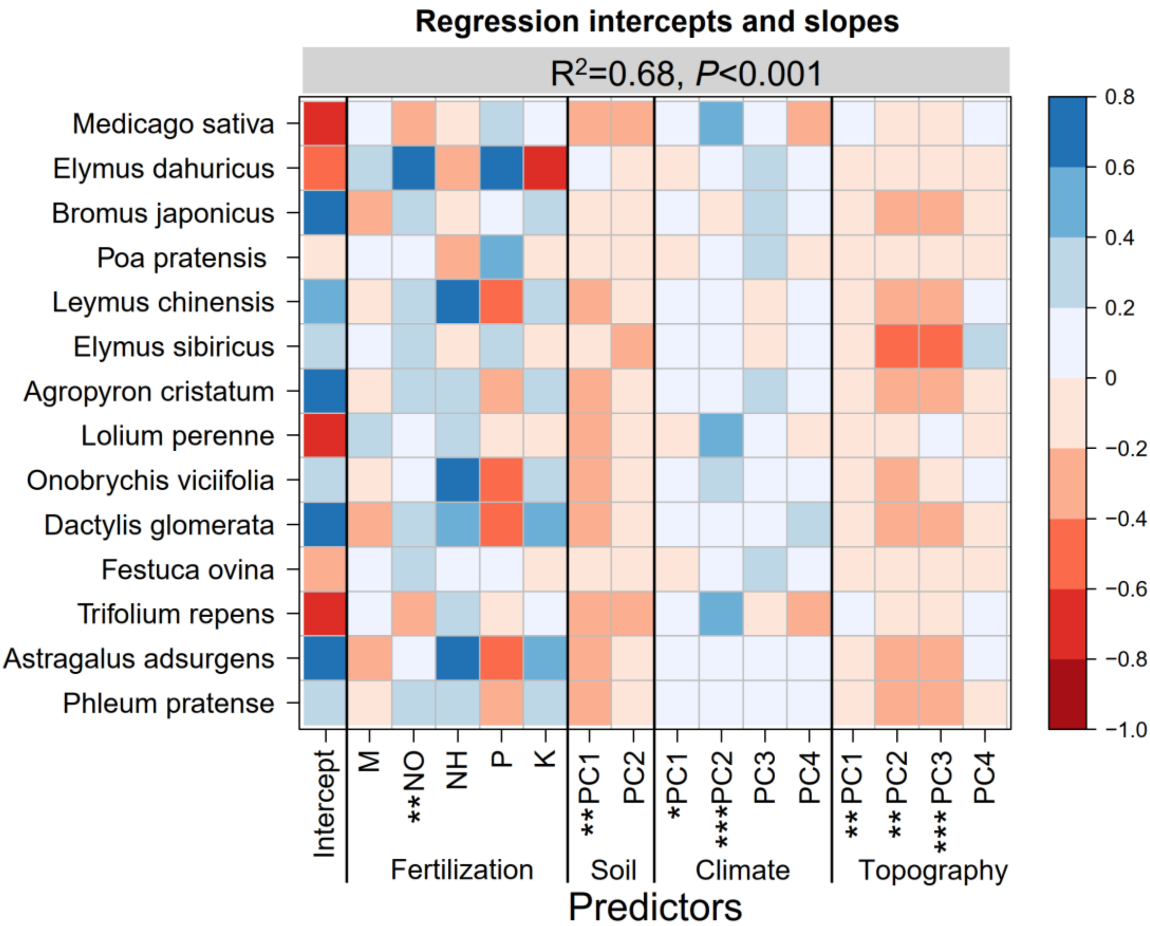

Figure 5. Coefficients of the fitted linear mixed-effects regression (LMER) in simulating AGB. Intercept is the intercept of the LMER. M, NO, NH, P, and K are the amounts of different fertilizers (manure, nitrate nitrogen, ammonium nitrogen, phosphorus, and potassium, respectively) applied during a plant growing season. PC1, PC2, PC3, and PC4 are the most important principal components (PCs) of different groups of driving factors (i.e., soil, climate, and topography). The R^2 for the LMER model is 0.68. *, ** and *** under the predicting variables indicate that the coefficients are statistically significant at the levels of $p < 0.05$, $p < 0.01$ and $p < 0.001$, respectively. Detailed principal component analyses on the predictor variables are presented in Figure A4.

The fitted machine learning-based model (i.e., random forest) indicated that 57% of the variances in AGB can be explained by the species, management of fertilization and irrigation, and the environmental attributes selected in Section 2.2 (Figure 6a). As indicated by the random forest model, three climatic variables (i.e., T8, P2, and T4) are the top three most important regulators of AGB (Figure 6b).

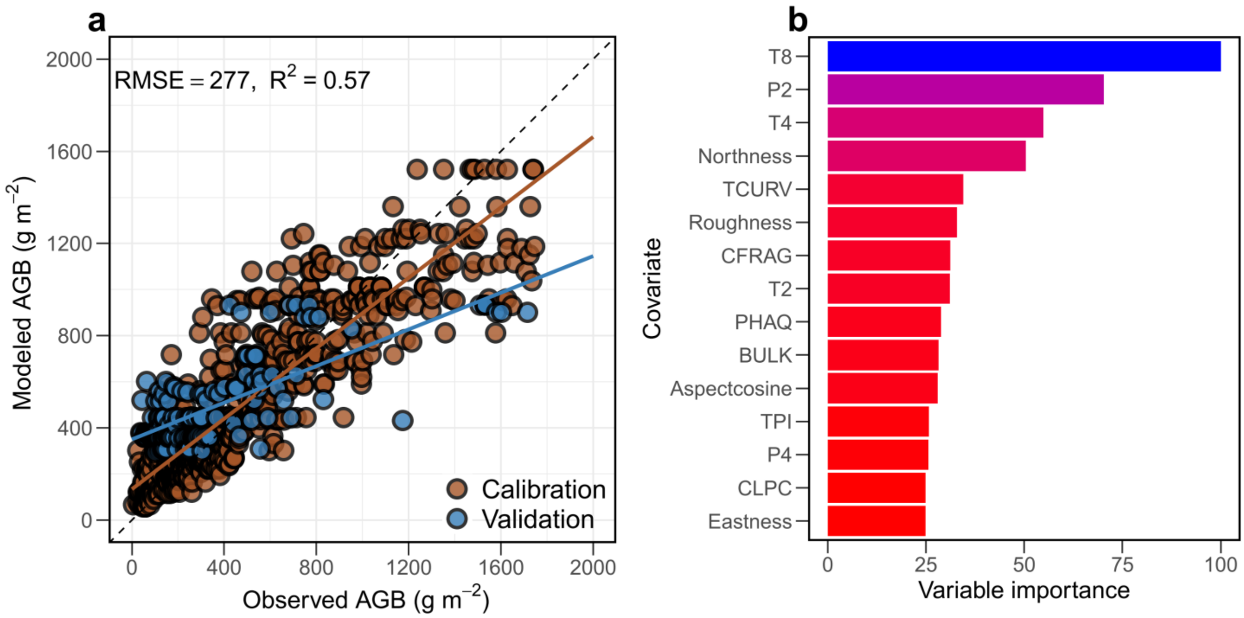

Figure 6. Performance of the fitted random forest model to predict aboveground biomass (AGB) (**a**) and the relative importance of the top 15 most important variables for predicting AGB (**b**). See Table A1 for detailed descriptions of the variables.

4. Discussion

Managed grasslands in China are mainly distributed in the northern and western regions, from Inner Mongolia to the Qinghai–Tibetan Plateau (Figure 1). These regions are generally characterized by a relatively cold and/or dry climate due to high altitudes and/or more northern latitudes [30,31]. As such, both temperature and precipitation were found to be positively correlated with grassland AGB (Figure 3c,d). As expected, fertilization significantly increased AGB compared with zero fertilization (Figure 3a), which is consistent with existing findings that addition of nutrients (e.g., nitrogen, phosphorus, and potassium) can enhance the nutritional quality of plant tissues, thereby promoting grassland AGB [32–34]. This is because in the world's most terrestrial ecosystem [35,36], including China's grasslands [37,38], plant productivity is widely acknowledged to be nutrient-limited. Apart from nutrients, water availability is another strong constraint on plant productivity in global terrestrial ecosystems, particularly in grasslands [39,40]. This can help to explain the general promoting effect of water irrigation on AGB (Figure 3b). Moreover, in a system with sufficient water supply, the impact of precipitation on AGB can be eliminated [41], which underpins our results that, when irrigation was involved, precipitation seemed to have limited influence on AGB (Figure A3b). In addition, our results demonstrated the coregulating effects of edaphic and topographic attributes on AGB (Figures 5 and 6b), which are generally comparable with the findings in the literature [42–44].

Regardless of plant species, AGB in managed grasslands averaged approximately 630 g m^{-2} of dry matter, ranging from 6 to 7 times China's national natural grassland AGB [45–48]. Although grasslands account for approximately 40% of China's land [4,49], only around 3% of the grassland area is under managed conditions (i.e., managed grasslands), which is substantially lower than those in developed regions such as Europe, Australia and New Zealand [11]. In addition, improving management practices and species varieties can help to enhance AGB. It has been reported that *Medicago sativa* is one of the world's most popular species due to its high forage productivity, high nutritional quality, and wide adaptability to different climatic and edaphic conditions [50]. Our results indicate that, on average, the AGB of *Medicago sativa* can reach approximately 700 g m^{-2} (Figure 2), i.e., ~7 Mg ha^{-1}, which is only half the production of that in developed countries, such as the USA [51]. This could be attributed to the fact that most managed grassland experiments in China (Appendix B) were conducted on existing degraded lands with relatively poorer soil nutrient condition.

Despite the positive effect on AGB, management of grasslands at large scales should be undertaken with caution due to the possible negative consequences on other ecosystem functionalities. For example, growing evidence has suggested that nutrient enrichment due to fertilization can lead to widespread decreases in grassland biodiversity [52], which is deemed another key characteristic of grassland degradation [53]. Moreover, conversion from natural lands to managed grasslands can possibly result in significant losses of ecosystem carbon stock. In natural grasslands, root biomass, rather than AGB, constitutes the majority of the total plant biomass carbon stocks [45,47]. Furthermore, the largest carbon reservoir of grassland is soil, containing more than 90% of the carbon in the whole grassland system [54]. A number of studies have indicated that conversion from natural grasslands to managed grasslands would not only reduce root biomass [55–57] but also substantially decrease the soil carbon pool [58,59], thereby causing a net warming effect on climate. In contrast, in regions that have already suffered from degradation, the establishment of managed grasslands can significantly enhance both root biomass productivity and soil carbon content [60,61]. On this basis, we suggest that priority of managed grassland establishment should be given to grasslands that have been severely degraded to benefit not only forage production but also ecosystem restoration. In addition, since managed grassland is in general established in areas with soil degradation possibly caused by water limitation, we highlight a need for introducing the plant species with high drought tolerance and/or deep rooting capacity in the future.

5. Conclusions

We comprehensively and quantitatively assessed the aboveground biomass (AGB) of dominant plant species in China's managed grasslands. We found that the establishment of managed grasslands via practices such as introducing advanced species, fertilization, and irrigation can potentially increase aboveground biomass. The magnitude of enhanced AGB through establishing managed grasslands is associated with a series of biotic and abiotic factors, such as species and climatic, edaphic, and topographic attributes. We highlight the need for a more extensive establishment of managed grasslands, particularly in areas suffering degradation of natural grasslands, thereby favoring not only livestock production, but also grassland restoration. Apart from improving management practices, introducing plant species with drought tolerance and/or deep rooting capacity may also contribute to productivity enhancement and grassland restoration.

Author Contributions: Conceptualization, G.W. and W.S.; methodology, H.M. and J.Y.; formal analysis, H.M., L.X. and G.W.; investigation, G.W. and L.X., J.Y.; data curation, J.Y.; writing—original draft preparation, G.W.; writing—review and editing, W.S.; funding acquisition, W.S. All authors have read and agreed to the published version of the manuscript.

Funding: This study was financially supported by the Strategic Priority Research Program of the Chinese Academy of Sciences (Grant No. XDA26010103) and the Major Program for Basic Research Project of Yunnan Province (Grant No. 202101BC070002).

Data Availability Statement: All data used in this paper is publicly obtainable via this link: https://figshare.com/articles/dataset/AGB_of_managed_grasslands_in_China/19641654 (accessed on 1 July 2022).

Acknowledgments: We thank Zhongkui Luo from Zhejiang University and Zhangcai Qin from Sun Yat-sen University for their help on editing the MS.

Conflicts of Interest: The authors declare no conflict of interest.

Appendix A

Table A1. Environmental covariates.

Covariates	Code	Description	Unit
Edaphic variables	CFRAG	Coarse fragments (>2 mm)	%
	BULK	Bulk density	g cm^{-3}
	ORGC	Organic carbon	g kg^{-1}
	SDTO	Sand content	%
	CLPC	Clay content	%
	STPC	Silt content	%
	TAWC	Available water capacity	cm m^{-1}
	TOTN	Total nitrogen	g kg^{-1}
	CNrt	C:N ratio	-
	PHAQ	pH measured in H_2O	-
Bioclimatic variables	T1	Annual mean temperature	°C
	T2	Mean diurnal range	°C
	T3	Isothermality (T2/T7×100)	%
	T4	Temperature seasonality (standard deviation×100)	°C
	T5	Max temperature of warmest month	°C
	T6	Min temperature of coldest month	°C
	T7	Temperature annual range (T5–T6)	°C
	T8	Mean temperature of wettest quarter	°C
	T9	Mean temperature of direst quarter	°C
	T10	Mean temperature of warmest quarter	°C
	T11	Mean temperature of coldest quarter	°C
	P1	Annual precipitation	mm
	P2	Precipitation of wettest month	mm
	P3	Precipitation of driest month	mm
	P4	Precipitation seasonality (coefficient of variation)	%
	P5	Precipitation of wettest quarter	mm
	P6	Precipitation of driest quarter	mm
	P7	Precipitation of warmest quarter	mm
	P8	Precipitation of coldest quarter	mm
Topographic variables	Elevation	Elevation	m
	Roughness	Roughness	-
	TRI	Terrain Ruggedness Index	-
	TPI	Topographic Position Index	-
	VRM	Vector Ruggedness Measure	-
	Aspectcosine	Aspect Cosine	-
	Aspectsine	Aspect Sine	-
	Slope	Slope	-
	Eastness	Index from −1 to 1 of how east or west a site faces	-
	Northness	Index from −1 to 1 of how north a site faces	-
	PCURV	Profile curvature	°
	TCURV	Tangential curvature	°
	dx	First order partial derivative (E-W slope)	-
	dy	First order partial derivative (N-S slope)	-
	dxx	Second order partial derivative (E-W slope)	-
	dyy	Second order partial derivative (N-S slope)	-

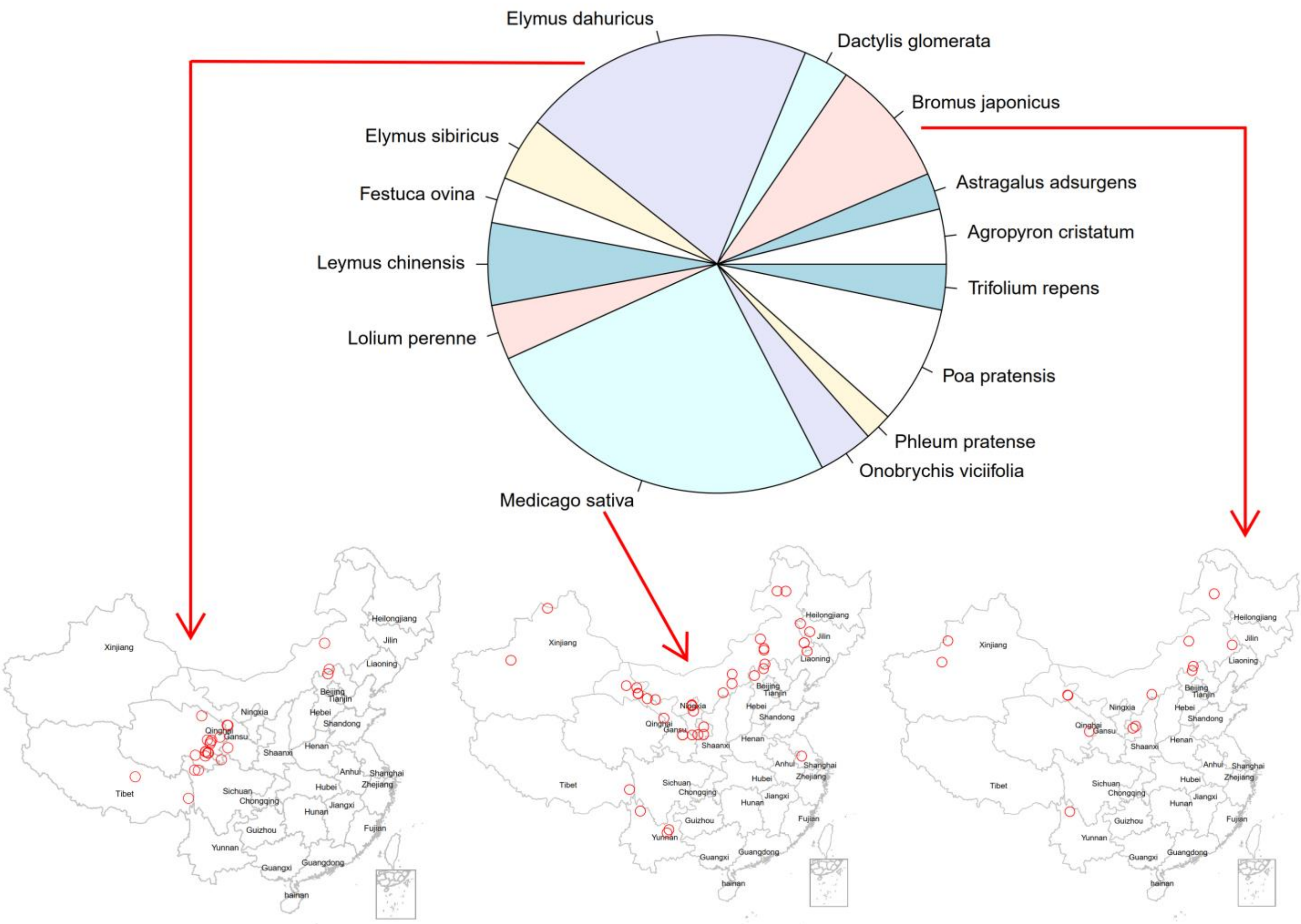

Figure A1. Proportions of plant species and spatial distribution of the top three species that were most commonly found in the 101 literature articles. Spatial distribution of the remaining 11 species is presented in Figure A2.

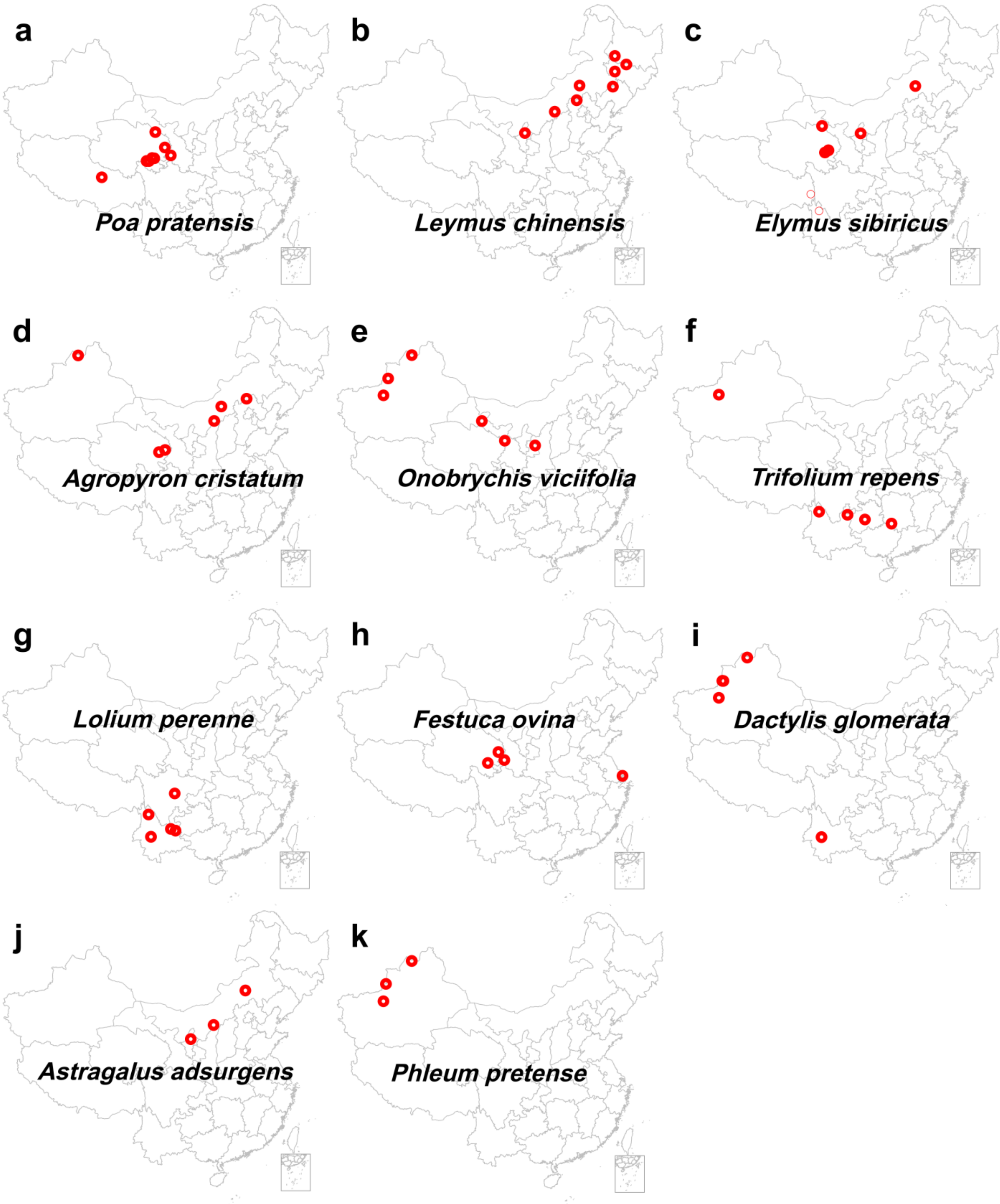

Figure A2. Spatial distribution of the 11 plant species other than those top three species presented in Figure A1.

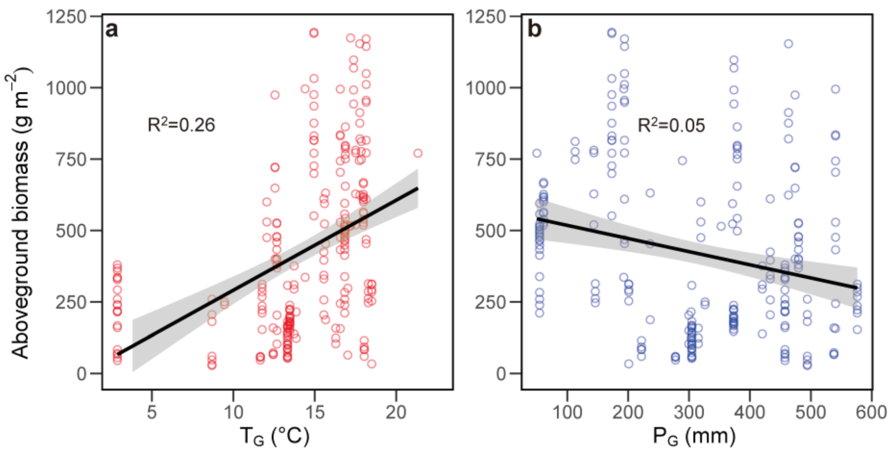

Figure A3. Relationship between aboveground biomass and two climatic attributes: (**a**): mean temperature during plant growing seasons (April–October; T_G), (**b**): accumulated precipitation during plant growing seasons (April–October; P_G). Data for all management such as fertilization and water were included.

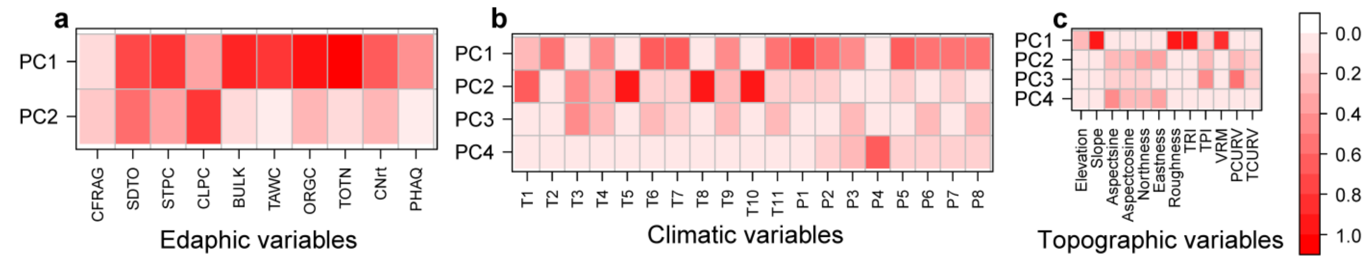

Figure A4. Contributions of each variable to the most *n* important principal components (PCs) of edaphic variables (**a**), climatic variables (**b**), and topographic variables (**c**). *n* is the number of PCs retained based on Kaiser's criterion.

Appendix B. References for Extracting AGB in China's Managed Grasslands

(1) Chen, F., Xia, H. and Qin, X.-j., 2019. Effect of mixture sowing on biomass allocation in the artificially-planted pastures, Southeastern Tibetan. Journal of Mountain Science, 16(1): 54–63.
(2) Chi, Y., Xiong, K., Dong, Y. and Zhang, J., 2015. Community characteristics of white clover and Ophiopogon japonicus mixed planting system under forest in karst area. Jiangsu Agricultural Sciences, 43(1): 114–116 (in Chinese).
(3) Chu, X., Shan, G., Bi, Y., Xue, S. and Kuang, C., 2012. Production performance and persistence of ten introduced alfalfa varieties. Pratacultural Science, 29(4): 610-614 (in Chinese).
(4) Dong, W. et al., 2010. The study on dynamics of aboveground biomass and nutrients of perennial sowing grassland in a 'Grain for Green' area. Pratacultural Science, 27(2): 54–58 (in Chinese).
(5) Fang, Y., Huang, Z., Cui, Z., He, H.H. and Liu, Y., 2021. Trade-offs between forage crop productivity and soil nutrients for different ages of alfalfa grassland. Land Degradation & Development, 32(1): 374–386.
(6) Feng, B., Liu, Z., Baoyin, T. and Tang, H., 2021. Effects of mowing frequency on community characteristics of dry mixed sowing artificial pasture. Chinese Journal of Grassland, 43(03): 10–18 (in Chinese).
(7) Feng, M. et al., 2016. Effects of water and nitrogen fertilizer on biomass distribution and water use efficiency of alfalfa (Medicago sativa) in Hexi Corridor. Chinese Journal of Eco-Agriculture, 24(12): 1623–1632 (in Chinese).

(8) Gao, C., Han, G., Wang, Z., Li, Z. and Ren, H., 2017. Carbon sequestration effect of different artificial grasslands in Inner Mongolia desert grassland area. Chinese Journal of Grassland, 39(4): 81–85 (in Chinese).
(9) Geng, W. et al., 2000. Study on establishing or improving pasture with phytocide tillage. Grassland of China, (5): 41–45 (in Chinese).
(10) Guan, H., Fan, J. and Li, Y., 2019. The impact of different introduced artificial grassland species combinations on community biomass and species diversity in temperate steppe of the Qinghai-Tibetan Plateau. Acta Prataculturae Sinica, 28(9): 192 (in Chinese).
(11) Han, D., Xu, Z., Ai, L. and Han, L., 2009. Effect of fertilization on the forage biomass and quality of aged leafy Elymus sibiricus. Plant Nutrition and Fertilizer Science, (6): 1486–1490 (in Chinese).
(12) He, F. et al., 2019. Variation characteristics of CO_2 fluxes of Elymus nutans artificial grassland for a planting cycle in Agro-pastoral transition area of Sanjiangyuan. Ecology and Environmental Sciences, 28(5): 918–929 (in Chinese).
(13) He, H. et al., 2018. The asymptotic response of soil water holding capacity along restoration duration of artificial grasslands from degraded alpine meadows in the Three River Sources, Qinghai–Tibetan Plateau, China. Ecological research, 33(5): 1001–1010.
(14) He, X., Yang, H., Ma, Y. and He, S., 2016. Study on biomass dynamic changes of Poa pratensis L.cv. Qinghai. Chinese Qinghai Journal of Animal and Veterinary Sciences, 46(1): 13-16 (in Chinese).
(15) He, Y., Wang, H. and Qi, B., 2014. Productivity dynamic of Festuca sinensis pasture built on 'bare soil land' degraded meadow during 5years on Tibetan plateau. Pratacultural Science, 31(1): 200-204 (in Chinese).
(16) Hou, X. et al., 2015. Study on the community structure characteristics and soil physicochemical property of Poa pratensis L.cv.Qinghai single artificial grasslands in different ages. Chinese Journal of Grassland, (1): 65-69 (in Chinese).
(17) Hu, D. et al., 2017. Effects of fertilization on yield and quality of Leymus chinensis cultivated grassland. Chinese Journal of Grassland, 39(1): 35-41 (in Chinese).
(18) Hu, L., Zi, H., Luo, X., Lerdau, M. and Wang, C., 2021. Root dynamics along a restoration chronosequence of revegetated grasslands in degraded alpine meadows of the Qinghai-Tibetan Plateau, China. Land Degradation & Development, 32(13): 3561-3572.
(19) Huang, Z. et al., 2018. Soil water storage deficit of alfalfa (Medicago sativa) grasslands along ages in arid area (China). Field Crops Research, 221: 1-6.
(20) Ji, B. et al., 2020. Soil carbon storage characteristics of alfalfa (Medicago sativa) artificial grasslands in the semi-arid hilly gully region of the loess plateau, China. Russian Journal of Ecology, 51(5): 466-476.
(21) Ji, W. et al., 2012. Suitability of several alfalfa varieties to alpine regions in the Qinghai-Tibetan Plateau. Pratacultural Science, 29(7): 1137-1141 (in Chinese).
(22) Jing, M., Wang, Y., Ma, S. and Li, S., 2019. Optimum conditions of Poa pratensis L.cv.Qinghai cultivation in Qilian Mountain. Acta Agriculturae Boreali-occidentalis Sinica, 28(1): 31-40 (in Chinese).
(23) Li, H., Zhu, C., An, S., Ma, J. and Deng, H., 2013. Changes of community characteristics in the legume/grass pasture in different year after establishment. Pratacultural Science, 30(3): 430-435 (in Chinese).
(24) Li, J.-H., Xu, D.-H. and Wang, G., 2008. Weed inhibition by sowing legume species in early succession of abandoned fields on Loess Plateau, China. Acta Oecologica, 33(1): 10-14.
(25) Li, Q., Zhang, H., Huang, Y. and Zhou, D., 2019a. Forage nitrogen yield and soil nitrogen in artificial grasslands with varied Medicago seedling proportion. Archives of Agronomy and Soil Science, 66(1): 110-125.

(26) Li, S. et al., 2019b. Effect of different grazing intensity on plant community and soil property in cultivated grassland in Weining, Guizhou Province. Grassland and Turf, 39(4): 19-24 (in Chinese).
(27) Li, X. et al., 2020. Effect of stubble height on yield and quality of alfalfa artificial grassland. China Herbivore Science, 40(06): 43-45+54 (in Chinese).
(28) Li, Y.-Y., Dong, S.-K., Wen, L., Wang, X.-X. and Wu, Y., 2014. Soil carbon and nitrogen pools and their relationship to plant and soil dynamics of degraded and artificially restored grasslands of the Qinghai–Tibetan Plateau. Geoderma, 213: 178-184.
(29) Li, Z., Hou, F. and An, Y., 2011. Effects of grazing and light on productivity of artificial pasture of understory. Pratacultural Science, 28(3): 414-419 (in Chinese).
(30) Lian, P.Y., Zeng, D.H., Liu, J.Y., Ding, F. and Wu, Z.W., 2012. Impact of land-use change on carbon stocks in meadow steppe of Northeast China, Applied Mechanics and Materials. Trans Tech Publ, pp. 262-268.
(31) Liu, D. et al., 2009. Impact of enclosure on community characters of sowed Elymus nutans grassland in "black soil Land". Pratacultural Science, 26(10): 59-66 (in Chinese).
(32) Liu, M. and Baoyin, T., 2004. An experiment on mix-sowing of Elymus Sibiricus and Medicago Varia. Grassland of China, 26(1): 22-27 (in Chinese).
(33) Liu, M. et al., 2016. Effects of Legume-grass mixed sowing on forage grass yield and quality in artificial grassland. Arid Zone Research, 33(1): 179-185 (in Chinese).
(34) Liu, Y. et al., 2019. Vegetation biomass allocation relationships in the different utilization patterns in alpine meadow. Grassland and Turf, 39(6): 58-65 (in Chinese).
(35) Luo, S. et al., 2018. Vegetation community of Poa pratensis L. cv. Qinghai cultivated grassland with different growth years. Journal of Grassland and Forage Science, (5): 24-29 (in Chinese).
(36) Luo, Z. et al., 2015. Soil moisture and alfalfa productivity response from different years of growth on the Loess Plateau of central Gansu. Acta Prataculturae Sinica, (1): 31-38 (in Chinese).
(37) Ma, L., Yang, H., Pan, Z. and Rong, Y., 2020. In situ measurements and meta-analysis reveal that land-use changes combined with low nitrogen application promote methane uptake by temperate grasslands in China. Science of the Total Environment, 706: 136048.
(38) Ma, Y. et al., 2003. Study on Cultivation and Tame of Poa Paratensis. Chinese Qinghai Journal of Animal and Veterinary Sciences, 33(3): 6-7 (in Chinese).
(39) Ma, Z., Zhang, C., Zhou, H.K., Yao, B.Q. and Zhao, X.Q., 2017. Role of seed bank in establishment of single and mixed-sowing artificial grasslands of Tibetan Plateau. Polish Journal of Ecology, 65(4): 334-344.
(40) Min, X., Ma, Y., Li, S. and Wang, Y., 2014. Effects of sheep manure on productivity and nutrition of soil for Poa pratensis cv. Qinghai pasture. Pratacultural Science, (6): 1039-1044 (in Chinese).
(41) Mu, Y., Liu, Y., Tian, F.-P., Chang, X.-F. and Wu, G.-L., 2016. Influence of artificial grassland restoration on soil carbon pool in an arid mining land. Journal of soil science and plant nutrition, 16(4): 890-900.
(42) Pan, L. et al., 2012. Effects of fertilizers and sowing rates on growth characteristics and forage yields of alfalfa in Yangzhou region. Acta Prataculturae Sinica, 20(6): 1099-1104 (in Chinese).
(43) Qi, Y., Zhu, L. and Xu, X., 2015. Effects of mixed combination and proportion between leguminous and graminaceous forages grown in Ningxia desert steppe. Pratacultural Science, 32(9): 1463-1472 (in Chinese).
(44) Qin, J. et al., 2019. Effects of grazing intensity in spring on forage growth in Poa pratensis L. cv. Qinghai artificial grassland in Qilian mountains. Journal of Qinghai University, 37(4): 1-6 (in Chinese).
(45) Ren, W., Zhang, Z., Lin, C., Yang, Q. and Shen, Y., 2020. Effects of mixed seeding ratio on biomass allocation and competition of Onobrychis viciifolia and Elymus nutans

under cold conditions in the Tianzhu alpine region. Pratacultural Science, 37(10): 2035-2048 (in Chinese).
(46) Ruan, K. et al., 2013. Experiment on adaptive selection and cultivation of artificial grassland in Liangshan Tianchi. Hubei Journal of Animal and Veterinary Sciences, 34(12): 88-90 (in Chinese).
(47) Shan, G. et al., 2016. Adaptability evaluation of 12 perennial forage cultivars in alpine region of Diqing. Pratacultural Science, 33(9): 1793-1800 (in Chinese).
(48) Sun, H., 2000. Studies on the degradation succession of mixed artificial grassland. Grassland of China, (2): 8-14 (in Chinese).
(49) Tai, J., Zhang, L. and Yang, H., 2009. Effect of different planting years on the yield of alfalfa and content of N, P, K in soil. Pratacultural Science, 26(12): 82-86 (in Chinese).
(50) Tang, L., Dang, X., Liu, G., Shao, C. and Xue, S., 2014. Response of artificial grassland carbon stock to management in mountain region of Southern Ningxia, China. Chinese Geographical Science, 24(4): 436-443.
(51) Tao, Z.W. et al., 2021. Effects of different artificial planting schemes on invasive weeds. Global Ecology and Conservation, 28: e01651.
(52) Wang, C. et al., 2009. Community succession of differently aged artificial grasslands and their soil nutrient changes in three rivers' source regions in Qinghai, China. Chin J Appl Environ Biol, 15(6): 737-744 (in Chinese).
(53) Wang, C. et al., 2020. Variation characteristics of plant communities in black soil shoals with different establishment years in the source area of the Yellow River. Pratacultural Science, 37(12): 2422-2430 (in Chinese).
(54) Wang, D. et al., 2018. Response of microbial C, N and respiration characteristics to sowing rates in alfalfa cultivation grasslands in Hulunber, Inner Mongolia. Acta Prataculturae Sinica, 27(3): 135-143 (in Chinese).
(55) Wang, L., 2012. The study of the alfalfa cultivation experiment in the artificial grass, Western Jilin. Chinese Agricultural Mechanization, (4): 165-167 (in Chinese).
(56) Wang, L., Bi, Y., Ma, Y. and Shi, J., 2007. Study of the optimal combination of mixed seeding artificial pasture in "Black Soil Type" degraded meadow. Journal of Qinghai University, 25(3): 1-5 (in Chinese).
(57) Wang, P. et al., 2021. Effects of conservation seeding on the yield and quality of perennial mowing mixed grassland in alpine area. Acta Prataculturae Sinica, 29(08): 1818-1827 (in Chinese).
(58) Wang, Q. et al., 2017. Effects of sowing depth on botanical characters and production performance of Alfalfa (Medicago sativa) under different soil salt concentration. Chinese Journal of Grassland, 39(1): 19-26 (in Chinese).
(59) Wang, Q., Wang, S., Chen, W. and Chen, B., 2016. Effects of fertilization on the yield, quality and economic benefits of alfalfa in low-production croplands of Minle. Pratacultural Science, 33(2): 230-239 (in Chinese).
(60) Wang, S., Hao, M., Pu, Q. and Wu, Z., 2014. Ecological and productive succession process of a cultivated alfalfa grassland community on Loess Plateau. Acta Prataculturae Sinica, 23(6): 1-10 (in Chinese).
(61) Wang, S. et al., 2015. Effects of sowing quantity and stubble height on the yield and quality of Elymus sibiricus. Pratacultural Science, (1): 107-113 (in Chinese).
(62) Wang, X. et al., 2021d. Effects of perennial Legume-Gramineae mixtures on forage yield and quality in the Hexi Corridor Region. Pratacultural Science, 38(7): 1339-1350 (in Chinese).
(63) Wen, L., Jinlan, W., Xiaojiao, Z., Shangli, S. and Wenxia, C., 2018. Effect of degradation and rebuilding of artificial grasslands on soil respiration and carbon and nitrogen pools on an alpine meadow of the Qinghai-Tibetan Plateau. Ecological Engineering, 111: 134-142.
(64) Wen, Z. and Hui, Y., 1996. Establishment of rape-forage mixture pasture in Bashang Plateau Region. Grassland of China, (1): 27-30 (in Chinese).

(65) Wu, G.L., Liu, Z.H., Zhang, L., Hu, T.M. and Chen, J.-M., 2010. Effects of artificial grassland establishment on soil nutrients and carbon properties in a black-soil-type degraded grassland. Plant and soil, 333(1): 469-479.
(66) Wu, H. et al., 2019. Sediment addition and legume cultivation result in sustainable, long-term increases in ecosystem functions of sandy grasslands. Land Degradation & Development, 30(14): 1667-1676.
(67) Xiao, X. et al., 2021. Effects of utilization modes, planting patterns, and nitrogen applications on the yield and quality of perennial forage. Pratacultural Science, 38(4): 703-715 (in Chinese).
(68) Xing, Y. et al., 2020. Characteristics of plant community and soil organic carbon and nitrogen in artificial grassland with different establishment years. Acta Prataculturae Sinica, 28(2): 521-528 (in Chinese).
(69) Xu, K., Wu, X., Xie, Y. and Yang, J., 2013. Main factors controlling soil CO_2 efflux from alfalfa fields of different standing ages in an arid region. Ecology and Environmental Sciences, 22(10): 1671-1677 (in Chinese).
(70) Xu, R., Chang, S. and Jia, Q., 2020. Effects of nitrogen application and utilization methods on yield, quality and water use of grass-legume mixed grassland in Loess Plateau. Acta Prataculturae Sinica, 28(6): 1744-1755 (in Chinese).
(71) Xu, S. et al., 2000a. Study of the pasture improvement by CaMgP application. Pratacultural Science, 17(12): 13-17 (in Chinese).
(72) Xu, S. et al., 2000b. Renewing deteriorated pasture without cultivation. Pratacultural Science(z1): 10-12 (in Chinese).
(73) Xu, Z. et al., 2018. Effects of grazing methods on vegetation productivity and carbon density in artificial grassland. Journal of Northern Agriculture, 4(46): 110-117 (in Chinese).
(74) Yang, H. et al., 2011. Dynamics of vegetation characteristics and soil physical properties of Poa pratensis cv. Qinghai. Pratacultural Science, 28(6): 910-914 (in Chinese).
(75) Yang, K. et al., 2015a. Effects of nitrogen application on Phleum pretense pasture's forage yield and quality. Pratacultural Science, 32(12): 2071-2077 (in Chinese).
(76) Yang, X., Li, P., Dong, C., Ma, X. and Gou, W., 2020. Studies on the dynamics of above-ground biomass and nutritive value of annual ryegrass and common oat mixtures. Acta Prataculturae Sinica, 28(1): 149-158 (in Chinese).
(77) Yang, X., Li, X., Jin, L. and Sun, H., 2019. Effectiveness of different artificial restoration measures for soil and vegetation recovery on coal mine tailings in an alpine area. Acta Prataculturae Sinica, 28(3): 1-11 (in Chinese).
(78) Yang, X., Wang, C., Zi, H. and Liu, M., 2015b. Soil microbial community structure characteristics in artificial grassland with different cultivation years in the headwater region of Three Rivers, China. Chin J Appl Environ Biol, 21(2): 341-349 (in Chinese).
(79) Yang, Y., Zhou, W., Lian, X. and Kou, S., 2018. R. Comprehensive evaluation of production characteristics of annual forage crops based on principal component analysis: A case study of Zhuanglang in Gansu. Pratacultural Science, 35(6): 1503-1509 (in Chinese).
(80) Yang, Z., Wang, D., Liu, Y., Zhu, Y. and Wu, G., 2015c. Soil moisture and infiltration characteristics for artificial pasture planted on opencast coal mining tailings. Acta Prataculturae Sinica, 24(12): 29-37 (in Chinese).
(81) Yao, Z., Li, J. and Song, L., 2020a. Study on the effect of cross sowing of elymus nutans and medicago sativain different periods. Acta Prataculturae Sinica, 28(5): 1454-1459 (in Chinese).
(82) Yao, Z. et al., 2020b. Study on the leguminous-gramineous grass mixed sowing in Bashang area of Zhangjiakou. Acta Prataculturae Sinica, 28(4): 1076-1082 (in Chinese).
(83) Yu, X. et al., 2014. Plant community characteristics of plateau pika rathole hazard zone in head waters region of three rivers. Journal of Gansu Agricultural University, 49(3): 107-112 (in Chinese).

(84) Zhai, X. et al., 2019. Stoichiometric characteristics of different agroecosystems under the same climatic conditions in the agropastoral ecotone of northern China. Soil Research, 57(8): 875-882.
(85) Zhang, H. et al., 2021. Effects of water regulation on yield, quality and water use of mixed artificial grassland. Water Resources Planning and Design, (4): 63-69 (in Chinese).
(86) Zhang, J. et al., 2010. Effects of clipping on forage yield and quality of mixed-sown artificial grassland in Yangtze and Yellow river headwater region. Pratacultural Science, 27(1): 92-96 (in Chinese).
(87) Zhang, J., Zhang, J., Wang, Y. and Han, T., 2014a. Adaptability of introduced species for improvement of degraded alpine grassland in Gannan areas, China. Pratacultural Science, 31(4): 744-753 (in Chinese).
(88) Zhang, L. et al., 2012. Relationships of dominant species root activity, plant community characteristics and soil micro-environment in artificial grassland over different cultivation periods. Acta Prataculturae Sinica, 21(5): 185-194 (in Chinese).
(89) Zhang, Q., Jing, Y., Yang, X., Jiang, L. and Li, F., 2014b. Preliminary study on mix-sowed pasture in eastern section of Tal Barker Taishan mountain. Pratacultural Science, 31(5): 943-948 (in Chinese).
(90) Zhang, R. et al., 2018. Characteristics of biomass carbon density of degraded natural grassland and artificial grassland in the "Three-River Headwaters" Region. Journal of Natural Resources, 33(2): 185-194 (in Chinese).
(91) Zhang, X. et al., 2019. Effects of fertilization rate on forage yield and water use efficiency of artificial grassland in an alpine arid area. Scientia Agricultura Sinica, 52(8): 1368-1379 (in Chinese).
(92) Zhang, X. et al., 2020. Study on plant community structure characteristics of alpine mixed-seeding grassland in Three Rivers Source Regions. Acta Prataculturae Sinica, 28(4): 1090-1099 (in Chinese).
(93) Zhang, X., Zhu, J. and Ding, H., 2014c. Effects of different mixed sowing patterns on productivity of legume/grass mixture. Grassland and Turf, 34(1): 44-48 (in Chinese).
(94) Zhang, Y. and Zhang, L., 2006. A Study on forage yield dynamics of Nedicago varia/Bromus inermis mixture and single grassland. Chinese Journal of Grassland, 28(5): 23-28 (in Chinese).
(95) Zhang, Z., Xiong, Y. and Pan, Q., 2009. Study on the mix-sowing of five gramineous grasses and Medicago varia in pastoral agronomy area. Grassland and Turf, 2009(6): 15-19 (in Chinese).
(96) Zhao, Q. et al., 2013. Effect of different grazing systems on nutrition of artificial pasture and sheep weight. Chinese Journal of Grassland, 35(1): 67-72 (in Chinese).
(97) Zhao, W. et al., 2020. Effects of vegetation reconstruction on vegetation and microbial community characteristics of black soil beach grassland. Ecology and Environmental Sciences, 29(1): 71-80 (in Chinese).
(98) Zhao, Y., Chai, Q., Chen, Y. and Zhu, W., 2008. Improvement and utilization of saline-alkali grassland in Hexi Corridor. Pratacultural Science, 25(2): 21-25 (in Chinese).
(99) Zheng, W., Zhu, J., Jianaerguli, Li, H. and Zhang, J., 2011. Effects of different mixed sowing patterns on production performance of legume-grass mixture. Chinese Journal of Grassland, 33(5): 45-52 (in Chinese).
(100) Zhou, J., 2020. Artificial grassland productivity of native grass in north of Tibet. Tibet Journal of Agricultural Sciences, 42(S1): 69-72 (in Chinese).
(101) Zhou, Z. et al., 2003. Experimental study on mixed sowing of brome and alfalfa. Inner Mongolia Prataculture, 15(3): 43-44 (in Chinese).

References

1. Suttie, J.M.; Reynolds, S.G.; Batello, C. *Grasslands of the World*; Food & Agriculture Org: Rome, Italy, 2005; Volume 34.
2. Bardgett, R.D.; Bullock, J.M.; Lavorel, S.; Manning, P.; Schaffner, U.; Ostle, N.; Chomel, M.; Durigan, G.; Fry, E.L.; Johnson, D. Combatting global grassland degradation. *Nat. Rev. Earth Environ.* **2021**, *2*, 720–735. [CrossRef]
3. Gibbs, H.; Salmon, J.M. Mapping the world's degraded lands. *Appl. Geogr.* **2015**, *57*, 12–21. [CrossRef]
4. Kang, L.; Han, X.; Zhang, Z.; Sun, O.J. Grassland ecosystems in China: Review of current knowledge and research advancement. *Philos. Trans. R. Soc. B Biol. Sci.* **2007**, *362*, 997–1008. [CrossRef] [PubMed]
5. Cao, J.; Adamowski, J.F.; Deo, R.C.; Xu, X.; Gong, Y.; Feng, Q. Grassland degradation on the Qinghai-Tibetan Plateau: Reevaluation of causative factors. *Rangel. Ecol. Manag.* **2019**, *72*, 988–995. [CrossRef]
6. Qi, J.; Chen, J.; Wan, S.; Ai, L. Understanding the coupled natural and human systems in Dryland East Asia. *Environ. Res. Lett.* **2012**, *7*, 015202. [CrossRef]
7. Wu, G.L.; Ren, G.H.; Dong, Q.M.; Shi, J.J.; Wang, Y.L. Above-and Belowground Response along Degradation Gradient in an Alpine Grassland of the Qinghai-T ibetan Plateau. *CLEAN–Soil Air Water* **2014**, *42*, 319–323. [CrossRef]
8. Xu, H.P.; Zhang, J.; Pang, X.P.; Wang, Q.; Zhang, W.N.; Wang, J.; Guo, Z.G. Responses of plant productivity and soil nutrient concentrations to different alpine grassland degradation levels. *Environ. Monit. Assess.* **2019**, *191*, 678. [CrossRef]
9. Han, J.; Zhang, Y.; Wang, C.; Bai, W.; Wang, Y.; Han, G.; Li, L. Rangeland degradation and restoration management in China. *Rangel. J.* **2008**, *30*, 233–239. [CrossRef]
10. Zhou, H.; Zhao, X.; Tang, Y.; Gu, S.; Zhou, L. Alpine grassland degradation and its control in the source region of the Yangtze and Yellow Rivers, China. *Grassl. Sci.* **2005**, *51*, 191–203. [CrossRef]
11. Fang, J.; Bai, Y.; Li, L.; Jiang, G.; Huang, J.; Huang, Z.; Zhang, W.; Gao, S. Scientific basis and practical ways for sustainable development of China's pasture regions. *Chin. Sci. Bull.* **2016**, *61*, 155–164. (In Chinese)
12. Shan, G.; Zhang, M.; Liao, X.; Zhong, S.; Zhou, P.; Xue, S. Adaptability evaluation of 12 perennial forage cultivars in alpine region of Diqing. *Pratacultural Sci.* **2016**, *33*, 1793–1800. (In Chinese with English abstract)
13. Chen, F.; Xia, H.; Qin, X.-J. Effect of mixture sowing on biomass allocation in the artificially-planted pastures, Southeastern Tibetan. *J. Mt. Sci.* **2019**, *16*, 54–63. [CrossRef]
14. Han, D.; Xu, Z.; Ai, L.; Han, L. Effect of fertilization on the forage biomass and quality of aged leafy Elymus sibiricus. *Plant Nutr. Fertil. Sci.* **2009**, *15*, 1486–1490. (In Chinese with English abstract)
15. Pan, L.; Wei, Z.; Wu, Z.; Zhang, D.; Zheng, X.; Chen, F.; Liu, Q.; Li, W. Effects of Fertilizers and Sowing Rates on Growth Characteristics and Forage Yields of Alfalfa in Yangzhou Region. *Acta Prataculturae Sin.* **2012**, *20*, 1099–1104. (In Chinese with English abstract)
16. Zavalloni, C.; Vicca, S.; Büscher, M.; de la Providencia, I.E.; Dupré de Boulois, H.; Declerck, S.; Nijs, I.; Ceulemans, R. Exposure to warming and CO_2 enrichment promotes greater above-ground biomass, nitrogen, phosphorus and arbuscular mycorrhizal colonization in newly established grasslands. *Plant Soil* **2012**, *359*, 121–136. [CrossRef]
17. Yuan, Z.-Q.; Fang, C.; Zhang, R.; Li, F.-M.; Javaid, M.M.; Janssens, I.A. Topographic influences on soil properties and aboveground biomass in lucerne-rich vegetation in a semi-arid environment. *Geoderma* **2019**, *344*, 137–143. [CrossRef]
18. Xiao, Y.; Zhang, J.; Jia, T.T.; Pang, X.P.; Guo, Z.G. Effects of alternate furrow irrigation on the biomass and quality of alfalfa (*Medicago sativa*). *Agric. Water Manag.* **2015**, *161*, 147–154. [CrossRef]
19. Cui, H.; Sun, W.; Delgado-Baquerizo, M.; Song, W.; Ma, J.-Y.; Wang, K.; Ling, X. Phosphorus addition regulates the responses of soil multifunctionality to nitrogen over-fertilization in a temperate grassland. *Plant Soil* **2020**, *473*, 73–87. [CrossRef]
20. Wang, G.; Luo, Z.; Huang, Y.; Sun, W.; Wei, Y.; Xiao, L.; Deng, X.; Zhu, J.; Li, T.; Zhang, W. Simulating the spatiotemporal variations in aboveground biomass in Inner Mongolian grasslands under environmental changes. *Atmos. Chem. Phys.* **2021**, *21*, 3059–3071. [CrossRef]
21. Luo, Z.; Rossel, R.A.V.; Shi, Z. Distinct controls over the temporal dynamics of soil carbon fractions after land use change. *Glob. Chang. Biol.* **2020**, *26*, 4614–4625. [CrossRef]
22. Batjes, N.H. Harmonized soil property values for broad-scale modelling (WISE30sec) with estimates of global soil carbon stocks. *Geoderma* **2016**, *269*, 61–68. [CrossRef]
23. Amatulli, G.; Domisch, S.; Tuanmu, M.-N.; Parmentier, B.; Ranipeta, A.; Malczyk, J.; Jetz, W. A suite of global, cross-scale topographic variables for environmental and biodiversity modeling. *Sci. Data* **2018**, *5*, 180040. [CrossRef] [PubMed]
24. Fick, S.E.; Hijmans, R.J. WorldClim 2: New 1-km spatial resolution climate surfaces for global land areas. *Int. J. Climatol.* **2017**, *37*, 4302–4315. [CrossRef]
25. Peng, S.; Ding, Y.; Liu, W.; Li, Z. 1 km monthly temperature and precipitation dataset for China from 1901 to 2017. *Earth Syst. Sci. Data* **2019**, *11*, 1931–1946. [CrossRef]
26. Liu, J.Y.; Liu, M.L.; Zhuang, D.F.; Zhang, Z.X.; Deng, X.Z. Study on spatial pattern of land-use change in China during 1995–2000. *Sci. China Ser. D-Earth Sci.* **2003**, *46*, 373–384.
27. Gelman, A.; Hill, J. *Data Analysis Using Regression and Multilevel/Hierarchical Models*; Cambridge University Press: Cambridge, UK, 2006.
28. Kaiser, H.F. The Application of Electronic Computers to Factor Analysis. *Educ. Psychol. Meas.* **1960**, *20*, 141–151. [CrossRef]
29. R Development Core Team. *R: A Language and Environment for Statistical Computing*; R Foundation for Statistical Computing: Vienna, Austria, 2022.

30. Hu, Q.; Pan, F.; Pan, X.; Zhang, D.; Li, Q.; Pan, Z.; Wei, Y. Spatial analysis of climate change in Inner Mongolia during 1961–2012, China. *Appl. Geogr.* **2015**, *60*, 254–260. [CrossRef]
31. Yang, K.; Wu, H.; Qin, J.; Lin, C.; Tang, W.; Chen, Y. Recent climate changes over the Tibetan Plateau and their impacts on energy and water cycle: A review. *Glob. Planet. Chang.* **2014**, *112*, 79–91. [CrossRef]
32. Fay, P.A.; Prober, S.M.; Harpole, W.S.; Knops, J.M.H.; Bakker, J.D.; Borer, E.T.; Lind, E.M.; MacDougall, A.S.; Seabloom, E.W.; Wragg, P.D.; et al. Grassland productivity limited by multiple nutrients. *Nat. Plants* **2015**, *1*, 15080. [CrossRef]
33. Firn, J.; McGree, J.M.; Harvey, E.; Flores-Moreno, H.; Schütz, M.; Buckley, Y.M.; Borer, E.T.; Seabloom, E.W.; La Pierre, K.J.; MacDougall, A.M.; et al. Leaf nutrients, not specific leaf area, are consistent indicators of elevated nutrient inputs. *Nat. Ecol. Evol.* **2019**, *3*, 400–406. [CrossRef]
34. Xu, X.; Liu, H.; Song, Z.; Wang, W.; Hu, G.; Qi, Z. Response of aboveground biomass and diversity to nitrogen addition along a degradation gradient in the Inner Mongolian steppe, China. *Sci. Rep.* **2015**, *5*, 10284. [CrossRef]
35. Elser, J.J.; Bracken, M.E.; Cleland, E.E.; Gruner, D.S.; Harpole, W.S.; Hillebrand, H.; Ngai, J.T.; Seabloom, E.W.; Shurin, J.B.; Smith, J.E. Global analysis of nitrogen and phosphorus limitation of primary producers in freshwater, marine and terrestrial ecosystems. *Ecol. Lett.* **2007**, *10*, 1135–1142. [CrossRef]
36. LeBauer, D.S.; Treseder, K.K. Nitrogen limitation of net primary productivity in terrestrial ecosystems is globally distributed. *Ecology* **2008**, *89*, 371–379. [CrossRef]
37. Li, J.; Lin, S.; Taube, F.; Pan, Q.; Dittert, K. Above and belowground net primary productivity of grassland influenced by supplemental water and nitrogen in Inner Mongolia. *Plant Soil* **2011**, *340*, 253–264. [CrossRef]
38. Dai, L.; Ke, X.; Du, Y.; Zhang, F.; Li, Y.; Li, Q.; Lin, L.; Peng, C.; Shu, K.; Cao, G. Nitrogen controls the net primary production of an alpine Kobresia meadow in the northern Qinghai-Tibet Plateau. *Ecol. Evol.* **2019**, *9*, 8865–8875. [CrossRef]
39. Sala, O.E.; Parton, W.J.; Joyce, L.; Lauenroth, W. Primary production of the central grassland region of the United States. *Ecology* **1988**, *69*, 40–45. [CrossRef]
40. Knapp, A.K.; Smith, M.D. Variation among biomes in temporal dynamics of aboveground primary production. *Science* **2001**, *291*, 481–484. [CrossRef]
41. Bradford, J.B.; Lauenroth, W.K.; Burke, I.C.; Paruelo, J.M. The influence of climate, soils, weather, and land use on primary production and biomass seasonality in the US Great Plains. *Ecosystems* **2006**, *9*, 934–950. [CrossRef]
42. Ji, C.J.; Yang, Y.H.; Han, W.X.; He, Y.F.; Smith, J.; Smith, P. Climatic and edaphic controls on soil pH in alpine grasslands on the Tibetan Plateau, China: A quantitative analysis. *Pedosphere* **2014**, *24*, 39–44. [CrossRef]
43. Xie, Y.; Sha, Z.; Yu, M.; Bai, Y.; Zhang, L. A comparison of two models with Landsat data for estimating above ground grassland biomass in Inner Mongolia, China. *Ecol. Model.* **2009**, *220*, 1810–1818. [CrossRef]
44. Sun, J.; Cheng, G.; Li, W. Meta-analysis of relationships between environmental factors and aboveground biomass in the alpine grassland on the Tibetan Plateau. *Biogeosciences* **2013**, *10*, 1707–1715. [CrossRef]
45. Fang, J.Y.; Yang, Y.H.; Ma, W.H.; Mohammat, A.; Shen, H.H. Ecosystem carbon stocks and their changes in China's grasslands. *Sci. China-Life Sci.* **2010**, *53*, 757–765. [CrossRef] [PubMed]
46. Fang, J.; Guo, Z.; Piao, S.; Chen, A. Terrestrial vegetation carbon sinks in China, 1981–2000. *Sci. China Earth Sci.* **2007**, *50*, 1341–1350. [CrossRef]
47. Piao, S.; Fang, J.; Zhou, L.; Tan, K.; Tao, S. Changes in biomass carbon stocks in China's grasslands between 1982 and 1999. *Glob. Biogeochem. Cycles* **2007**, *21*, GB2002. [CrossRef]
48. Ni, J. Forage yield-based carbon storage in grasslands of China. *Clim. Chang.* **2004**, *67*, 237–246. [CrossRef]
49. Shen, H.; Zhu, Y.; Zhao, X.; Geng, X.; Gao, S.; Fang, J. Grassland area, biomass and productivity in China: A literature survey and model evaluation. *Chin. Sci. Bull.* **2016**, *61*, 139–154. (In Chinese with English abstract)
50. Brink, G.; Sanderson, M.; Casler, M. Grass and legume effects on nutritive value of complex forage mixtures. *Crop Sci.* **2015**, *55*, 1329–1337. [CrossRef]
51. Lindenmayer, R.B.; Hansen, N.C.; Brummer, J.; Pritchett, J.G. Deficit Irrigation of Alfalfa for Water-Savings in the Great Plains and Intermountain West: A Review and Analysis of the Literature. *Agron. J.* **2011**, *103*, 45–50. [CrossRef]
52. Stevens, C.J.; Dise, N.B.; Mountford, J.O.; Gowing, D.J. Impact of nitrogen deposition on the species richness of grasslands. *Science* **2004**, *303*, 1876–1879. [CrossRef]
53. Allan, E.; Manning, P.; Alt, F.; Binkenstein, J.; Blaser, S.; Blüthgen, N.; Böhm, S.; Grassein, F.; Hölzel, N.; Klaus, V.H. Land use intensification alters ecosystem multifunctionality via loss of biodiversity and changes to functional composition. *Ecol. Lett.* **2015**, *18*, 834–843. [CrossRef]
54. Yang, Y.; Fang, J.; Ma, W.; Smith, P.; Mohammat, A.; Wang, S.; Wang, W. Soil carbon stock and its changes in northern China's grasslands from 1980s to 2000s. *Glob. Chang. Biol.* **2010**, *16*, 3036–3047. [CrossRef]
55. Glover, J.D.; Culman, S.W.; DuPont, S.T.; Broussard, W.; Young, L.; Mangan, M.E.; Mai, J.G.; Crews, T.E.; DeHaan, L.R.; Buckley, D.H. Harvested perennial grasslands provide ecological benchmarks for agricultural sustainability. *Agric. Ecosyst. Environ.* **2010**, *137*, 3–12. [CrossRef]
56. DuPont, S.T.; Culman, S.W.; Ferris, H.; Buckley, D.H.; Glover, J.D. No-tillage conversion of harvested perennial grassland to annual cropland reduces root biomass, decreases active carbon stocks, and impacts soil biota. *Agric. Ecosyst. Environ.* **2010**, *137*, 25–32. [CrossRef]

57. Guan, Z.-H.; Li, X.G.; Wang, L.; Mou, X.M.; Kuzyakov, Y. Conversion of Tibetan grasslands to croplands decreases accumulation of microbially synthesized compounds in soil. *Soil Biol. Biochem.* **2018**, *123*, 10–20. [CrossRef]
58. Post, W.M.; Kwon, K.C. Soil carbon sequestration and land-use change: Processes and potential. *Glob. Change Biol.* **2000**, *6*, 317–327. [CrossRef]
59. Chang, J.; Ciais, P.; Gasser, T.; Smith, P.; Herrero, M.; Havlík, P.; Obersteiner, M.; Guenet, B.; Goll, D.S.; Li, W. Climate warming from managed grasslands cancels the cooling effect of carbon sinks in sparsely grazed and natural grasslands. *Nat. Commun.* **2021**, *12*, 118. [CrossRef]
60. Li, Y.-Y.; Dong, S.-K.; Wen, L.; Wang, X.-X.; Wu, Y. Soil carbon and nitrogen pools and their relationship to plant and soil dynamics of degraded and artificially restored grasslands of the Qinghai–Tibetan Plateau. *Geoderma* **2014**, *213*, 178–184. [CrossRef]
61. Wen, L.; Jinlan, W.; Xiaojiao, Z.; Shangli, S.; Wenxia, C. Effect of degradation and rebuilding of artificial grasslands on soil respiration and carbon and nitrogen pools on an alpine meadow of the Qinghai-Tibetan Plateau. *Ecol. Eng.* **2018**, *111*, 134–142. [CrossRef]