Cultivated Grassland Development on the Tibetan Plateau: Current Status, Challenges, Suggestions

Authors: Ge, Hou, Peili, Shi, Guangshuai, Zhao, Xueying, Chen, Xiaofang, Huang, et al.

Source: Journal of Resources and Ecology, 15(4) : 804-813

Published By: Institute of Geographic Sciences and Natural Resources Research, Chinese Academy of Sciences

URL: https://doi.org/10.5814/j.issn.1674-764x.2024.04.002

J. Resour. Ecol. 2024 15(4): 804-813
DOI: 10.5814/j.issn.1674-764x.2024.04.002
www.jorae.cn

Cultivated Grassland Development on the Tibetan Plateau: Current Status, Challenges, Suggestions

HOU Ge[1], SHI Peili[1,3], ZHAO Guangshuai[2,*], CHEN Xueying[1,3], HUANG Xiaofang[1,3], DUAN Cheng[1]

1. Key Laboratory of Ecosystem Network Observation and Modeling, Institute of Geographic Sciences and Natural Resources Research, Chinese Academy of Sciences, Beijing 100101, China;
2. Development Research Center, National Forestry and Grassland Administration, Beijing 100714, China;
3. University of Chinese Academy of sciences, Beijing 100049, China

Abstract: The Tibetan Plateau is vital for animal husbandry in China, and relies heavily on its natural grasslands. However, grassland degradation, increasing livestock numbers, and uneven grazing practices are exacerbating the grass-livestock imbalance. Cultivated grasslands are a key strategy to address this issue. In this review, we evaluate the current status, challenges, and suggestions for developing and managing Tibetan Plateau cultivated grasslands. While discernible advancements have been made in the cultivated grasslands in this region, persistent challenges exist. These challenges stem from issues like low awareness and enthusiasm among farmers and herders, uneven cultivated grassland distribution, and limited scientific and technological contributions. Based on these challenges, we propose strengthening the promotion of artificial forage, implementing a rationalized grassland layout, and improving the scientific and technological contributions to forage species selection, sowing, management, and storage. In summary, cultivated grasslands in the Tibetan Plateau offer promising prospects but still face significant challenges. Overcoming these obstacles will require innovative approaches to unlock the full potential of cultivated grasslands in this unique ecological niche.

Key words: animal husbandry; balance of grass and livestock; cultivated grassland; Tibetan Plateau

1 Introduction

The Tibetan Plateau, spanning approximately 2.57×10^6 km^2, is a unique eco-economic zone characterized by several remarkable features. These include an average altitude of nearly 4000 m, frigid temperatures, with most regions experiencing annual mean temperatures below freezing, a sparse human population, and heavy reliance on animal husbandry (Shang et al. 2014; Ren et al., 2016; Luo et al., 2019). Animal husbandry plays a pivotal role in the Tibetan Plateau's economy and primarily relies on natural resources for livestock forage (Tachiiri et al., 2008; Fang et al., 2016; Wei et al., 2017). Although alpine grasslands encompassing steppe and meadow dominate the Tibetan Plateau, covering approximately two-thirds of its total area (Piao et al., 2006; Li et al., 2018a), over 50% of these grasslands have experienced degradation due to climate change and human activities (Huang et al., 2017; Liu et al., 2018; Zhuang et al., 2019; Dong et al., 2020). Additionally, increasing livestock numbers and uneven grazing practices are exacerbating the pressure on the Tibetan Plateau's natural grasslands (Huang et al., 2017), creating a pervasive imbalance in the grassland-livestock relationship. Therefore, the development of cultivated grasslands has emerged as a crucial strategy to solve the imbalance between grass and livestock (Niu and

Received: 2023-09-21 **Accepted:** 2023-11-02
Foundation: The Central Government Leading Project for Tibetan Science and Technology Development (XZ202202YD0028C); The Entrusted Project of the Development Research Center, National Forestry and Grassland Administration (JYC-2022-0053); The Natural Science Foundation of Tibet (XZ202201ZR0063G).
First author: HOU Ge, E-mail: houge0415@163.com
***Corresponding author:** ZHAO Guangshuai, E-mail: zhaogs.10s@igsnrr.ac.cn

Citation: HOU Ge, SHI Peili, ZHAO Guangshuai, et al. 2024. Cultivated Grassland Development on the Tibetan Plateau: Current Status, Challenges, Suggestions. *Journal of Resources and Ecology*, 15(4): 804–813.

Jiang, 2004; Wu et al., 2010; Luescher et al., 2014).

Cultivated grasslands created through advanced cultivation techniques offer supplementary feed and high-quality forage for animal husbandry, and they contribute to the protection and restoration of degraded natural grasslands (Wang et al., 2013; Tang et al., 2014; Tian et al., 2017; Cui et al., 2019). Cultivated grasslands are primarily located in degraded areas, and can effectively mitigate grassland deterioration while enhancing land use efficiency (Hill et al., 2000; Hu et al., 2019). They provide abundant and nutritious forage, reducing the pressure on natural grasslands and promoting the coexistence of animal husbandry and ecological preservation (Steenwerth et al., 2002; Kline et al., 2013; Liu et al., 2017). Moreover, cultivated grasslands reduce wind erosion and contribute to soil stabilization (Chen et al., 2017; Chen et al., 2018; Chu et al., 2019; Hu et al., 2019). In summary, cultivated grasslands are crucial for advancing the economic development of grassland animal husbandry, preserving grassland ecology, and maintaining national ecological security (Hu et al., 2019).

Currently, the development of cultivated grasslands represents an effective strategy to alleviate grazing pressure on natural grasslands, both domestically and internationally (Wang et al., 2013; Cui et al., 2019). Countries such as Australia, New Zealand, and various European nations have embraced and enhanced the cultivation of grasslands, with cultivated grasslands accounting for over 50% of the total grassland area in some cases (Korn et al., 2005; Duan et al., 2019). The intensive management of cultivated grasslands has evolved into a low-cost, high-efficiency model for animal husbandry (Ferguson, 1932; Korn et al., 2005; Duan et al., 2019). However, cultivated grasslands account for only approximately 5% of the total grassland area in China, with an even lower proportion found on the Tibetan Plateau (Tang et al., 2014; Duan et al., 2019). The development of cultivated grasslands in China, and especially on the Tibetan Plateau, faces multifaceted challenges (Tang et al., 2014; Duan et al., 2019). These encompass ecological concerns, such as soil erosion, water scarcity, and biodiversity loss, as well as potential impacts on water resources and global climate patterns. The human dimension, including herder resettlement and land tenure rights, also requires attention to prevent social instability. A sustainable approach combining ecological restoration, water resource management, climate adaptation, and sound social policies is essential. Robust scientific research and monitoring are crucial for policy adjustments. The crux lies in achieving a balance between environmental conservation, herder welfare, and sustainable land use in this development scenario (Dong et al., 2003; Zhu et al., 2010; Zhang et al., 2015). In this review, we consolidate the findings from domestic and international publications that address topics related to cultivated grasslands, grazing-livestock systems, and sustainable grazing management. We aim to address three key questions:

(1) What is the current status of cultivated grasslands on the Tibetan Plateau?

(2) What are the challenges facing the development of cultivated grasslands on the Tibetan Plateau?

(3) How can these challenges be effectively addressed to promote sustainable grassland management in this unique ecological context?

2 Current status and advantages in the development of cultivated grassland on the Tibetan Plateau

2.1 Current status in the development of cultivated grassland

The research and development of cultivated grasslands began in the 1970s, but because of the cold climate, weak technical support, and inadequate transportation, the development of cultivated grassland in the Tibetan Plateau has been relatively slow (Dong et al., 2003; Shang et al., 2014). Through many years of effort and development, there is some progress in the establishment of cultivated grasslands around the Tibetan Plateau (Cao et al., 2019; Cheng, 2019; Guan et al., 2019). In 2019, the total area of cultivated grassland in Tibet has reached 10.5×10^4 ha, with perennial forage grass and other perennial forages accounting for more than 20%. The high-quality and high-yielding cultivated grassland exceeded 3.4×10^4 ha in Tibet. In Qinghai Province, the total area of cultivated grassland has reached 2.1×10^4 ha in 2011. Based on published research reports on cultivated grasslands of the Tibetan Plateau, the cultivated grasslands are mainly distributed in six regions around the Tibetan Plateau: Northern Tibet, Nyingchi Prefecture, Region of Yushu and Guoluo, Region of Gansu and Sichuan, Valley of Yellow and Huangshui River, and the Middle reaches of the Yarlung Zangbo River (Dong et al., 2003; Zhu et al., 2010; Zhang et al., 2015; Guan et al., 2019; Fig. 1). Of these six artificial grassland distribution areas, Nyingchi Prefecture and the valley of the Yellow and Huangshui River are located at an altitude of less than 3100 m, the middle area of the Yarlung Zangbo River, Region of Yushu and Guoluo are located at an altitude of more than 4000 m, and the Northern Tibet area is located at an altitude of more than 4500 m. Climatic factors have specific impacts on the growth of herbage, including temperature fluctuations, short growing seasons, and high-altitude conditions, all of which challenge the development of grasslands.

The annual average temperatures of the six regions can basically reach 0 ℃, while that of the region of Yushu and Guoluo is the lowest, at –6–0 ℃, and that of Nyingchi Prefecture is the highest, at 5–17 ℃, accompanied by high precipitation (600–800 mm). The annual average precipitation in the regions of Gansu and Sichuan can reach 400–800 mm, but in the areas of Yushu and Guoluo and Hehuang Valley, it

is less than 600 mm. The precipitation in the middle of the Yarlung Zangbo River and Northern Tibet are less than 550 mm and 514 mm, respectively (Table 1).

The development of cultivated grassland not only depends on a reasonable layout, but also the selection of appropriate forage species according to the environmental suitability of various species (Duan et al., 2019; Guan et al. 2019). Beyond that, the suitable forage grasses must have the characteristics of high yield, strong regeneration capacity, rich nutrition, and especially cold resistance (Zhang et al., 2015; Husse et al., 2016). Based on these characteristics, some scholars have reported that Oat grass, a high-quality gramineous forage, is suitable for planting in most alpine regions of the Tibetan Plateau because of its strong cold resistance (Cui et al., 2015). In addition, oat also has a high grass yield, strong adaptability, and a soft grass quality, but the only drawback is the low content of crude protein in oat grass (Cui et al., 2015; Zhang et al., 2019).

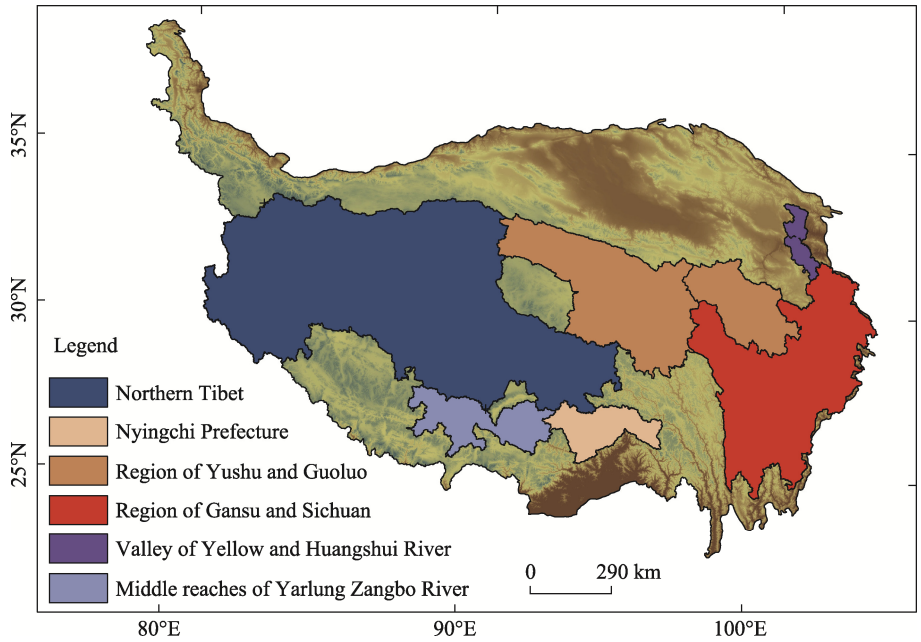

Fig. 1 The main distribution regions of cultivated grassland in the Tibetan Plateau

Table 1 Natural climatic conditions and the main forage-related characteristics of cultivated grassland regions

Region	Annual average temperature (℃)	Annual average precipitation (mm)	Altitude (m)	Main forage varieties	Growth period (d)	Cold resistance	Drought resistance
Northern Tibet	–2.8– –1.6	247–514	>4500	oats *Elymus nutans* *Elymus siberian*	80–100	√	√
Nyingchi Prefecture	5–17	600–800	1100–3100	Alfalfa	60	–	–
Region of Yushu and Guoluo	–6–0	150–600	4000–5000	*Elymus nutans* *Poa pratensis*	120–150	√	–
Valley of Yellow and Huangshui River	3–8	200–600	1700–3000	oats Alfalfa Gramineous forage	60	–	–
Region of Gansu and Sichuan	0–4	400–800	3000–4000	oats Leguminous forage Gramineous forage	120	–	–
Middle reaches of Yarlung Zangbo River	2.4–8.5	270–550	3500–4100	oats *Vicia sativa*	62–75	–	√

Note: "√" indicates the presence of this feature; "–" indicates the absence of this feature, or no literature report is available.

After continuous cultivation and optimization, most areas of the Tibetan Plateau have chosen their relatively suitable pastures. Oats, *Elymus nutans* and *Elymus siberian* are the main forage species in the cultivated grasslands of northern Tibet. They have certain drought resistance and cold resistance, so they can adapt to the growth environment of northern Tibet. The growth periods of these forages are generally 80–100 days. The environment of Nyingchi prefecture is suitable to meet the growth conditions of most forages, and the main forage species is alfalfa, which has a

growth period of about 60 days. *Elymus nutans* and *Poa pratensis* are main forage varieties in the region of Yushu and Guoluo, which have growth periods of 120–150 days and better cold resistance. The main forage varieties in the valley of Yellow and Huangshui River are oats and Alfalfa with growth periods of 60 days. The main forage varieties in the region of Gansu and Sichuan are oats, Leguminous forage and Gramineous forage with growth periods of 120 days. In addition, the main forage varieties in the middle of the Yarlung Zangbo River are oats and *Vicia sativa* with growth periods of 62–75 days.

At present, the cultivated grassland in the Tibetan Plateau is mainly distributed in the areas with an altitude of less than 4300 m. This distribution is largely influenced by factors such as soil nutrient availability and climatic conditions. However, recent research shows that a kind of oat can grow in the Tibetan Plateau area at an altitude of more than 4600 m, because of its cold resistance, fast growth and mid-late maturation. The success of artificial grass planting in the Tibetan Plateau at 4600 m above sea level has filled the gap in the local high-yield cultivation techniques for high-altitude forage grasses at altitudes above 4300 m. This is of great significance for the development of cultivated grassland in the Tibetan Plateau. In addition, the increase in economic demand led to an increase in grazing on the Tibetan Plateau, but the natural grassland cannot meet the needs of the growing of animal husbandry industry, and this situation has led to a more serious imbalance of grass-livestock (Dong et al., 2003; Shang et al., 2014; Pang et al., 2016). Hence there is a great need for the development of cultivated grasslands in the Tibetan Plateau.

2.2 Advantages of cultivated grassland development on the Tibetan Plateau

Animal husbandry is not only a traditional industry, but also an important pillar industry for the economic development of the pastoral area on the Tibetan Plateau (Shang et al., 2014). The development of the animal husbandry economy not only affects the production and living standards of the herdsmen, but it also affects China's sustainable development and ecological environmental protection of the Tibetan Plateau (Shang et al., 2014; Guo and Zhang, 2015). Although the development of cultivated grassland in the Tibetan Plateau started late, the speed of its development has been relatively slow compared with some developed countries, but the development of cultivated grassland on the Tibetan Plateau has certain advantages, such as the natural conditions, policy support, and other factors.

2.2.1 The natural condition of the cultivated grassland

For the development of cultivated grassland, the Tibetan Plateau has abundant natural grassland resources. In the total area of the Tibetan Plateau, grassland accounts for 64%, cultivated land accounts for 0.36%, forest land accounts for 5.65%, and hard-to-use land accounts for 30%. The per capita grassland area in the Tibetan Plateau is 40 times the national average and 17.8 times the world average (Duan et al., 2019; Dong et al., 2020).

Grassland animal husbandry has a long history in the Tibetan Plateau, and it is currently the most important economic component (Wu et al., 2003; He, 2007). Animal husbandry is the main sector of the agricultural structure in the Tibetan Plateau, which is mainly distributed in the western and northern parts of the Tibetan Plateau (Wu et al., 2003). The farming areas of the Tibetan Plateau also have animal husbandry grassland. The alpine grassland of the Tibetan Plateau has little pollution from pesticides and fertilizers, so its livestock products can be called ecological or green products, which makes them unique and gives them strong market competitiveness (Wu et al., 2003; He, 2007). Hence the development of cultivated grassland has a great demand foundation and a natural resource foundation.

2.2.2 Certain policies and scientific research support for the development of cultivated grassland

The construction of cultivated grassland in the Tibetan Plateau began in the 1950s. At that time, to solve the imbalance between forage and animal grazing, Qinghai's state-owned farms began to introduce fine pastures. Beyond that, in response to the serious ecological and environmental problems caused by the expansion of the degraded grassland in the source area of the Three Rivers, the Qinghai Provincial Government and relevant national departments have initiated projects to implement the "Grassland Retreat Project in Natural Grasslands of Qinghai Province", "Grass in Barren Mountains", "natural grassland protection" and other engineering projects (Wan, 2002).

The Tibet Autonomous Region has also carried out research and extension work on the construction of cultivated grasslands since the 1960s. Units such as the Tibet Autonomous Region Animal Husbandry Bureau, Animal Science Research Institute, Grassland Research Institute of Chinese Academy of Agricultural Sciences, Gansu Agricultural University and others have successively carried out scientific research on forage introduction and cultivation. Based on this long-term research, we have accumulated a wealth of information and experience in the construction of cultivated grassland in the Tibetan Plateau. Furthermore, to accelerate the healthy and rapid development of cultivated grassland, the government has increased its investment in the construction and development of cultivated grassland in the Tibetan Plateau in recent years.

3 Challenges facing the development of cultivated grasslands

In the last decade, cultivated grassland in the Tibetan Plateau has shown rapid development thanks to government support (Shang et al., 2014). The area and quality of cultivated grassland have improved to different degrees (Huang et al., 2017; Li et al., 2018b; Hu et al., 2019), but there are

still some problems in the development process of cultivated grassland in the Tibetan Plateau (Wang et al., 2013; Shang et al., 2014; Dong et al., 2015). These problems restrict the further development of cultivated grassland and the local economy (Liu et al., 2003). Problems in the management of cultivated grasslands have arisen due to various factors, such as low awareness and enthusiasm of farmers and herdsmen, irrational distribution, and the relatively low contribution rate of science and technology.

3.1 Low awareness and enthusiasm of farmers and herdsmen for establishing cultivated grassland

Due to the influence of traditional ideas, the enthusiasm for establishing cultivated grassland among farmers and herdsmen is not high. Some scholars have found that the area of cultivated grassland planted by local farmers and herdsmen in the Tibetan Plateau is very small (Cui et al., 2015; Cheng, 2019). In general, farmers and herdsmen mainly use the circular land and leisure cultivated land for cultivating grassland, so those plots of land have a small area, lack water and fertilizer supplies, and it is difficult to achieve the needed scale of the yield and area of cultivated grassland (Cheng, 2019). Hence, improving the enthusiasm for using cultivated grassland among the famers and herdsmen is crucial for establishing cultivated grassland in the Tibetan Plateau.

3.2 The irrational distribution of cultivated grassland

The selection of specific cultivated grassland areas must be consistent with the biological characteristics of the forage grasses grown, and the fertility of the soil must be at a medium level, otherwise obtaining high yields will be difficult (Cui et al., 2015; Duan et al., 2019). Due to limitations of the geographical environment, the potential area for cultivated grassland in the Tibetan Plateau is limited (Duan et al., 2019). The agricultural areas with low altitude and good water and heat conditions are the key areas for the development of cultivated grassland (Guo et al., 2019). For example, due to the relatively low altitude, good water and heat conditions, and the rich land resources, the agricultural areas in the Middle area of the Yarlung Zangbo River in Tibet are more suitable for the cultivation of cultivated grassland (Li et al., 2007; Guo et al., 2019). However, because of the food security demand in agricultural areas, those land resources have been mainly cultivated land for a long time, and the construction of cultivated grassland has not received enough attention. As a result, the competition for land between food and grass has existed for a long time, and the maximum benefit of grassland in agricultural areas has not been fully exploited (Li et al., 2007; Duan et al., 2019). Given the spatial elasticity differences in the supply and demand of grassland ecosystem services in different regions, the service utility of the ecosystem can be maximized only by adjusting the supply and demand difference according to local conditions (Li et al., 2007). Therefore, determining how to arrange the cultivated grassland reasonably and effectively is one of the major problems in the development of the cultivated grassland in the Tibetan Plateau.

3.3 The lower contribution rate of science and technology for cultivated grassland

In the developed countries that have an accelerated development of cultivated grassland, the contribution rate of science and technology in the forage industry is more than 70%, but it is less than 30% in China, and the contribution rate in the Tibetan Plateau is even lower (Liu, 2015; Duan et al., 2019). In the early years, incorporating the necessary forage species basically depended on external introduction with a high cost and strong restrictions, which hindered the healthy and fast development of cultivated grassland in the Tibetan Plateau (Cui et al., 2015; Liu, 2015; Duan et al., 2019). Thus, numerous experimental studies have investigated the introduction, cultivation and production performance of forage in the Tibetan Plateau, which mainly involve explorations of the drought resistance, cold resistance, salt tolerance, and physiological characteristics of forage varieties, and other factors (Nimazaxi et al., 2011; Duan et al., 2019). However, most of these experiments are still in the introduction and cultivation stage, without large-scale planting and breeding efforts after the selection of the introduced varieties, and studies on the long-term regional suitability and production research on quantity and quality are also rare (Cui et al., 2015; Liu, 2015; Duan et al., 2019). Beyond that, the introduction of new varieties without standardized regional testing may cause the invasion of alien species and endanger the ecological environment of the Tibetan Plateau (Mcgeoch et al., 2010; Liu, 2015). Fortunately, under the continuous introduction and selection of the forage species, there are some forage grasses suitable for planting in areas below 4000 m altitude in the Tibetan Plateau, such as *Avena sativa* L., *Vicia sativa* L., *Medicago sativa* L., *Elymus sibiricus* L., *Festuca arundinacea* Schreb, and others (Cui et al., 2015; Zhang et al., 2015). However, the altitudes of most areas around Tibetan Plateau are higher than 4000 m, and the research results of forage suitable for such high altitude areas are almost non-existent (Nimazaxi et al., 2011; Cui et al., 2015). In addition, there is no artificial cultivation of the excellent local forage varieties in the Tibetan Plateau.

In addition to the cultivation of excellent forage, advanced planting technology is also of great significance for the development of cultivated grassland (Duan et al., 2019; Zhu et al., 2020). As early as 20 years ago, some researchers began to conduct studies on the planting mode of cultivated grassland in the Tibetan Plateau (Dong et al., 2002). Through many years of research, various scholars have summarized the advantages of the mixed planting mode, such as enriching biodiversity, improving the micro growth environment of perennial grasses by improving the accumulated temperature and average temperature of different

soil layers in the growing season of the grass, improving the conversion rate of light energy and increasing the biomass of the grassland (Dong et al., 2002; Lai et al., 2020; Zhu et al., 2020). For instance, the final output of *Avena sativa* L. and Arrowhead peas mixed in proportion increased by nearly 30% (Zhu et al., 2020). However, many principles need to be considered when different plants are to be mixed, such as whether the introduced plants will destroy the ecological stability of the alpine region, the consistency of biological characteristics such as the color, height and growth speed of the mixed varieties, the final output of the grass, the proportion of mixed planting, and others (Zhang et al., 2011; Lai et al., 2020). At present, the technology of forage mixed planting is not mature enough, so most of the cultivated grasslands in the Tibetan Plateau are still single species. In addition to mixed planting, there is also the multiple planting method which mainly occurs in low altitude areas, and this important planting method can greatly improve the efficiency of land use and increase the yield of artificial grass (Duan et al., 2019). For example, the annual harvest time of *Avena sativa* L. is in mid-August, and the nearly 2 months from mid-August to mid-October of the growing season are wasted in the lower latitude regions of the Tibetan Plateau. Meanwhile, the climatic conditions are sufficient, so it is more suitable for forage growth. If *Avena sativa* L. is replanted at this time, a higher forage yield can be obtained (Liu, 2015; Duan et al., 2019). Therefore, the cultivation timing of cultivated grasslands at different altitudes should also be adjusted to the local conditions.

Forage processing, which is the production process of changing fresh grass into hay, silage or semi hay, is an important part of the development of cultivated grassland (Zhang et al., 2006). The processing of forage can improve the storage and utilization rate, which is convenient for transportation and feeding and plays an important role in the annual feed balance (Zhang et al., 2006; Duan et al., 2019). Many developed countries have huge forage processing systems, but there are no mature and advanced forage processing enterprises in Tibetan Plateau (Zhang et al., 2006; Cui et al., 2015). As a result, the forage production and processing rate in Tibet is very low. More than 85% of forage production depends on natural air drying, resulting in serious nutrient losses (Cui et al., 2015). At present, there are only five (one state-owned) forage processing enterprises in Tibet, with a small processing capacity and scale. The lag of industrialization of the grass industry seriously restricts the sustainable development of the grass industry in the Tibetan Plateau.

4 Recommended measures for the development of cultivated grassland in the Tibetan Plateau

According to the current development status, the existing problems and natural policy basis of cultivated grassland in the Tibetan Plateau, and combined with previous studies on cultivated grassland of Tibetan Plateau, some suggestions for the development of cultivated grassland in the Tibetan Plateau are presented as a development thinking map in Fig. 2.

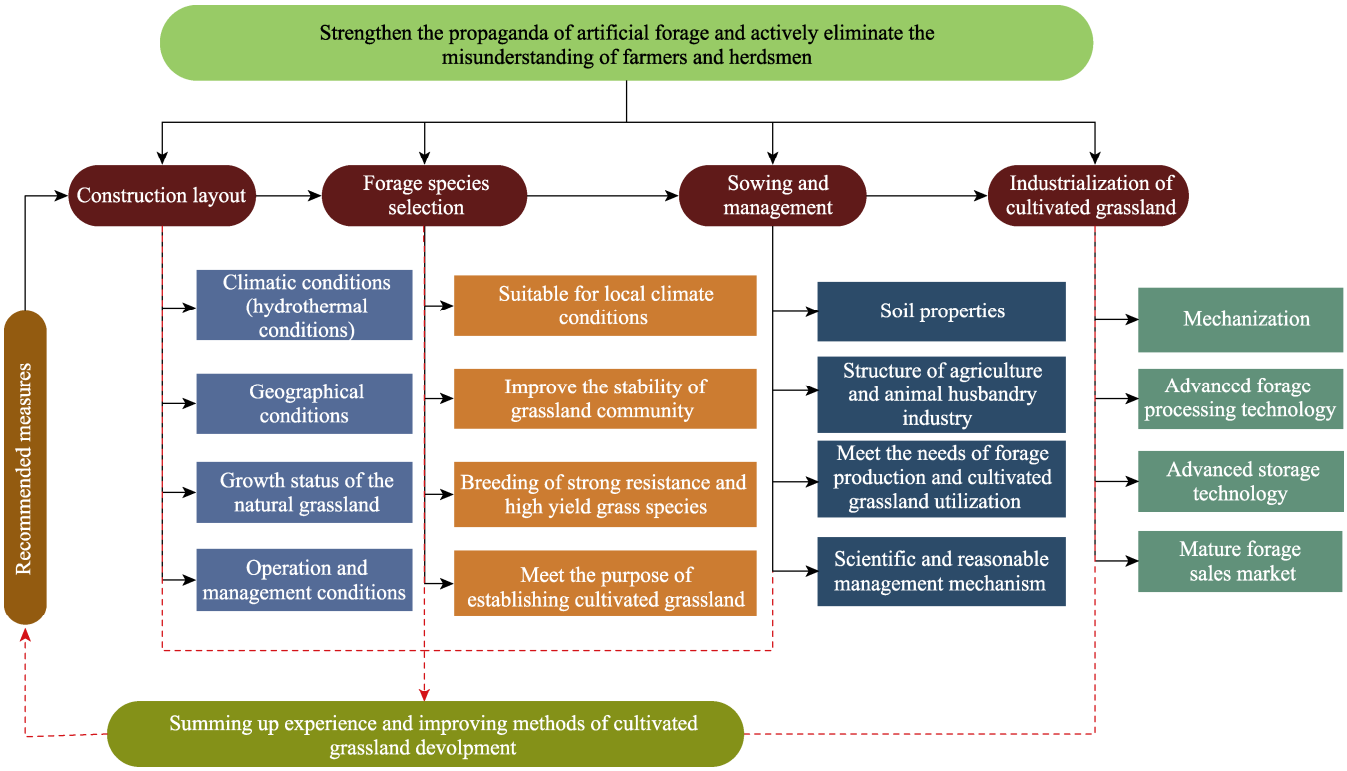

Fig. 2 Idea map for the development of cultivated grassland on the Tibet Plateau

4.1 Strengthen the propaganda for artificial forage and actively eliminate the misunderstanding among farmers and herdsmen

Firstly, the farmers and herdsmen should understand the importance of the construction of cultivated grassland in the development of animal husbandry, so their enthusiasm for developing cultivated grassland should be cultivated. Secondly, because of the lower cultural level of farmers and herdsmen in the Tibetan Plateau, some techniques and means for managing cultivated grassland are difficult for them to understand, so scientific and systematic training must be carried out to select leaders with a high level of professional proficiency (Duojidunzhu, 2016). Furthermore, the village officials of college students majoring in agriculture and animal husbandry should be invited to participate in the management and operation of the cooperatives.

In addition, we must not only train farmers and herdsmen in high-yield planting techniques, but also pay attention to training in forage product processing and marketing. By cultivating these various grassland talents, we must quickly establish a set of technology, information, and circulation aspects for the whole grass industry to promote the circulation of forage products in the market. This system will allow farmers to sell grass in the market, and farmers will have places to buy grass, which will promote the harmonious and rapid development of the livestock industry.

4.2 Scientific and reasonable arrangement of the cultivated grassland layout

The soil, as the fundamental substrate for grass growth, plays a pivotal role in determining the quality and yield of cultivated grasslands in the Tibetan Plateau, where the fragile ecosystem demands careful management (Duojidunzhu, 2016). It is widely acknowledged that the Tibetan Plateau boasts unique environmental conditions, characterized by high altitudes, cold temperatures, and challenging terrain. These factors necessitate a scientific and well-thought-out approach to the layout and distribution of cultivated grasslands to ensure sustainable and healthy development (Wu et al., 2010; Shang et al., 2014; Duan et al., 2019).

Soil is the material basis of grass growth, so better soil can produce good grass and a high grass yield. The sustainable and healthy development of cultivated grassland is inseparable from the scientific and reasonable distribution of cultivated grassland. The environment for forage grass growth needs to meet the certain hydrothermal conditions (Lin et al., 2016; Geng et al., 2017). Due to the geographical conditions of the Tibetan Plateau, the productivity of grasslands is limited in most areas, and the potentially suitable areas for the development of cultivated grasslands are also very limited (Hill et al., 2000; Duan et al., 2019). In addition, the distribution of cultivated grassland on the Tibetan Plateau should not only meet the biological characteristics of forage grass, but also allow for convenient transportation and management by the residents (Wu et al., 2010; Shang et al., 2014; Duan et al., 2019).

Moreover, a critical element of the strategy for cultivated grasslands is the approach to reclaiming areas from natural grasslands (Lin et al., 2016; Geng et al., 2017). It is essential to adopt a nuanced perspective, recognizing that not all natural grasslands are in the same state of degradation. For instance, lightly degraded grasslands should not be destroyed indiscriminately; instead, they should be improved using appropriate methods (Wu et al., 2010; Shang et al., 2014; Duan et al., 2019). This approach ensures that we balance the preservation of existing ecosystems with the expansion of cultivated grasslands, thereby promoting overall sustainability.

In conclusion, the scientific and reasonable arrangement of cultivated grassland layouts in the Tibetan Plateau is a multifaceted challenge that involves considerations of soil quality, hydrothermal conditions, geographic limitations, transportation and management needs, and the judicious reclamation of natural grasslands. This holistic approach is crucial for the sustainable and healthy development of cultivated grasslands in this unique and ecologically sensitive region.

4.3 Improving the contributions of science and technology to forage species selection, sowing and management, and storage

The cultivation of forage varieties should follow certain principles. For instance, adapting to the climatic conditions of the planting land and improving the stability of the grassland community are necessary. The decisions regarding artificial forage should consider its effect on the ecological stability of the grassland community. In addition, the cold resistance and drought resistance of forage are important because of the cold and water-deficient climatic conditions in the alpine region. Finally, the selection of artificial forage species should meet the needs of the local construction of artificial forage, such as what kind of forage needs to be produced, whether it can meet the needs of local animal husbandry and other considerations (Fig. 2). Science and technology are the solid foundation for the development of artificial forage, and the cultivation of artificial forage must rely on the support of science and technology (He, 2007; Duojidunzhu, 2016). The rise of modern biotechnology provides a convenient and practical way to cultivate and improve forage grass varieties (Zhang, 1994; Lemaire et al., 2005). Combined with traditional breeding methods, the use of genetic engineering to modify the genetic traits of forages at the molecular level not only broadens the range of ectoplasm resources in forage cultivation, but also uses the existing genetic variant materials to enable more effective

forage breeding. It is more operable and purposeful, which greatly shortens the breeding cycle and comprehensively reforms the research status of traditional new breeds.

For the planting of artificial forage, the planting mode should be determined scientifically and reasonably according to the soil conditions and the structure of local agriculture and animal husbandry (Li et al., 2007; Duojidunzhu, 2016). In addition, according to the different needs of forage production and cultivated grassland utilization, various monoculture, mixed sowing and inter-planting planting measures can be put in effect (Duojidunzhu, 2016). For example, to increase the forage yield and improve the forage quality, the cultivated grassland established mainly by mowing can be planted with more than two varieties of forage. In order to reduce the production cost of cultivated grassland and realize stable production for many years, we should vigorously promote the protective inter-planting of perennial high-quality forage varieties when building the cultivated grassland. In the grassland mainly for vegetation restoration and grassland improvement, perennial forage mixed planting should be adopted (He, 2007; Duojidunzhu, 2016). Establishing a scientific and reasonable management mechanism is beneficial for the management of cultivation. In this management mechanism, we should strength the management of the irrigation, fertilization, pest control, harvesting and other technical links of the cultivated grassland to improve the overall management level of the cultivated grassland (Duojidunzhu, 2016).

The development of the cultivated grassland is inseparable from modern tools. To promote the full mechanization of artificial (natural) pasture, the model's agricultural machinery products that are suitable for the cultivated grassland of the Tibetan Plateau should be invented with modern scientific and technological means. The sowing, field management, mowing, gathering, transportation, and storage after mowing of the cultivated grassland should be fully mechanized and equipped with high-tech equipment and agricultural tools to reduce losses and improve forage production. In addition, modern forage processing equipment must be introduced to promote the deep processing technology of grass products, such as high-density bales, grass cakes, grass pellets, and grass blocks with high density, small space occupation, and long storage time, so as to realize the mechanization, standardization and specialization of the forage production process. A mature forage trading market should be established in the Tibetan Plateau, where farmers and herders can buy and sell at will.

In summary, the development of cultivated grassland is a long-term process, which needs continuous analysis and summarization of the experience to improve the development of the cultivated grassland, so as to promote the healthy, rapid and sustainable development of the artificial grassland (Fig. 2).

5 Conclusions

Based on a comprehensive review of cultivated grassland development on the Tibetan Plateau, it is evident that the primary impediments to its progress include low awareness and enthusiasm among farmers and herders, uneven distribution of cultivated grasslands, and limited contributions from the realm of science and technology. To overcome these challenges, we recommend a multifaceted approach. First, there is a pressing need to enhance the promotion of artificial forage, thereby fostering greater awareness and enthusiasm among local communities. Second, a rationalized grassland layout should be prioritized to ensure equitable land use. Lastly, a heightened focus on scientific and technological contributions is paramount, especially concerning forage species selection, sowing techniques, management practices, and storage methods. In conclusion, cultivated grasslands offer a multifaceted solution that can address the imbalance between grass and livestock, foster local economic development, combat grassland degradation and desertification, and safeguard the ecological environment (Cambardella and Elliott, 1993; Wang et al., 2007; Valmorbida et al., 2018). Moreover, integrating cultivated grasslands with natural grasslands can bolster the health of the Tibetan Plateau's grassland ecosystem and create a robust ecological security barrier (Husse et al., 2016; Siebers et al., 2017; Valmorbida et al., 2018). However, there remains ample room for further development, warranting increased governmental investments in the growth of cultivated grasslands on the Tibetan Plateau.

References

Cambardella C A, Elliott E T. 1993. Carbon and nitrogen distribution in aggregates from cultivated and native grassland soils. *Soil Science Society of America Journal*, 57(4): 1071–1076.

Cao Y Y, Wu J S, Zhang X Z, et al. 2019. Dynamic forage-livestock balance analysis in alpine grasslands on the Northern Tibetan Plateau. *Journal of Environmental Management*, 238: 352–359.

Chen J, Luo Y Q, Li J W, et al. 2017. Costimulation of soil glycosidase activity and soil respiration by nitrogen addition. *Global Change Biology*, 23: 1328–1337.

Chen J, Luo Y Q, Xia J Y, et al. 2018. Divergent responses of ecosystem respiration components to livestock exclusion on the Qinghai Tibetan Plateau. *Land Degradation & Development*, 29: 1726–1737.

Cheng F. 2019. Significance and problems of developing artificial grass planting in Tibet. *Xizang Science and Technology*, (5): 13–15. (in Chinese)

Chu H S, Venevsky S, Wu C, et al. 2019. NDVI-based vegetation dynamics and its response to climate changes at Amur-Heilongjiang River Basin from 1982 to 2015. *Science of the Total Environment*, 650: 2051–2062.

Cui G, Li B, Wang M, et al. 2015. Development status, existing problems and their solutions of artificial pasture in Tibet. *Heilongjiang Animal Science and Veterinary Medicine*, (11): 137–139. (in Chinese)

Cui Z, Liu Y, Huang Z, et al. 2019. Potential of artificial grasslands in crop rotation for improving farmland soil quality. *Land Degradation & Development*, 30: 2187–2196.

Dong S, Hu Z, Pu X, et al. 2002. Study on the physiological-ecological

characteristics of mixture grassland of cultivated perennial grasses in alpine area. *Acta Prataculturae Sinica*, 11: 39–45. (in Chinese)

Dong S, Shang Z, Gao J, et al. 2020. Enhancing sustainability of grassland ecosystems through ecological restoration and grazing management in an era of climate change on Qinghai-Tibetan Plateau. *Agriculture*, *Ecosystems Environment*, 287: 106684. DOI: 10.1016/j.agee.2019.106684.

Dong S K, Long R J, Hu Z Z, et al. 2003. Productivity and nutritive value of some cultivated perennial grasses and mixtures in the alpine region of the Tibetan Plateau. *Grass and Forage Science*, 58: 302–308.

Dong S K, Wang X X, Liu S L, et al. 2015. Reproductive responses of alpine plants to grassland degradation and artificial restoration in the Qinghai-Tibetan Plateau. *Grass and Forage Science*, 70: 229–238.

Duan C, Shi P L, Zhang X Z, et al. 2019. Suitability analysis for sown pasture planning in an alpine rangeland of the northern Tibetan Plateau. *Acta Ecologica Sinica*, 39(15): 5517–5526. (in Chinese)

Duojidunzhu. 2016. Problems and countermeasures of the artificial grassland construction in cold and semi-arid areas of high plateau. *Journal of Anhui Agricultural Sciences*, 44(5): 63–64, 67. (in Chinese)

Fang Y P, Zhao C, Ding Y J, et al. 2016. Impacts of snow disaster on meat production and adaptation: An empirical analysis in the Yellow River source region. *Sustainability Science*, 11: 249–260.

Ferguson W S. 1932. Investigations into the intensive system of grassland management by the Agricultural Research Staff of Imperial Chemical Industries, Limited. X. A further study of the mineral content of intensively treated pasture. *Journal of Agricultural Science*, 22: 251–256, DOI: 10.1017/S0021859600053600.

Geng Y, Baumann F, Song C, et al. 2017. Increasing temperature reduces the coupling between available nitrogen and phosphorus in soils of Chinese grasslands. *Scientific Reports*, 7: 43524. DOI: 10.1038/srep43524.

Guan H L, Fan J W, Li Y Z. 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): 192–201. (in Chinese)

Guo Q Q, Zhang W H. 2015. Sap flow of Abies georgei var. smithii and its relationship with the environment factors in the Tibetan subalpine region, China. *Journal of Mountain Science*, 12: 1373–1382.

Guo R, Li B, Zhang W. 2019. Current situation, problems and development countermeasures of artificial grassland in agro-pastoral ecotone of Tibet. *Tibet Journal of Agricultural Sciences*, 41: 167–170. (in Chinese)

He J. 2007. Current situation, difficulty and countermeasure of Tibet animal husbandry development. *Xizang Science and Technology*, (5): 51–53. (in Chinese)

Hill M J, Willms W D, Aspinall R J. 2000. Distribution of range and cultivated grassland plants in southern Alberta. *Plant Ecology*, 147: 59–76.

Hu Z, Zhao Z, Zhang Y, et al. 2019. Does "Forage-Livestock Balance" policy impact ecological efficiency of grasslands in China? *Journal of Cleaner Production*, 207: 343–349.

Huang W, Bruemmer B. 2017. Balancing economic revenue and grazing pressure of livestock grazing on the Qinghai-Tibetan Plateau. *Australian Journal of Agricultural and Resource Economics*, 61: 645–662.

Huang W, Bruemmer B, Huntsinger L. 2017. Technical efficiency and the impact of grassland use right leasing on livestock grazing on the Qinghai-Tibetan Plateau. *Land Use Policy*, 64: 342–352.

Husse S, Huguenin-Elie O, Buchmann N, et al. 2016. Larger yields of mixtures than monocultures of cultivated grassland species match with asynchrony in shoot growth among species but not with increased light interception. *Field Crops Research*, 194: 1–11.

Kline K L, Singh N, Dale V H. 2013. Cultivated hay and fallow/idle cropland confound analysis of grassland conversion in the Western Corn Belt. *Proceedings of the National Academy of Sciences of the USA*, 110(31): E2863. DOI: 10.1073/pnas.1306646110.

Korn U, Muller M, Behrendt U, et al. 2005. Fusaria and their mycotoxins in hay and grass silage from grassland with different intensities of management. *Mycotoxin Research*, 21: 36–39.

Lai X, Shi S, Wu F, et al. 2020. Nutrient characteristics of soil sowed with different combinations of alfalfa and three perennial grasses. *Pratacultural Science*, 37: 52–64. (in Chinese)

Lemaire G, Wilkins R, Hodgson J. 2005. Challenges for grassland science: Managing research priorities. *Agriculture Ecosystems & Environment*, 108: 99–108.

Li L H, Zhang Y L, Liu L S, et al. 2018a. Current challenges in distinguishing climatic and anthropogenic contributions to alpine grassland variation on the Tibetan Plateau. *Ecology and Evolution*, 8: 5949–5963.

Li P, Yang G, Feng Y. 2007. Analysis of the structure of compound agriculture-herding ecological system in the YLN Region of Tibet. *Agricultural Research in the Arid Areas*, 25(3): 180–184.

Li W, Wang J, Zhang X, et al. 2018b. 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.

Lin L, Zhu B, Chen C. et al. 2016. Precipitation overrides warming in mediating soil nitrogen pools in an alpine grassland ecosystem on the Tibetan Plateau. *Scientific Reports*, 6: 31438. DOI: 10.1038/srep31438.

Liu L Y, Shi P J, Zou X Y, et al. 2003. Short-term dynamics of wind erosion of three newly cultivated grassland soils in Northern China. *Geoderma*, 115: 55–64.

Liu Q. 2015. Studyand suggestions for the development of prataculture of Tibet. *Tibet Journal of Agricultural Sciences*, 34(4): 41–45. (in Chinese)

Liu S B, Zamanian K, Schleuss P M, et al. 2018. Degradation of Tibetan grasslands: Consequences for carbon and nutrient cycles. *Agriculture Ecosystems & Environment*, 252: 93–104.

Liu Y, Tian F P, Jia P Y, et al. 2017. Leguminous species sequester more carbon than gramineous species in cultivated grasslands of a semi-arid area. *Solid Earth*, 8: 83–91.

Luescher A, Mueller-Harvey I, Soussana J F, et al. 2014. Potential of legume-based grassland-livestock systems in Europe: A review. *Grass and Forage Science*, 69: 206–228.

Luo R, Fan J, Wang W, et al. 2019. Nitrogen and phosphorus enrichment accelerates soil organic carbon loss in alpine grassland on the Qinghai-Tibetan Plateau. *Science of the Total Environment*, 650: 303–312.

Mcgeoch M A, Butchart S H M, Spear D, et al. 2010. Global indicators of biological invasion: Species numbers, biodiversity impact and policy responses. *Diversity Distributions*, 16: 95–108.

Nimazaxi, Yudailin, Bianba. 2011. Introduction of new varieties of forage maize and demonstration of the results. *Tibet Journal of Agricultural Sciences*, 33(3): 17–20. (in Chinese)

Niu S, Jiang G. 2004. Function of artificial grassland in restoration of degraded natural grassland and its research advance. *Chinese Journal of Applied Ecology*, 15: 1662–1666. (in Chinese)

Pang Z, Sun T, Wu J, et al. 2016. The effect of different artificial grasslands on the soil organic carbon content in a degraded land. Proceedings of the 2016 international forum on energy, environment and sustainable development. Shenzhen, China: 1061–1064. (in Chinese)

Piao SL, Fang J Y, He J. 2006. Variations in vegetation net primary production in the Qinghai-Xizang Plateau, China, from 1982 to 1999. *Climatic Change*, 74: 253–267.

Ren F, Yang X, Zhou H, et al. 2016. Contrasting effects of nitrogen and phosphorus addition on soil respiration in an alpine grassland on the Qinghai-Tibetan Plateau. *Scientific Reports*, 6: 34786. DOI: 10.1038/srep39895.

Shang Z H, Gibb M J, Leiber F, et al. 2014. The sustainable development of grassland-livestock systems on the Tibetan Plateau: Problems, strate-

gies and prospects. *Rangeland Journal*, 36: 267–296.
Siebers N, Sumann M, Kaiser K, et al. 2017. Climatic effects on phosphorus fractions of native and cultivated north American grassland soils. *Soil Science Society of America Journal*, 81: 299–309.
Steenwerth K L, Jackson L E, Calderon F J, et al. 2002. Soil community composition and land use history in cultivated and grassland ecosystems of coastal California. *Soil Biology & Biochemistry*, 34(11): 1599–1611.
Tachiiri K, Shinoda M, Klinkenberg B, et al. 2008. Assessing Mongolian snow disaster risk using livestock and satellite data. *Journal of Arid Environments*, 72: 2251–2263.
Tang L, Dang X, Liu G, et al. 2014. Response of artificial grassland carbon stock to management in mountain region of Southern Ningxia, China. *Chinese Geographical Science*, 24: 436–443.
Tian Y, Liu Y, Jin J. 2017. Effect of irrigation schemes on forage yield, water use efficiency, and nutrients in artificial grassland under arid conditions. *Sustainability*, 9(11): 2035. DOI: 10.3390/su9112035.
Valmorbida I, Cherman M A, Jahn D S, et al. 2018. Abundance and diversity in the Melolonthidae community in cultivated and natural grassland areas of the Brazilian Pampa. *Environmental Entomology*, 47: 1064–1071.
Wan M J. 2002. Artificial grassland is an important part of grassland construction and ecological management in Qinghai Province in the 21st century. *Chinese Qinghai Journal of Animal and Veterinary Sciences*, 32(5): 44. (in Chinese)
Wang C T, Wang G X, Liu W, et al. 2013. Effects of establishing an artificial grassland on vegetation characteristics and soil quality in a degraded meadow. *Israel Journal of Ecology & Evolution*, 59: 141–153.
Wang Y F, Chen J J, Liu W H, et al. 2007. Effect of cultivating croplands and grazing in arid grassland habitats on the conservation of melitaeine butterflies in a mountainous area in Northern China. *Science in China Series C—Life Sciences*, 50: 40–46.
Wei Y, Wang S, Fang Y, et al. 2017. Integrated assessment on the vulnerability of animal husbandry to snow disasters under climate change in the Qinghai-Tibetan Plateau. *Global and Planetary Change*, 157: 139–152.
Wu G L, Liu Z H, Zhang L, et al. 2010. Effects of artificial grassland establishment on soil nutrients and carbon properties in a black-soil-type degraded grassland. *Plant Soil*, 333: 469–479.
Wu J, Meng L, Miao Y. 2003. The exploration of current situation and thinking of development of the Tibet animal husbandry. *Xizang Science and Technology*, 5: 34–37. (in Chinese)
Zhang R, Gao Z Q, Dou W, et al. 2011. Study on the planting technique of mixed grassland in alpine pasture area. *Pratacultural Science*, 28: 1512–1516.
Zhang X, Liu X, Zhang L, et al. 2019. Comparison of energy partitioning between artificial pasture and degraded meadow in three-river source region on the Qinghai-Tibetan Plateau: A case study. *Agricultural and Forest Meteorology*, 271: 251–263.
Zhang X S. 1994. Principles and optimal models for development of Maowusu Sandy grassland. *Acta Phytoecologica Sinica*, 18: 1–16. (in Chinese)
Zhang Y, Gao Q Z, Dong S K, et al. 2015. Effects of grazing and climate warming on plant diversity, productivity and living state in the alpine rangelands and cultivated grasslands of the Qinghai-Tibetan Plateau. *Rangeland Journal*, 37: 57–65.
Zhang Z S, Wang X B, Yang F Y, et al. 2006. Introduction of forage processing industry in China. *Chinese Journal of Grassland*, 28(3): 77-80. (in Chinese)
Zhu L, Dong S K, Wen L, et al. 2010. Effect of cultivated pasture on recovering soil nutrient of "black-beach" in the Alpine region of headwater areas of Qinghai-Tibetan Plateau, China. *Procedia Environmental Sciences*, 2: 1355–1360.
Zhu Y, Yu H, Zheng W, et al. 2020. Effects of different planting configurations on yield of Avena sativa and Vicia sativa mixed plantings with soybean in alpine pastures. *Acta Prataculturae Sinica*, 29: 74–85. (in Chinese)
Zhuang M, Gongbuzeren, Zhang J, et al. 2019. Community-based seasonal movement grazing maintains lower greenhouse gas emission intensity on Qinghai-Tibet Plateau of China. *Land Use Policy*, 85: 155–160.

青藏高原人工草地发展现状、挑战与建议

侯 阁[1]，石培礼[1,3]，赵广帅[2]，陈雪莹[1,3]，黄小芳[1,3]，段 呈[1]

1. 中国科学院地理科学与资源研究所生态系统网络观测与模拟重点实验室，北京 100101；
2. 国家林业和草原局发展研究中心，北京 100714；
3. 中国科学院大学，北京 100049

摘 要：青藏高原对我国畜牧业具有重大意义，其天然草原是当地畜牧业发展的基础。然而，草原退化、牲畜数量增长及放牧方式失衡加剧了当地草畜关系的不平衡。人工草地的发展成为解决此问题的关键策略。本综述评估了青藏高原人工草地的发展现状、所面临的挑战以及应对建议。尽管该地区的人工草地取得了显著成果，但仍然存在持续性的挑战。这些问题主要源于农民及牧民的认识热情不足、人工草原分布不均以及科技贡献受限等因素。针对这些挑战，我们建议强化人工饲草的推广，优化草地布局，提高饲草品种选择、播种、管理及储存的科技水平。总之，青藏高原的人工草地发展潜力巨大，但需克服诸多挑战。要实现其在特殊生态位中的全面潜力，需创新性地推动科技发展。

关键词：畜牧业；草畜平衡；人工草地；青藏高原