Long-term Ecological Research and Experimental Demonstration Provides Scientific and Technological Support for Grassland Ecological Conservation and Sustainable Development of Grassland-Livestock Industry: Postprint

Authors: Bai Yongfei, Wang Yang

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Abstract

For a long time, China has overexploited the production function of grasslands in livestock production while neglecting their ecological function, resulting in large-scale grassland degradation, imbalance in the grassland-livestock relationship, and unsustainability of traditional grassland animal husbandry. There is an urgent need to explore new models of ecological protection and forage-livestock industry development suited to the characteristics of pastoral areas, and to promote the development of the forage-livestock industry through scientific and technological innovation. Since its establishment, the Inner Mongolia Grassland Ecosystem Research Station, Chinese Academy of Sciences (hereinafter referred to as the "Inner Mongolia Station"), based in China's temperate grasslands, has conducted long-term monitoring of water, soil, atmosphere, and biota elements in grassland ecosystems, basic research in grassland ecology, and applied research on degraded grassland restoration, artificial grassland construction, and ecosystem management, providing scientific and technological support for the protection and sustainable utilization of Inner Mongolia grasslands through demonstration and extension. Based on long-term monitoring, nutrient addition, and grazing control experiments, the station has revealed the mechanisms underlying the maintenance of biodiversity and ecosystem stability in Inner Mongolia grasslands, with major findings including: (1) compensatory effects among different species and functional groups constitute an important mechanism for maintaining ecosystem stability; (2) stoichiometric homeostasis at both species and community levels forms the basis for ecosystem stability maintenance, with communities dominated by species with high stoichiometric homeostasis exhibiting higher productivity and stability; and (3) mixed-use approaches (rotational grazing and haymaking) are conducive to maintaining diversity, productivity,

and ecosystem stability. Based on the above basic research and long-term experimental demonstrations, the Inner Mongolia Station has developed a forage species configuration and efficient artificial grassland establishment technology system for perennial mixed-sown artificial grasslands. This system enhances the productivity and stability of perennial artificial grasslands, extends their utilization period, and improves forage quality. To further explore new models of ecological protection and forage industry development suited to pastoral area characteristics, the Inner Mongolia Station has proposed a rational allocation technology system for grassland production and ecological functions. This system addresses forage production issues through the construction of efficient artificial grasslands and basic grassland pastures, while simultaneously enhancing grassland ecological functions through degraded grassland restoration and rational utilization of natural grasslands. These research achievements have not only advanced China' s grassland ecology research to internationally advanced levels but have also established the Inner Mongolia Station as a base for transforming grassland scientific and technological achievements and an important platform for domestic and international collaborative research.

Full Text

Abstract

For decades, China has overexploited the production functions of grasslands while neglecting their ecological functions in livestock production, resulting in large-scale grassland degradation, imbalance between forage and livestock, and the unsustainability of traditional grassland animal husbandry. There is an urgent need to explore new models for ecological protection and grassland husbandry development suited to pastoral areas, relying on scientific and technological innovation to promote sustainable grassland management. Since its establishment in 1979, the Inner Mongolia Grassland Ecosystem Research Station (IMGERS) of the Chinese Academy of Sciences has focused on long-term monitoring of hydrological, soil, atmospheric, and biological factors in temperate grassland ecosystems, conducting fundamental research in grassland ecology alongside applied studies on degraded grassland restoration, cultivated pasture establishment, and ecosystem management. Through demonstration and extension activities, IMGERS has provided scientific and technological support for the protection and sustainable utilization of Inner Mongolia grasslands. Based on long-term monitoring, nutrient addition experiments, and grazing control trials, IMGERS has revealed the mechanisms underlying biodiversity and ecosystem stability maintenance in Inner Mongolia grasslands. Key findings include: (1) compensatory interactions among different species and functional groups represent an important mechanism for maintaining ecosystem stability; (2) stoichiometric homoeostasis at both species and community levels forms the foundation for ecosystem stability maintenance, with communities dominated by species exhibiting high stoichiometric homoeostasis demonstrating greater productivity and stability; and (3) mixed management systems (annual rotation

of grazing and haymaking) facilitate the maintenance of diversity, productivity, and ecosystem stability. Building upon these fundamental research findings and long-term demonstration trials, IMGERS has developed a technical system for forage species disposition and efficient establishment of perennial mixed-sown cultivated pastures. This system enhances the productivity and stability of perennial cultivated pastures, extends their usable lifespan, and improves forage quality. To further explore new models for ecological protection and grassland development appropriate for pastoral regions, IMGERS has proposed a technical framework for the rational allocation of production and ecological functions in grassland ecosystems. This framework addresses forage production challenges through the establishment of high-efficiency cultivated pastures and prime grassland farms, while simultaneously enhancing ecological functions through degraded grassland restoration and rational utilization of natural grasslands. These research achievements have not only advanced China' s grassland ecology research to internationally competitive levels but have also established IMGERS as a base for translating scientific achievements into practical grassland management and as an important platform for domestic and international collaborative research.

Keywords

compensatory interactions, stoichiometric homoeostasis, cultivated pastures, forage species disposition, grassland management

Author Information

Bai Yongfei is a Principle Investigator and Ph.D. supervisor at the Institute of Botany, Chinese Academy of Sciences (CAS), and a Professor at the University of CAS. He serves as Director of the Inner Mongolia Grassland Ecosystem Research Station, CAS. Born in October 1966, he received his Ph.D. from Inner Mongolia Agricultural University in 1998, pursued postdoctoral research at the Institute of Botany, CAS from 1998 to 2000, and worked as a Visiting Research Fellow at Arizona State University from 2004 to 2006. Prof. Bai received the National Science Fund for Distinguished Young Scholars in 2008, was selected for CAS' s "One Hundred Talents Program" in 2010, named "Grassland Talent" of Inner Mongolia Autonomous Region in 2011, and appointed as a national member of the "New Century Hundreds and Thousands of Talents Project" in 2014. In recent years, he has led or participated in over ten major projects, including National Key R&D Program sub-projects, National Key Basic Research Program ("973" Program) sub-projects, CAS Strategic Priority Research Program sub-projects, and key and general projects of the National Natural Science Foundation. He has published more than 140 research papers, including over 90 SCI-indexed articles. Prof. Bai currently serves as Director of the Plant Ecology Professional Committee of the Chinese Society for Plant Sciences and Deputy Director of the Long-term Ecological Research Professional Committee of the Ecological Society of China. He has served as Associate Editor for *Range-*

land Ecology & Management (2009–2011) and *Chinese Journal of Plant Ecology* (2009–2014), and as Associate Editor for *Journal of Integrative Plant Biology* (2015–present). He also serves on the editorial boards of *Journal of Arid Environments*, *Chinese Science Bulletin*, *Chinese Journal of Plant Ecology*, *Acta Ecologica Sinica*, *Biodiversity Science*, *Plant Science Journal*, and *Life World*. E-mail: yfbai@ibcas.ac.cn

Bai Yongfei is a Principle Investigator and Ph.D. supervisor of Institute of Botany, Chinese Academy of Sciences (CAS), and Professor of the University of CAS. He is the director of the Inner Mongolia Grassland Ecosystem Research Station, CAS. He received his Ph.D. from Inner Mongolia Agriculture University in 1998, pursued postdoctoral training in Institute of Botany from 1998 to 2000, and worked as a Visiting Research Fellow at School of Life Sciences, Arizona State University from 2004 to 2006. Prof. Bai is recognized by the National Natural Science Foundation of China (NSFC) as a distinguished young scholar, the "One Hundred Talents Program" of CAS, and a national member of the "New Century Hundreds and Thousands of Talents Project" . He is also the President of the plant ecology branch of the Chinese Society for Plant Sciences. His main research areas include: relationships between plant functional traits, functional diversity, and multiple ecosystem functions; sensitivity, mitigation, and adaptation of ecosystem services to global change drivers; and adaptive management of grassland ecosystems. He has published more than 140 papers in peer reviewed journals, such as Nature*,* Ecology*,* Journal of Ecology*, and* Global Change Biology*. E-mail: yfbai@ibcas.ac.cn*

Introduction

China possesses nearly 4 × 10^8 hm² of grassland, accounting for approximately 41.7% of the country' s total land area—3.2 times the area of cultivated land and 2.5 times that of forestland [1]. However, about 90% of China' s natural grasslands are experiencing varying degrees of degradation, with severely degraded grasslands comprising over 60% of the total [2,3]. Anthropogenic factors and climatic aridity, particularly deviations in grassland management policy and backward management practices, constitute the primary drivers of grassland degradation in northern China. Given the unsustainability of traditional grassland animal husbandry, there is an urgent need to explore new models for ecological protection and grassland husbandry development suited to pastoral regions, relying on scientific and technological innovation to promote sustainable grassland management.

The Inner Mongolia Grassland Ecosystem Research Station (IMGERS) of the Chinese Academy of Sciences, established in March 1979, represents the first long-term ecological research station in China' s temperate grassland region. Over nearly four decades, IMGERS has conducted long-term monitoring of water, soil, atmospheric, and biological factors, revealing the mechanisms underlying grassland biodiversity and ecosystem function maintenance, as well as the impacts of global change on ecosystem functions and services. Simultaneously,

IMGERS has consistently applied its research findings to societal needs, developing technologies for rational natural grassland utilization (including rest grazing, rotational grazing, rotational mowing, and mixed grazing-haymaking systems), comprehensive sandland and sandy grassland management, forage species disposition and establishment systems for perennial cultivated pastures, and ecological grassland husbandry frameworks for rational allocation of production and ecological functions. Through demonstration trials, IMGERS has facilitated the translation of scientific achievements into practice, providing robust scientific and technological support for ecological protection, scientific utilization, and sustainable socio-economic development of Inner Mongolia grasslands, thereby contributing significantly to ecological civilization construction in pastoral regions. These efforts have earned high recognition from national authorities and governments at all levels in the Inner Mongolia Autonomous Region.

Mechanisms for Maintaining Grassland Biodiversity and Ecosystem Stability

The maintenance mechanisms of biodiversity and ecosystem function stability represent a hot topic in international ecological research and debate [4,5]. For decades, IMGERS has focused on the Mongolian Plateau grassland ecosystem, revealing the mechanisms underlying biodiversity and ecosystem stability maintenance through long-term monitoring, nutrient addition experiments, and grazing control studies in representative grassland types.

Compensatory Effects Based on systematic analysis of 24 consecutive years (1980–2003) of long-term monitoring data from *Leymus chinensis* and *Stipa grandis* grassland communities, IMGERS researchers systematically investigated the relationship between ecosystem stability and compensatory effects in Inner Mongolia grasslands. Key findings include: (1) rainfall from January to July constitutes the primary driver of fluctuations in grassland ecosystem primary productivity; (2) ecosystem stability increases progressively across organizational levels, from plant species to functional groups to communities, with mature grassland communities achieving maximum species diversity, primary productivity, and ecosystem stability; and (3) compensatory interactions among different species and functional groups represent an important mechanism for maintaining ecosystem stability [Figure 1: see original paper] [6]. The scientific significance of these findings manifests in three aspects: (1) theoretically revealing the importance of biodiversity and its influence mechanisms on ecosystem functions, providing detailed scientific evidence to guide grassland biodiversity conservation; (2) offering important guidance for restoring biodiversity in degraded grasslands, enhancing their production and ecological functions, and achieving sustainable grassland utilization; and (3) providing crucial theoretical guidance for cultivated pasture establishment. IMGERS' s key technological achievement, the "Perennial Mixed-Sown Cultivated Pasture Establishment Technique," was developed under this theoretical framework by fully utilizing species compensatory effects.

Stoichiometric Homoeostasis Stoichiometric homoeostasis—the capacity of organisms to maintain relatively constant elemental composition despite changes in environmental or food nutrient composition—represents an evolutionary adaptation to environmental variability and reflects physiological and biochemical regulation. Based on two years of nitrogen and phosphorus addition experiments, combined with a 1,200 km transect survey and 27 years (1980–2007) of long-term monitoring data, IMGERS conducted the first temporal and spatial scale study of plant stoichiometric homoeostasis and its relationship with biodiversity and ecosystem function. The research demonstrated that species with high stoichiometric homoeostasis exhibit high dominance and stability, and ecosystems with high homoeostasis demonstrate greater productivity and stability [Figure 2: see original paper]. This study expanded the scope of ecological stoichiometry research and provided important theoretical foundations for understanding biodiversity-ecosystem function relationships [7].

Using *Leymus chinensis* grassland as a model ecosystem and employing a plant functional group removal experimental platform, IMGERS further demonstrated that compensatory effects constitute a crucial mechanism for maintaining grassland biodiversity and ecosystem function [8]. The study revealed that ecosystem functions declined following functional group removal, with the magnitude of decline varying significantly depending on which functional groups were removed. Simultaneous removal of two dominant functional groups caused significant reductions in multiple ecosystem functions, which failed to recover even after six years.

Mixed Management Systems Grazing and haymaking represent the primary utilization methods in Inner Mongolia grasslands. Analysis of 17 consecutive years (1982–1998) of mowing experiment data revealed that human disturbance caused gradual changes in community structure, while ecosystem functions exhibited abrupt shifts only after community structure changes accumulated to a certain threshold. Grassland ecosystems rely on continuous adjustment of community structure to maintain relative functional stability, but excessive structural changes can ultimately lead to functional degradation [9]. Furthermore, long-term grazing and mowing control experiments demonstrated that different grassland utilization and management approaches (traditional vs. mixed use) significantly impact species diversity, productivity, and stability. Compared with traditional management (grazing-only pastures and haymaking-only meadows), mixed utilization systems (annual rotation of grazing and haymaking) better maintain species diversity, productivity, and ecosystem stability, thereby promoting sustainable utilization of Inner Mongolia grasslands [10].

Forage Species Disposition and Establishment Technology for Perennial Mixed Sown Pastures

Based on niche theory, species compensatory interactions, and plant community succession theory, IMGERS proposed five scientific forage species combinations for perennial mixed-sown cultivated pastures: (1) long-lived species combined with short-lived species, (2) deep-rooted species combined with shallow-rooted species, (3) legume forages combined with grasses, (4) drought-tolerant species combined with moisture-loving species, and (5) annual species combined with perennial species [Figure 3: see original paper]. This technical system significantly enhances the productivity and stability of perennial cultivated pastures, extends pasture lifespan, and improves forage quality. In terms of pasture management, the system achieves full mechanization of cultivated pasture establishment under dryland conditions, improving seeding quality and, through mechanized inter-tillage and rainy-season fertilization, realizing the scientific concept of "fertilizer following water," which substantially improves water and nutrient use efficiency. This provides scientific foundations and technical support for achieving high and stable yields and extending pasture lifespan. The technology system received two national invention patents in 2007 (Patent Numbers: ZL353706 and ZL396567) [Figure 4: see original paper].

The innovations of this technical system manifest in six key aspects: (1) combining long-lived and short-lived forages exploits the yield advantages of different species across various successional stages, solving the critical problems of low initial yields and severe later-stage degradation in current cultivated pastures and thereby extending pasture lifespan; (2) combining deep-rooted and shallow-rooted species, as well as non-nitrogen-fixing grasses with nitrogen-fixing legumes, leverages complementary and mutualistic relationships in water and nutrient utilization, achieving efficient use of water and soil nutrient resources; (3) using annual forages as protective crops effectively suppresses weed damage to perennial forage seedlings during the establishment year, while the higher stubble left after annual forage harvest increases snow cover in winter, reduces spring wind erosion, facilitates perennial forage overwintering, and ensures some forage yield in the seeding year, thereby improving economic benefits; (4) the compensatory relationship in forage yield between drought-tolerant and moisture-loving varieties across different years reduces yield differences between dry and wet years, achieving high and stable yields; (5) in forage variety selection, choosing superior domestic varieties adapted to local ecological conditions addresses problems with imported varieties such as poor drought resistance and low overwintering survival, while avoiding potential ecological issues from 盲目 introduction of exotic species; and (6) the establishment process achieves full mechanization of precision seeding, weed control, inter-tillage, rainy-season fertilization, harvesting, and processing, improving seeding quality and field management levels. Particularly, mechanized inter-tillage and rainy-season fertilization improve water use efficiency and ensure "fertilizer following water," providing guarantees for high and stable yields.

Rational Allocation of Production and Ecological Functions in Grasslands

China' s grassland husbandry is currently transitioning from traditional utilization and management models to modern grassland husbandry development. In this process, degraded grassland restoration and rational natural grassland utilization constitute the foundation, cultivated pasture establishment serves as the key, and rational allocation of production and ecological functions represents the hallmark of successful transformation [11]. Rational allocation of production and ecological functions involves, within a specific geographic region or administrative unit (e.g., herder cooperatives, villages, townships, counties, or leagues), establishing a certain proportion (1/20–1/10) of high-yield, high-efficiency cultivated pastures on quality land and prime grassland farms on quality natural grasslands. This shifts traditional livestock dependence from natural grasslands to cultivated pastures and prime grassland farms, which assume primary production functions, allowing most natural grasslands to return to their natural ecological attributes and restoring/enhancing their ecological functions, thereby achieving sustainable grassland husbandry development in China. Therefore, establishing high-efficiency cultivated pastures and prime grassland farms represents the key to realizing rational allocation of production and ecological functions. Such establishments can increase grassland forage yields by 10–20 fold. For example, alfalfa cultivated pastures can yield 22.5 t/hm², approximately 11 times that of natural grasslands; *Leymus chinensis* cultivated pastures can yield 24 t/hm², about 12 times natural grassland yields; and silage corn can achieve dry matter yields of 45 t/hm², 23 times that of natural grasslands [1]. This demonstrates that establishing high-quality, high-efficiency cultivated pastures and prime grassland farms can solve forage production challenges and fundamentally curb large-scale grassland degradation and severe ecological function decline caused by overgrazing [11].

Achieving rational natural grassland utilization to maximize ecological functions constitutes the foundation for rational allocation of production and ecological functions. Natural grassland rational utilization technologies include: (1) **Degraded grassland enclosure**: For degraded grasslands, constructing fences or prohibiting grazing eliminates continued livestock disturbance, allowing natural recovery to gradually improve productivity, diversity, and stability. To date, grassland enclosure represents one of the most effective degraded grassland restoration techniques and a prerequisite for implementing other restoration measures. (2) **Rotational grazing**: This planned grazing utilization technology combines protection and use, providing pastures with rest and recovery periods and representing the central component of rational natural grassland utilization [10]. (3) **Seasonal rest grazing**: This includes spring rest grazing (prohibiting grazing during the grass regreening period from late April to mid-June, allowing degraded grasslands to recover) and autumn rest grazing (stopping grazing during the seed maturation period from mid-August to mid-September, allowing seeds to mature and replenish the soil seed bank). (4)

Meadow rotational mowing: This technique helps maintain soil seed bank density and slows community degradation caused by continuous mowing, promoting long-term grassland utilization. (5) **"Three-part model" for sandland management**: For wind erosion pits, mobile dunes (bald dunes), and semi-mobile dunes accounting for one-third of the area, engineering measures (biological grids + pioneer sand-fixing plants) are implemented; for sandy degraded grasslands with low vegetation coverage accounting for two-thirds of the area, enclosure and rest grazing rely on natural self-repair to accelerate vegetation recovery and enhance ecological functions.

Future Directions

During the 13th Five-Year Plan period, IMGERS will focus on CAS' s goal of achieving the "Four Firsts" and the Institute of Botany' s development objective of becoming a "world-class research institution with significant international influence." The station will continuously improve and upgrade its infrastructure, strengthen integrated sky-air-ground ecosystem monitoring and information management systems, and enhance capacity building for research and technical support teams. IMGERS aims to achieve international leadership in long-term ecological research and addressing national needs, while establishing itself as a base for translating grassland scientific achievements, a platform for high-level international collaboration, and a cradle for cultivating outstanding scientific teams.

References

1. Du Q L. *China' s Sustainable Development Strategy for Grassland Industry*. Beijing: China Agriculture Press, 2005.
2. Ministry of Environmental Protection of the People' s Republic of China. *China Environmental Status Bulletin 2005*. Beijing: Ministry of Environmental Protection of the People' s Republic of China, 2006.
3. Han J. *Investigation on Grassland Ecological Problems in China*. Beijing: Shanghai Far East Publishers, 2011.
4. Tilman D, Downing J A. Biodiversity and stability in grasslands. *Nature*, 1994, 367: 363-365.
5. McCann K S. The diversity-stability debate. *Nature*, 2000, 405: 228-233.
6. Bai Y F, Han X G, Wu J G, et al. Ecosystem stability and compensatory effects in the Inner Mongolia grassland. *Nature*, 2004, 431: 181-184.
7. Yu Q, Chen Q S, Elser J J, et al. Linking stoichiometric homoeostasis with ecosystem structure, functioning and stability. *Ecology Letters*, 2010, 13: 1390-1399.
8. Bao Y J, Li Z H, Zhong Y K. Compositional dynamics of plant functional groups and their effects on stability of community ANPP during 17 yr of mowing succession on *Leymus chinensis* steppe of Inner Mongolia, China. *Acta Botanica Sinica*, 2004, 46(10): 1155-1162.
9. Wan H W, Bai Y F, Schönbach P, et al. Effects of grazing management

system on plant community structure and functioning in a semiarid steppe: scaling from species to community. *Plant and Soil*, 2011, 340: 215-226.
10. Bai Y F, Pan Q M, Xing Q. Theoretical basis and key technologies for rational allocation of production and ecological functions in grasslands. *Chinese Science Bulletin*, 2016, 61: 201-212.

Note: Figure translations are in progress. See original paper for figures.