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Towards Regional Synergy: Reconciling Rangeland Ecological Functioning with Forage Production of Cultivated Pasture

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Abstract: Animal husbandry and crop farming are specialized for development in separate areas on the Tibetan Plateau. Such a pattern of isolation has led to current concerns of rangeland and farming system degradation due to intensive land use. The crop-livestock integration, however, has been proven to increase food and feed productivity thorough niche complementarity, and is thereby especially effective for promoting ecosystem resilience. Regional synergy has emerged as an integrated approach to reconcile rangeland livestock with forage crop production. It moves beyond the specialized sectors of animal husbandry and intensive agriculture to coordinate them through regional coupling. Therefore, crop-livestock integration (CLI) has been suggested as one of the effective solutions to forage deficit and livestock production in grazing systems. But it is imperative that CLI moves forward from the farm level to the regional scale, in order to secure regional synergism during agro-pastoral development. The national key R & D program, Technology and Demonstration of Recovery and Restoration of Degraded Alpine Ecosystems on the Tibetan Plateau, aims to solve the problems of alpine grassland degradation by building up a grass-based animal husbandry technology system that includes synergizing forage production and ecological functioning, reconciling the relationship between ecology, forage production and animal husbandry, and achieving the win-win goals of curbing grassland degradation and changing the development mode of animal husbandry. It is imperative to call for regional synergy through integrating ecological functioning with ecosystem services, given the alarming threat of rangeland degradation on the Tibetan Plateau. The series of papers in this issue, together with those published previously, provide a collection of rangeland ecology and management studies in an effort to ensure the sustainable use and management of the alpine ecosystems.

Key words: Tibet Plateau; ecosystem restoration and reconstruction; crop-livestock integration; regional synergy; reconciling rangeland functioning with forage production

1 Background

Animal husbandry and crop farming are specialized for development through a long history in the northern plateau and southern valleys, respectively, on the Tibetan Plateau. Such a pattern of isolation has led to current concerns over rangeland degradation and forage shortages with the increasing pressures of livestock growth and declining soil fertility due to intensive farming (Duan et al., 2019). Rangeland degradation is a widespread concern, especially in the highly vulnerable and sensitive alpine environment. On the Tibetan Plateau, reports indicate that more than half of the rangeland has been degraded (Dong et al., 2010), which directly threatens ecosystem goods and services. Moreover, as the major terrestrial ecosystem, rangeland

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degradation will also impair its functioning nationally as an ecological security shelter. Cropland degradation is also a common phenomenon, showing a decline in soil organic matter, soil compaction and poor soil structure, and thereby resulting in decreasing food production in southern Tibet. Intensive farming, low input, monoculture and soil erosion are the main causes of agricultural land degradation and decreasing food production (Cai, 2003).

Due to rangeland degradation and shortages of forage, especially at the end of the season, herders are facing the curse of animal husbandry: emaciation in winter and death in spring. Similarly, more than 90% of the valley cropland is cultivated with food crops by monoculture, so it is difficult to improve the income of local farmers. Therefore, the development of Tibetan agriculture, animal husbandry and social economy is severely constrained thanks to the separate and non-holistic development patterns. To tackle both predicaments of forage shortage and low-income agriculture, an alternative to the existing specialized agriculture is crop-forage rotation for potential crop-livestock integration. Cultivated pasture for forage production is a major source of livestock rations in grazing systems due to its intensive production and high nutrient content (Duan et al., 2019). Adjusting the planting structure has become the only way for the continuing development of agriculture and animal husbandry. One of the feasible options is to enhance forage production while ensuring food security in the southern river valley agricultural area with better hydrothermal conditions. That is, after the harvest of one season of grain crops, rotate forage crops for silage before the end of the season, i.e., use the time span between crop harvest and the next sowing to plant short-term forage in autumn (He et al., 2011). The alternative is to use marginal land and low-yield cropland for expanding forage cultivation. This option can not only increase the income of local farmers, but also relieve the pressure of livestock on the rangeland in northern Tibet and ensure its function as the national ecological security shelter of the Tibet Plateau.

Regional synergy has emerged as an integrated approach to link rangeland livestock with the cropland farming system. It moves beyond the specialized animal husbandry and intensive agriculture systems to coordinate these two sectors through regional cooperation. By focusing on this integration, regional synergy enables a new way of facilitating mixed-system diversity and production and meeting sustainable development goals. In this paper, we first introduce crop-livestock integration and its development from local to regional scales. We then introduce the national R & D program in Tibet with a focus on regional synergy through reconciling rangeland ecological functioning and cropland production services. Finally, some progress of this program and a series of papers on the theme of rangeland ecology and management are also presented.

2 Crop-Livestock Integration: from local to regional scale

Crop-livestock integration (CLI) represents a model of sustainable farming for harvesting both food and livestock products according to the principles of nutrient recycling and efficient use of land and resources (Moraine et al., 2014). Integrated crop-livestock systems can improve nutrient conditions while reducing chemical inputs, achieving agricultural sustainability and environmental benefits at the farm level (Ryschawy et al., 2012). Traditionally, it is a relatively low-cost and self-sufficient system for maintaining the livelihoods of smallholders. CLI has also been suggested as one of the effective solutions to forage deficits and livestock production in grazing systems. There is a long history of combining agricultural production with livestock in homestead farms in terms of rangeland, grain crops, crop/pasture rotations, agro-pastoral system and ponds. However, the practice of CLIs is a major challenge for agricultural modernization and seems difficult to implement at a large scale (Moraine et al., 2014). Since the middle of the 20th century, agriculture has evolved towards monoculture systems, which aim to maximize yield and satisfy food demands. Therefore, there is a shift from extensive integrated crop-livestock production systems to intensive specialised systems in order to enable productivity, but this also brings about detrimental impacts on the environment and threatens the economic viability (Hou et al., 2008).

As individual farms have become more specialized, separate crop and livestock systems are faced with problems such as difficult and costly waste recycling, inevitable pollution and environmental degradation risks. Specialization has resulted in an uncoupling of the crop and livestock production enterprises, loss of landscape diversity and a decreasing resilience to environmental change and disasters. This dilemma again calls for the improvement of crop-livestock integration by adding livestock to a cropping system to seek a solution for both livelihood diversification and environmental goals. Livestock components also add species diversity and additional value to the cropping system and take advantage of synergism and niche complementarity effects among plant species that are more profitable than monoculture systems (Tanaka et al., 2005).

The integrated crop-livestock systems promote diverse and ecological interactions over space and time among the system components of crops, rangelands, and animals. CLI is common and efficient in local or on-farm levels due to the easy allocation of resources. However, the major constraints of on-farm integration are related to the limited farm workforce that is available, and the loss in skills and knowledge required to optimize both crop and livestock sub-systems (Asai et al., 2018). It is imperative to carry out CLIs on a regional scale, in order to obtain the profit benefits from regional synergy of the crop and livestock sectors. Asai et al.

(2018) promoted upscaling CLI to a regional scale, where spatially separated groups of specialized livestock and crop farmers integrate through coordination by a third party, for example a contractor company or government support. Crop-livestock integration at the regional scale requires networks to link and motivate stakeholders including farmers, herdsmen and other contractors, particularly if regional specialization exists. This is especially the case on the Tibetan plateau. Larger regional integration between animal husbandry in the northern Tibetan rangeland and the southern valley crop system demands cooperation among different stakeholders, and the knowledge and financial investment across such a vast differentiation of topography and biophysical conditions.

3 Aiming at synergy through reconciling rangeland function with forage production

For a long time, the effort of restoration focused only on degraded rangeland per se, for example through fenced grazing exclusion, reseeding, fertilization, or killing off weeds and insects. The framework of rangeland capacity for carrying livestock, i.e. forage-livestock balance, is at the center of rangeland management. However, the carrying capacity cannot meet the demand of animal husbandry due not only to growing livestock numbers but also to great variations in forage production caused by interannual precipitation fluctuations. This practice suggests that forage-livestock balance is very difficult to maintain in the fluctuating environment on the Tibetan plateau (Cao et al., 2019). Consequently, rangeland is prone to degradation and the trend of degradation is increasing. This issue is still not solved, and the only real solution is to increase forage production through expanding the planting area of sown pasture. In addition, reducing the livestock pressure in the northern Tibetan Changtang Natural Reserve through ecological migration out of that reserve may provide the solution in that area. In the last two decades, sown pasture was established on the plateau mainly for preventing disasters from snow and pest infestation (Duan et al., 2019). Though some researchers worry about the negative effects of sown pasture from damaging natural grassland and leading to soil erosion, this perspective has received wider attention only in recent years, in part through the perception of benefits from sown pasture in Inner Mongolia and Qinghai Province (Fang et al., 2016a; Zhao et al., 2018). More recently, the concept of grass-based livestock husbandry (GLiH) has been put forward and practiced in Hulun Buir, Inner Mongolia. It focuses on the coupling and coherent development of an inter-dependent grass-livestock relationship, and asks whether small, highly productive and high-quality sown pasture can meet the forage demand of livestock from a large area of natural grassland in order to protect and restore the degraded grassland (Fang et al., 2018). This *small vs. big* theory designates a small area of resource-rich land for cultivation of forage crops with high biomass and high quality to protect the vast but fragile grasslands from over-grazing and over-exploitation (Fang et al., 2016b). The central idea is to integrate intensive forage crop production with rangeland animal husbandry, a type of CLI, so as to achieve regional synergy by reconciling the production service of grasses from sown pasture and the multiple ecological functioning of rangeland.

The integrated crop-livestock system can solve the problems of forage shortage and agro-pastoral development through cultivating pasture, promoting animal husbandry and maintaining the sustainability of the nutrient cycle and resource use of the farming and animal husbandry system, which is considered an important way to diversify the livelihoods of farmers and herdsmen and promote ecosystem resilience (Moraine et al., 2014). Evidence is mounting which proves the success of regional crop-livestock integration. For example, in the high-altitude area of Hindu Kush Himalaya region, traditional animal husbandry is common, while cultivated forage is produced for feed in the low altitude area close to highway (Rahman et al., 2008). Legume forage production provides forage resources to compensate for the shortage of grassland in the cold season in the Great Lakes region of the United States (Rao et al., 2005). There is also some use of an integrated crop-livestock system in the middle reach of the Yarlung Zangbo River in Tibet, in which a two harvest within a year model is advocated; that is, planting common vetch and other forages in the short autumn after the barley harvest (Guan et al., 2008). However, in the high-altitude area and at the regional scale, they are still waiting for the development of a regional synergy model of agriculture and animal husbandry. In addition, this practice needs the support of policies, information, technology and infrastructure (Thornton and Herrero, 2014).

To change the traditionally separated modes of grassland grazing and crop monoculture, integration of agriculture with animal husbandry is becoming the development trend of Tibet's structural adjustment of agriculture and animal husbandry. Ensuring the production and supply of sufficient forage and feed is the key to the success of this agro-pastoral structural adjustment. In Tibet, compared with pastoral areas, the agricultural areas have the advantages of lower altitude and relatively good water and heat conditions for the development of forage and feed production. On the other hand, in recent decades, the total grain production of 0.96 million tons per year provided a surplus over the food consumption demand in Tibet, causing a large amount of food overstock in some areas. According to the latest estimation, Tibet's farmers and herdsmen need about 0.70-0.80 million tons of grain, and 1.5×10^5 hectare of arable land, accounting for only ca. 60% of the existing arable land (Cheng and Min, 2002). Therefore, it is feasible that 40% of cultivated land could be used for forage production. Together with suitable marginal land, the regional integration of agriculture and animal husbandry is potentially very prosperous.

4 Implementation of national R & D program

To rehabilitate the degraded rangeland, China has implemented a series of ecological engineering programs and taken adaptive ecosystem management measures, such as adopting fenced grazing exclusion and establishing cultivated pasture. Among them, a national key R & D program, *Technology and Demonstration of Recovery and Restoration of Degraded Alpine Ecosystems on the Tibetan Plateau* has been implemented since 2016 in order to restore the degraded grasslands and upgrade the rangeland quality. The overarching aim of that project is to solve the problems of alpine grassland degradation through building up a grass-based animal husbandry technology system by synergizing forage production and ecological functioning, reconciling the relationship between ecology, forage production and animal husbandry, and achieving the win-win goals of curbing grassland degradation and changing the development mode of animal husbandry (Zhang et al., 2016).

The Tibetan Plateau is one of the important ecological security shelters in China. With the features of high altitude, cold and drought, alpine ecosystems are extremely vulnerable to environmental changes, and are thereby prone to degradation under the pressures of climate change and anthropogenic disturbance. Rehabilitation of degraded ecosystems is quite difficult due to a fairly low recovery rate. The restoration of degraded rangeland and deserted land has always been the top priority among the protection and construction programs of the national ecological security shelter on the plateau. The main factors leading to alpine grassland degradation in northern Tibet are the decline of ecological functioning and forage production, and the imbalance between forage supply and animal feed demand. The key solution to this degradation problem is to build up a grass-based livestock husbandry technology system by enhancing forage production to meet the growing demand of an increasing livestock population. Land desertification is mainly the result of the interaction of climate change and human activities. An integrated approach to curb the expansion of desertified land area is to establish a sustainable land use technological system and enhance ecosystem functioning and services. Focusing on the above key issues and research objectives, and aiming to restore alpine rangeland degradation in Tibet, the national R & D project is devoted to adopting innovative technologies, such as optimally allocating ecological and production functions, reseeding native varieties of forage, planting high-yield cultivated pasture, processing high-quality forage products, and developing organic livestock products (Zhang et al., 2016).

To this end, the regional synergy of ecosystem functioning and services is essential for rangeland degradation control. On the Northern Tibetan Plateau, rangeland has low grass yield, poor carrying capacity, severe shortages of forage grass in winter and spring, and poor capacity for regulating the forage-livestock balance, so maintaining ecological functioning is the top priority. In the south of Tibet, the water and heat conditions are much better in the lower watersheds, so developing high-yield and high-quality cultivated pasture is beneficial. Forage production in South Tibet can provide the feed supply for the north Tibet rangelands and regulate the regional balance of grass and livestock (Duan et al., 2019). Therefore, the production service and ecological functioning are both important there. The key point of ecosystem rehabilitation is to establish an efficient restoration technology and mode for the degraded rangeland, which focuses on the coordination and optimization of ecological and production functions, so as to achieve harmonious development of grassland production ecology within and across the regions.

Three pathways are identified for securing the above-mentioned regional synergy. First, design different restoration technologies and models for various degrees of degraded alpine rangelands and steadily improve the ecological functioning in northern Tibet, and simultaneously reclaim appropriate cultivated pasture in the suitable areas with available irrigation to increase the winter and spring forage supply so as to indirectly achieve the goal of restoring and conserving the degraded rangeland. Second, focus on the construction of high-yield and high-quality cultivated pasture in the agriculture-pastoral ecotone of southern Tibet to boost ecological animal husbandry and improve the restoration technologies and modes of degraded rangeland so as to improve the ecological function of production. And finally, make use of the advantages of high yield cultivated pasture in marginal land or low-productivity arable land in the South Tibetan River Valley to provide a feed supply for livestock in the North Tibetan pastoral area. Through this regional agriculture and pastoral coordination, the shortages of grass products will be solved and animal pressure on the rangeland will be reduced, and therefore, the region will arrive at a win-win goal.

This special issue contains a series of papers broadly organized into two themes: (1) Rangeland ecosystem function and management, and (2) Ecosystem responses to climate change. In the first theme of ecosystem functioning, Song et al. (2020) used an ecosystem service framework to quantify and map the spatial patterns of multifunctionality in the Tibetan alpine grasslands. They found that annual precipitation explained the large variation of multifunctionality across the different types of grasslands, and that vegetation covers lower than the threshold of 25% would cause collapse of multifunctionality in the alpine meadow. These findings provide insight into land use and adaptive ecosystem management of alpine grassland. Niu et al. (2020) simulated and estimated the seasonal dynamics of canopy photosynthetic parameters based on satellite-based models and site monitoring in an alpine meadow. Cao et al. (2020) compared static equilibrium with dynamic non-equilibrium theory for assessing the forage-livestock balance at the county level and found that the dynamic method is more appropriate. However, the static method is still recommended for severely disturbed grasslands. Land surface heat balance is influenced by grazing exclusion. Land surface temperature (LST) shows an asymmetric diurnal variation in the daytime and nighttime, with a larger magnitude of warming in the day than cooling at night (Feng et al., 2020). Enclosure has positive effects on plant biomass and surface soil nutrients in different types of grassland, with the most prominent effects in desert steppe (Wang et al. 2020a). In addition, a meta-analysis approach was used to synthesise observations on the effects of inorganic and organic fertilizer addition. The soil microbial community was found to be related to both the forms of nitrogen and addition rates (Wang et al., 2020b).

With regard to ecosystem responses to climate change, Wang et al. (2020b) examined the correlations between the annual drought severity index (DSI) and climatic factors. They found that the DSI response to climate varied with vegetation types. Zhang et al. (2020c) assessed the drought resistance of wild weed (*Pennisetum centrasiaticum*) seedlings from 12 counties in Tibet. Zhang and Fu (2020) used an open top chamber experiment along an altitudinal gradient to show that experimental warming had inconsistent effects on the carbon and nitrogen stoichiometry of plant communities at different elevations and during different months. Soil ammonium nitrogen and nitrate nitrogen contents were the main factors affecting plant community carbon and nitrogen stoichiometry.

It is imperative to call for regional synergy through integrating ecological functioning with ecosystem service, considering the alarming threat of rangeland degradation on the Tibetan Plateau. The series of papers in this issue, and those published previously, provide a collection of rangeland ecology and management studies in an effort to ensure sustainable use and management of the alpine ecosystems. We hope that this effort will provide incentives for further research and have invaluable implications for alpine ecosystem management.

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走向区域协同：协调草地生态功能与牧草生产服务

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摘　要：畜牧业和种植业在西藏高原不同地区长期处于分离发展状态，这种分离的格局导致了土地利用强度加剧和草场与农田生态系统的退化。农牧结合可通过行业间生态位互补提高粮食和饲料生产力，并有效提升复合生态系统的弹性，因此，通过协调畜牧业和饲料作物生产，走向区域协同成为农牧业发展和退化生态系统恢复的综合解决途径。通过区域耦合，协调专业化畜牧业和集约化农业，是解决放牧系统牧草不足和畜牧业生产瓶颈的有效办法。目前，要实现农牧业发展的区域协同，还必须从局域农场向区域层面推进。为此，从 2016 年起，国家重点研发计划项目“青藏高原退化高寒生态系统恢复与重建与技术示范”开始实施，旨在通过建立生产和生态功能相协调的草牧业技术体系，协调生态-草-牧关系，实现遏制草地退化和转变畜牧业发展方式的双赢目标。面对青藏高原草地退化的严峻威胁，迫切需要通过生态功能与生产功能相协调的方式实现区域协同。本专辑组织发表草地生态和管理的相关论文，以期促进高寒生态系统的管理和可持续利用。

关键词：西藏高原；生态系统恢复与重建；农牧结合；区域协同；生态功能与生产功能协调