

REVIEW

Using balance of seasonal herbage supply and demand to inform sustainable grassland management on the Qinghai–Tibetan Plateau

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Abstract To mitigate the impacts of grassland degradation on the Qinghai–Tibetan Plateau (QTP), in recent decades China has been implementing large-scale conservation programs and has invested about 42 billion CNY (7 billion USD). However, these programs are faced with major challenges involving trade-offs between ecological function, livestock production and income of pastoralists. Scientific assessments, as well as technical and policy issues, have not fully captured the complex ecological, social and economic dynamics of the challenges facing grassland management on the QTP. Pastoral livestock production on the QTP is characterized by imbalance in both quality and quantity between livestock seasonal nutrient requirements and herbage production, which forces pastoralists to keep larger numbers of livestock for longer periods, leading to overgrazing. To solve these problems, an integrated crop-livestock system is promoted to improve the efficiency of livestock production and conserve natural grassland as well for a sustainable system for the QTP.

Keywords ecosystem function, grassland degradation, grassland management, integrated rangeland-cropland-livestock production system, Qinghai–Tibetan Plateau

1 Introduction

Ecosystems and humans on the alpine region are

experiencing a time of great climatic, ecological, political and socio-economic change^[1]. The Qinghai–Tibetan Plateau (QTP) covers an area of about 2.5 million km² and is an important but sensitive part of the global ecosystem. Due to the extensive area of grassland (almost 52% of the plateau), livestock husbandry has been the dominant form of land use on the plateau, providing livelihood for about five million pastoralists, many of whom live in poverty^[2].

Over the past 50 years, because of the abrupt climate change and increasing anthropogenic activities, more than 50% of the QTP grasslands have become degraded or desertified^[2,3], which will significantly affect not only the grassland ecosystem productivity and services, but also the livestock production, local economics and regional sustainability. So far, scientific understanding of the impacts of grassland degradation and development of management policy for these regions are subject to controversy. One of the critical questions of our time is how to develop the ecological-social-economic system to sustain the grassland ecosystem and improve livelihood for pastoralists.

In this study, we describe the ecological, social, eco-engineering and political features that characterize grassland-pastoralists systems and identify some of the recent changes that are occurring within them. We analyze the main challenges generated by these changes and propose several paradigms for addressing them. The framework we present at the end of this study draws on these elements and highlights characteristics and linkages that can improve the efficiency of livestock production while conserving natural grassland within a sustainable social-ecological system for the QTP.

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2 The current status and challenges

2.1 Imbalance between livestock requirements and herbage production

Grassland livestock production on the QTP is characterized by an imbalance in both quality and quantity between livestock seasonal nutrient requirements and herbage production^[4]. Livestock carrying capacity can vary two to three times between warm (May to September) and cold (October to April) seasons due to the seasonal variation in grassland productivity and herbage nutrition (Fig. 1a)^[5–7]. Large losses of livestock and live-weight usually occur during the cold season due to snowstorms (Fig. 1b). This imbalanced ecosystem presents great challenges for production practices and forces pastoralists to raise larger numbers of livestock to maintain their livelihood. Unfortunately, long-term livestock production is the leading cause of overgrazing on the QTP.

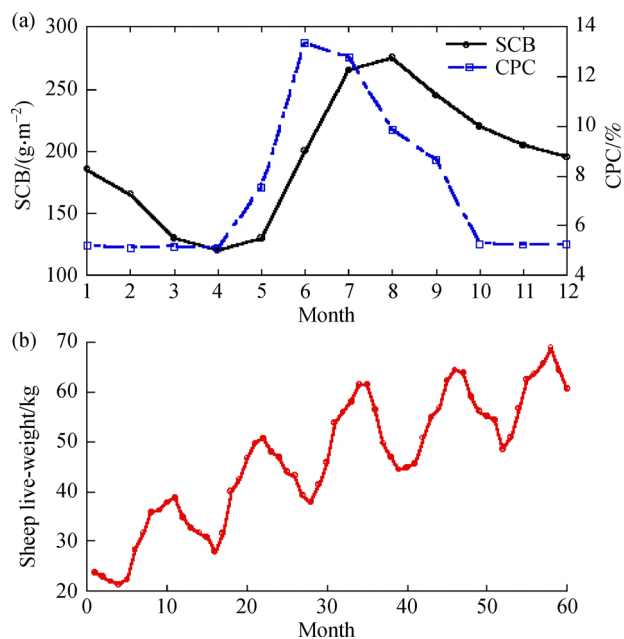


Fig. 1 Livestock production dilemma. (a) Seasonal dynamics of standing crop biomass (SCB, $\text{g}\cdot\text{m}^{-2}$) and crude protein content (CPC, %) ^[5,6]; (b) live-weight fluctuation of Tibetan sheep grazing on natural grassland.

2.2 Climate change, grazing and grassland degradation

Livestock husbandry has been the dominant grassland management on the QTP. However, the management is closely related to climate warming and grassland quality. The plateau surface air temperature has undergone a significantly positive trend during the period from 1961 to 2007. The warming rate ranged from 0.09°C per decade to 0.74°C per decade, with an average of 0.28°C per decade^[8]. Meanwhile, livestock have increased roughly

5-fold from the 1950s, reaching a peak in late 1980s. The overgrazing rate ranged from 1.25% to 102.87% (CV = 101.10%) due to large difference in spatial distribution^[9]. The rapidly changing climate and overgrazing lead to the degradation of grassland. In recent years, the degraded grassland area has reached about 6.5×10^7 hm^2 , accounting for 50% of the QTP grasslands. The “Black Soil Type” (i.e., “Black Soil Patch”) degraded grassland covers an area of approximately 7.0×10^6 hm^2 , accounting for 16%–54% of the total degraded grassland^[10]. Policymakers were concerned about overgrazing and its consequences, and have initiated the Grazing for Green Program and other programs to reduce, or even prevent, grazing through enclosure without considering the degree of grassland degradation.

2.3 National eco-engineering and supporting policies

To mitigate the impacts of grassland degradation on the QTP, in recent decades China has been implementing large-scale conservation programs, having invested about 42 billion CNY (7 billion USD). Launched in the 1990s, the QTP Grassland Restoration Project is the largest eco-construction program in China^[11]. It includes construction of ecological barriers on the QTP, the Sanjiangyuan National Nature Reserve and the Yellow River Water Resources Conservation Commission area. A number of eco-communities projects are still under construction. The majority of the investment has been used for engineering construction (e.g., infrastructure for immigrants, degraded grassland improvement, artificial pasture plantation and manmade rain, Table 1) rather than eco-compensation projects, which only account for about 1% of total investment^[2]. As a result, the condition of QTP grasslands has improved to some extent through enclosure and reduced grazing. However, such policies fail to consider the enthusiasm of pastoralists for participation in environmental protection. Whether the effectiveness of the projects continues after their completion, or the status returns to what it was before, remains to be seen. Policymakers should consider a higher proportion of investment in eco-compensation to encourage lasting effectiveness of the environmental protection projects.

2.4 Ecological migration and livelihood

Over the past decade, ecological migration (moving people from degraded to better areas) has been considered an important strategy and practice to reduce grazing pressure and improve the living conditions for the local people, especially in the Sanjiangyuan National Nature Reserve. In this region, more than 50000 pastoralists were moved to a nearby small town. However, this apparently sound ecological migration initiative was poorly designed, resulting in negative impacts on livelihoods and even social instability within the affected community. The

Table 1 Introduction of national eco-protection on the Qinghai–Tibetan Plateau, China

Project	Construction of ecological barriers on the Tibetan Plateau	Sanjiangyuan region	Yellow River water resources conservation Commission	Qinghai Lake natural reserve	Grain (Grazing) for Green Program
Duration/year	2008–2030	2005–2013	2006–2020	2008–2013	2003–2012
Investment/CNY	15.5 billion	7.5 billion	4.451 billion	1.568 billion	13.882 billion
Area covered	Whole of Tibet, including two prefecture-level cities, five regions, 73 counties, with a total area of 1.2 million km² .	Including 21 counties in 4 autonomous prefectures in Southern Qinghai and Tanggula Town in Golmud City, a total of 158 villages and towns, with a total area of 395000 km² .	Including Maqu, Luqu, Xiahe, Zhuoni and Lintan Counties, and Hezuo City in Gannan Prefecture of Gansu Province, with total land area of 30570 km² .	Including 25 towns in 4 counties of Tianjun, Haiyan, Gangeha and Gonghe in Qinghai Lake basin, with a total area of about 2.5 million km² .	Farming and pasturing townships in Qinghai, Tibet, Gannan, north-west Sichuan, with a total area of about 2.5 million km² .
Major projects	Five ecological protection projects: Natural Grassland Protection Project, Forest Fire Prevention and Pest Control Project, Wildlife and Protected Areas Construction Project, Important Wetlands Protection Project and Traditional Energy Alternative Project in agricultural and pastoral areas. Four ecological construction projects: Shelter Belt Construction Project, Aridification Grassland Construction and Natural Grassland Improvement Project, Desert Prevention and Transformation Project, and Soil Erosion Control Project.	Ecological protection and construction including the grazing withdrawal, returning grass to the cultivated grassland, returning farmland to forests, ecological degradation of land management, fire prevention of forest and grassland, grassland rodent pest management, soil and water conservation and protection management of facilities and capacity building. Production and living infrastructure construction contents of farmers and pastoralists including ecological relocation project, construction of small towns, grassland protection supporting projects and the people and livestock drinking water project.	Treatment projects based on protection and restoration in grasslands, forests and wetlands including grazing withdrawal of 887900 hm ² , grassland desertification comprehensive management of 180000 hm ² , forest protection of 171500 hm ² , closing-hill reforestation of 11300 hm ² , wetland ecological system protection of 40100 hm ² and wetland restoration of 42900 hm ² .	Wetland protection, degraded grassland management and restoration, desertification land management, ecological forest construction, river regulation, ecological monitoring system construction.	Returning farmland to forests and grasslands projects and fence construction.
Projects results and evaluation	As of December 2011, 3.2 billion CNY was invested, the Tibetan ecological security barrier protection and construction projects implemented, three major categories of ten projects implemented. A total fund of nearly 3 billion CNY was granted for ecological compensation, with 764 million CNY for implementation of forest ecological benefit compensation, 2.039 billion CNY for grassland ecological protection subsidy incentive, so as to gradually establish a long-term mechanism of environmental protection.	Ecosystem degradation trend has been tentatively curbed, with improved ecological conditions in key ecological construction areas. Despite increases in vegetation coverage and productivity, there is no substantial increase of soil conservation function. Root system layer of great significance to soil and water conservation recovers extremely slowly, and the recovery of soil physical and chemical properties even slower. Neither water loss nor soil erosion trends in the region is effectively controlled.	Through the comprehensive management of complete grazing-banning protection, grazing withdrawal and construction of artificial grassland, the vegetation coverage increased by 5%, height increased by more than 61%, and the biomass increased by more than 30%. Grass and livestock are getting balanced, vegetation coverage restored, water conservation features improved, water supply capacity enhanced, with the aftereffect in need of continuous monitoring.	The effect of each construction area is obvious. Grassland ecological environment tends to be improved in some project areas; the ecological service function comes into being; ecological degradation tends to be alleviated in local area. Project effects have yet to be further monitored and evaluated. insufficient participation of pastoralists, the inflexibility of the compensation policies and insufficient subsidies, the results of resettlement and alternative industries program were not satisfactory. The majority of pastoralists considered their interests not well protected, thus had little enthusiasm for participating in grazing withdrawal. The long-term implementation of the projects and the sustainability of the regional economy are faced with challenges.	After the projects of returning grazing land to grassland, the vegetation height increased by 9% to 22%, vegetation coverage by 17% to 23%, grass yield by 10% to 24%. However, affected by returning grazing to grassland, livestock production and the life of pastoralists were severely affected, especially influenced by grazing prohibition. Due to insufficient participation of pastoralists, the inflexibility of the compensation policies and insufficient subsidies, the results of resettlement and alternative industries program were not satisfactory. The majority of pastoralists considered their interests not well protected, thus had little enthusiasm for participating in grazing withdrawal. The long-term implementation of the projects and the sustainability of the regional economy are faced with challenges.

greatest challenge was to move, within a short time, the nomadic people who have wandered on the plateau for thousands of years to settle them in a small area. The government have recently realized this problem and have adjusted policies toward ecological compensation to reduce dependence on just livestock production and to encourage multi-resource management. The result of ecological compensation is livelihood improvement and ecological protection.

3 Strategies for sustainable grassland management

3.1 Natural grassland management: take half-leave half

Grassland livestock grazing on the QTP can be traced back at least 10000 years to the early Holocene^[12]. Long-term livestock grazing helped shape the current vegetation distribution and ecosystem structure^[13,14]. Though increased grazing intensity is considered to be responsible for a decrease in standing biomass and is blamed for replacing the palatable grasses (largely *Cyperus* spp. or *Stipa* spp.) with forbs (e.g., *Leontopodium* spp.)^[14], moderate grazing has been shown to accelerate ecosystem nutrient cycling, to maintain high primary productivity and species richness^[13,15]. Conversely, enclosure can lead to a simple and unstable ecosystem with poor primary productivity and quality^[7,15]. Therefore, policies preventing grazing may have a positive effect on moderate and heavily degraded grasslands, but a negative effect on healthy ones^[13,14]. Consequently, any policy to exclude grazing should consider the degree of degradation. For restored or healthy grasslands on the QTP, the reasonable grazing principle of take half-leave half (i.e., restricting grazing of aboveground biomass to less than 50% of what is available) seems more suitable than a simple grazing ban or enclosure^[16].

3.2 Artificial grasslands and ecosystem services

The most important considerations and challenges for ecological restoration projects on the QTP are to balance plant species diversity and ecological functions with pastoralists livelihoods. Therefore, restoration policies for the plateau should focus on how to sustain the development and functions of ecosystems under the current land use intensification^[16]. To fulfill this purpose, a large pool of species is required, especially when it comes to constructing artificial grasslands in seriously degraded areas.

Biomass quickly recovered in degraded bare land with < 20% plant cover (known in China as *hēitūtān* or black soil beach) to even higher levels than native grasslands after the planting of artificial grassland (composed of a mixture of perennial graminaceous

species). Such higher pasture productivity can better meet the forage needs of local pastoralists, alleviating the imbalance between the nutrient supply and livestock demands in the cold season, thereby reducing loss of livestock and live-weight^[6]. This agriculture practice also reverses the advance of poisonous plants and weeds, facilitating the recovery of native vegetation. However, the option of planting artificial grassland and related management to increase primary production (e.g., fencing, reseeding, weed control and fertilization) still leaves policymakers with the challenge of integrating diverse ecosystem services (Table 2). For example, regenerating degraded grasslands and related management may potentially increase soil organic matter, thus sequestering atmospheric carbon^[16,17]. A meta-analysis of 162 studies indicated that fertilization can increase soil carbon content by 5%, enclosure grazing by 6.3%, conversion of cropland to pasture by 6.4% and regenerating degraded grassland by 42.8%^[17]. However, after 20 years, soil carbon content has also been found to have decreased in artificial grasslands^[18]. Therefore, policymakers should consider constructing long-term monitoring networks to assess ecosystem services after restoration so that any outdated or unsuitable management practices and policies can be identified and replaced.

3.3 Nutritional balanced livestock production

Pastoral livestock production systems on the QTP generally follow the traditional nomadic style, in which Tibetan sheep and yaks graze on natural grassland throughout the entire year^[19]. As discussed, the available herbage is more than sufficient for livestock in the warm season, but is in seriously short supply during the cold season. Livestock production is thus characterized by a wasteful cycle with 80% of the live-weight gained during the warm season being lost during the cold season^[6]. This exacerbates the problem of overgrazing, culminating in ever more grassland degradation on the QTP. To address this problem, we present a new “warm season grazing and cold season lot-feeding” approach. The approach can achieve nutrient balance by the two periods livestock production system, which involve grazing during the warming season from June to October and lot-feeding during the cold season from November to the following May by providing forage from artificial grasslands and croplands.

3.4 Compensation and livelihood for ecological migration

Ecological compensation standards differ substantially between regions. In some cases, ecological compensation becomes a living allowance and fails to achieve the goal of reducing grazing pressure and enabling vegetation recovery (Table 3). At present, the ecological compensation standard on the QTP is low and inflexible. For

Table 2 Regeneration productivity of rehabilitation experiments in five different grassland types of the Qinghai–Tibetan Plateau¹

Item	Annual pasture ²	Perennial <i>Elymus nutans</i> pasture ³	Improved pasture	Fenced pasture	Degraded pasture
Total dry herbage productivity/(kg·hm ⁻²)	11300±2000	11000±500	4350±380	2630±420	1500±100
Times of increase in productivity	7.55	7.33	2.90	1.75	1.00
Ratio of palatable herbage/%	100	100	80	40	20
Yield of dry palatable herbage productivity/(kg·hm ⁻²)	11300±2000	11000±500	3500±270	1050±95	300±40
Carrying capacity (sheep units per hectare per year)	15.63±2.74	15.00±2.24	4.80±1.32	1.50±0.30	0.45±0.41
Times of increase in yield of palatable herbage compared with degraded pasture	34.73	33.33	10.67	3.33	1.00

Note: ¹ Data shown in the table are measured by the authors and unpublished; ² pastures were improved by artificially adding grass seeds in the natural pastures; ³ mixed plantation techniques of legumes and grasses.

Table 3 Overview of ecological compensation standard related to the production and life of farmers and pastoralists implemented in Zeku County, Huangnan Tibetan Prefecture and Qinghai Province

Compensation	Compensation objects	Compensation mode	Compensation standard	Starting year	Policy
Forbid herding	Farmers and pastoralists	Economic compensation	90 CNY·hm ⁻² ·yr ⁻¹	2011	Guiding suggestions for implementing of policy in grasslands ecological conservation subsidies and rewards, 2011
Decreasing livestock when overloading	Farmers and pastoralists	Economic compensation	22.5 CNY·hm ⁻² ·yr ⁻¹	2011	Guiding suggestions for implementing of policy in grasslands ecological conservation subsidies and rewards, 2011
Subsidy for fine herbage breeds	Farmers and pastoralists	Economic compensation	150 CNY·hm ⁻² ·yr ⁻¹	2011	Guiding suggestions for implementing of policy in grasslands ecological conservation subsidies and rewards, 2011
Comprehensive subsidy for production goods of pastoralist	Farmers and pastoralists	Economic compensation	500 CNY·yr ⁻¹ per household	2011	Guiding suggestions for implementing of policy in grasslands ecological conservation subsidies and rewards, 2011
Fuel subsidy	Ecological migrants	Economic compensation	800 CNY·yr ⁻¹ per household	2009	Administrative measures of subsidy for fuels for eco-migrants in Qinghai Province
Technical training within County	Farmers and pastoralists	Training & economic compensation	Living expenses 20 CNY·d ⁻¹ per person	2011	Implementation measures of technical training and compensation of employment after migrant for farmers and pastoralist in the Source Area of Three Rivers

example, in the Sanjiangyuan National Nature Reserve, ecological migration compensation standards for feed and grain funds are 3000 CNY per household for migration within the same district or 8000 CNY for migration to another district. The heating and fuel subsidies are 800 and 2000 CNY for each migrating household from within or outside the district, respectively. The compensation standards of Grain for Green and Natural Forest Protection projects are generally in the range of 26 to 75 CNY·hm⁻². These compensation policies do not take into consideration inflation or population increase, leaving the pastoralists to live on the initial cash compensation. Such compensation definitely lacks long-term effectiveness on grasslands restoration and livelihood improvement^[2]. Eco-compensation should address not only the lost income from reduced grazing, but also the costs associated with ecological reestablishment in order to maintain the livelihoods of pastoralists. Skills training and development in livestock production are keys to solving the problems of ecological migration^[2]. Lot-feeding or supplementary feeding during the cold season is recommended in areas suitable for development of artificial grassland. These practices not

only supplement traditional livestock production, but also allow the migrants full use of available human resources.

4 Integrated rangeland-cropland-livestock production system

The greatest challenge for policymakers is to ensure that the alpine grasslands can maintain moderate grazing levels and at the same time increase the income of pastoralists above that of traditional livestock production systems. It is obvious that local and national policies should encourage new livestock production systems with efficient herbage conversion to reduce the grazing periods and alleviate grassland grazing pressure. An effective integrated system is urgently needed to produce usable herbage for livestock production while conserving natural grassland in sustainable way for the long-term. The system should not totally replace the traditional pastoral livestock system, but add complementary advantages to the existing system.

We propose a new “three zones coupled system” approach of pastoral livestock on the QTP (Fig. 2), making

the best utilization of natural grassland, mixed crop/pastoral land, and cropland in the region through integrating spatiotemporal variations of resources. In such a system, Tibetan sheep and yaks mainly graze on the natural grassland area during the short warm season and turn to the mixed crop/pastoral area during the cold season. Agricultural byproducts of the mixed cropland/pastoral zone and cropland area also provide important supplementary forage for livestock. The use of large-scale artificial grasslands in the crop/pastoral zone reduces the grazing pressure on natural grasslands by providing an alternative supply of livestock feed. Implementation of this new approach for the QTP has demonstrated that the combination of livestock, forage and agricultural byproducts from the three zones brings benefits beyond the sum of the value of the individual resources. Taking advantage of the dynamic interaction of its various components, the

integrated livestock production system can guarantee more sustainable production. Experience shows that this new approach is a strategic way to decrease overgrazing caused by livestock production on the QTP. It also improves the efficiency of livestock production and increases the income of pastoralists and migrants. Of course, as a part of this comprehensive new approach, new frameworks such as forage planting and processing, disease prevention and improvement of nutrient conversion efficiency need to be introduced to pastoralists who have not received relevant training and experience. Such training will be especially important for serving and educating local communities and accelerating subsequent development of ecological migration.

In addition, there is a huge area of artificial zones with 4 m wide forage belts and woodland belts created through the Green for Grain Project on the QTP (Fig. 3). For

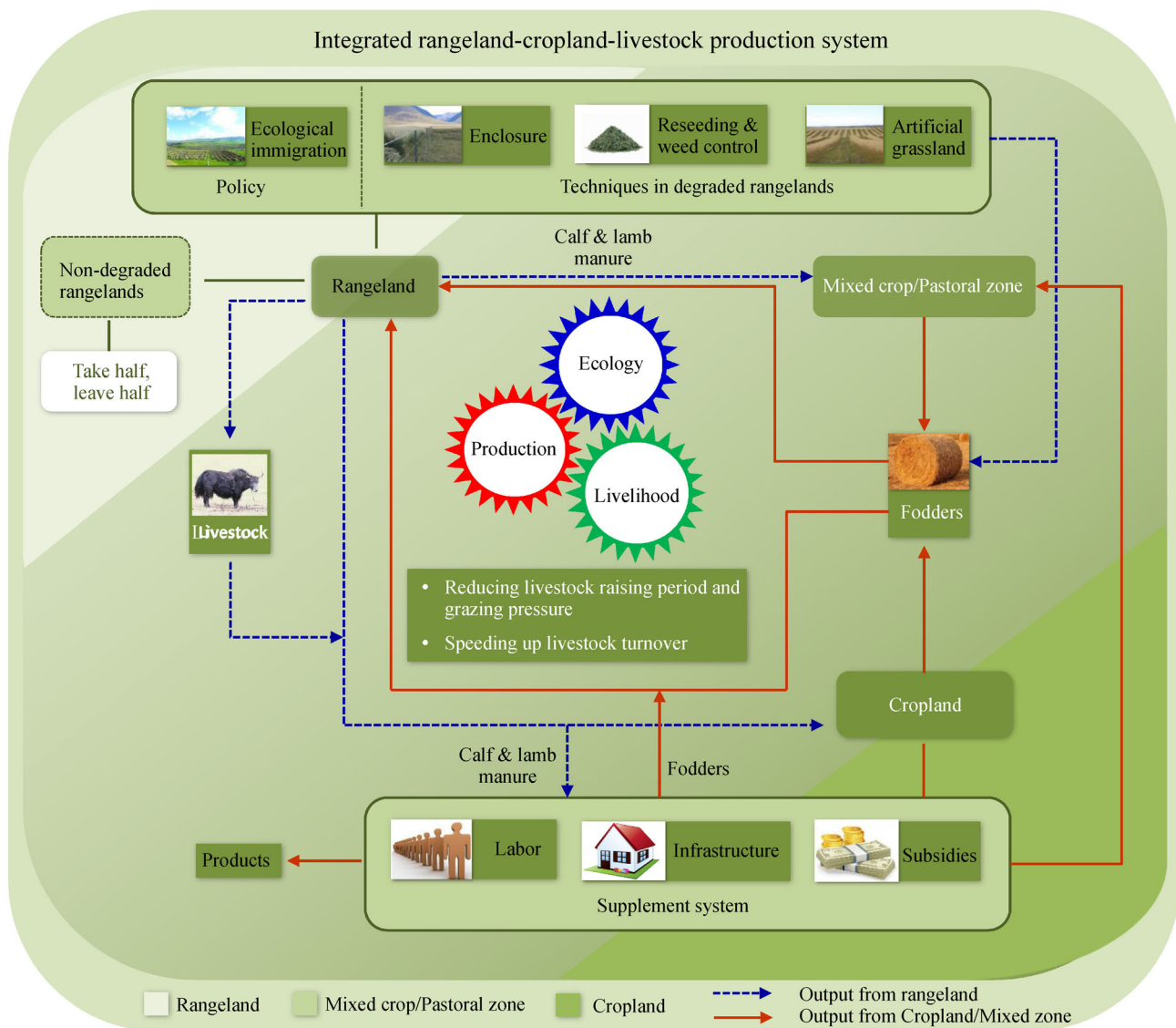


Fig. 2 The functions of rangeland, mixed crop/rangeland, cropland and its integrated production system in typical regions on Qinghai-Tibetan Plateau



Fig. 3 Giant area of artificial zones with 4 m wide forage belts and woodland belts created through the Green for Grain Project on the QTP. In Sanjiangyuan region, the total area of the grassland belts is about 67000 hm² in which forage biomass is allowed to lot-feed livestock for 4–5 million sheep units.

example, in the Sanjiangyuan region, the total area of the grassland belts is about 67000 hm² in which forage biomass is allocated to feeding livestock (4–5 million sheep units). This extensive artificial grassland made our new approach feasible on a large scale through providing substantial green supplement forage for livestock during the winter. Furthermore, a large number of ecological migrants provide essential human resources to support this approach. Therefore, this approach can also help solve the conflict between ecological principles and policies of grassland management on the QTP. Moreover, the experience of applying this approach on the QTP will provide useful information for similar contexts around the world.

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