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How to Develop Grass-based Livestock Husbandry in Areas of Low- and Middle-yield Fields

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Abstract

With increasing awareness of balanced and healthy diet, the demand for ruminant products has been drastically increasing in China over the past decades. Grass-based Livestock Husbandry (GLiH), a new paradigm for agricultural restructuring and sustainable development, is highly encouraged to meet such demand. Yet, the country's own production cannot self-support the demand, as envisaged by the soaring import of both red meats and forage products, albeit half of the nation's cereal production is devoted to animal feed and forage crop production area amounts to 12 million ha. With the affluent population and limited arable land, China is facing challenge to explore possible land areas for GLiH development. We argue that one of the effective ways is to transform the lowand middle-yield fields, which account for over 70% of the cultivated lands, into forage crop production. Our analysis indicated that cultivation of forage crops could avoid the risks of low yield and low economic returns frequently occurring for cereal production on such lands. Furthermore, a forage-cereal rotation cropping system can significantly increase dry mass production, reduce the incidence of pest and disease damage, and ameliorate soil physical and chemical properties by improving soil organic matter, soil fertility and reducing salt and alkaline constraints. Three scenarios have been projected for the potential of the exploitation of low- and middleyielding land for livestock production, and the amount of the red meat production is estimated to be 17.98, 21.58, and 26.98 million tons, respectively, which are 1.6, 1.9, and 2.4 times of the current production nationwide. A case study for Shandong Province is further presented, demonstrating that exploring the saline-alkali land at the Yellow River Delta for forage crop production could substantially alleviate the shortage of forage supplies and optimize the agricultural infrastructure of the province.

Keywords

Grass-based Livestock Husbandry (GLiH); low- and middle-yielding land; saline-alkali land; the Yellow River Delta

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How to Develop Grass-based Livestock Husbandry in Areas of Low- and Middle-yield Fields

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Abstract: With increasing awareness of balanced and healthy diet, the demand for ruminant products has been drastically increasing in China over the past decades. Grass-based Livestock Husbandry (GLiH), a new paradigm for agricultural restructuring and sustainable development, is highly encouraged to meet such demand. Yet, the country's own production cannot support the demand, as envisaged by the soaring import of both red meat and forage products, albeit half of the nation's cereal production is devoted to animal feed and forage crop production area amounts to 12 million hectares. With the abundant population and limited arable land, China is facing challenge to explore possible land areas for GLiH development. We argue that one of the effective ways is to transform the low- and middle-yield fields, which account for over 70% of the cultivated lands, for forage crop production. Our analysis indicated that cultivation of forage crops could avoid the risks of low yield and low economic returns frequently occurring for cereal production on such lands. Furthermore, a forage–cereal rotation cropping system can significantly increase dry mass production, reduce the incidence of pest and disease damage, and ameliorate soil physical and chemical properties by improving soil organic matter and soil fertility and reducing salt and alkali constraints. Three scenarios have been projected for the potential of the exploitation of low- and middle-yield land for livestock production, and the amount of the red meat production is estimated to be 17.98, 21.58, and 26.98 million tons, respectively, which are 1.6, 1.9, and 2.4 times of the current production nationwide. A case study for Shandong Province is further presented, demonstrating that exploring the saline-alkali land at the Yellow River Delta for forage crop production could substantially alleviate the shortage of forage supplies and optimize the agricultural infrastructure of the province. **DOI:** 10.16418/j.issn.1000-3045.20200120001-en

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As pointed out in the report of the 19th CPC National Congress, the main social contradiction in China has changed to be the contradiction between people's growing need for a better life and the unbalanced and insufficient development as the socialism with Chinese characteristics enters a new era. In agriculture, the main contradiction has shifted from insufficient yield to imbalanced structure. To advance the structural reform of agricultural supply, we must focus on the market trend and aim at increasing farmers' income and ensuring effective supply to pursue sustainable green development, meet qualitative need, and ultimately ensure the food security of China. Since the implementation of the reform and opening-up policy, the dietary structure of Chinese residents has changed for nutrition improvement and health enhancement and the proportion of meat, eggs, and milk in diet has kept increasing. From 1985 to 2017, the annual per capita grain ration of Chinese residents dropped from 233.8 kg to 130.1 kg, and the proportion of total grain consumption in food consumption dropped from 71.9% to 27.3%. At the same time, the annual per capita animal food consumption increased from 15.2 kg to 57.7 kg. Coupled with the population growth, the demand for meat, eggs, and milk has increased rapidly. For meat consumption, the ratio of grain-consuming pork dropped from 83% to 62%, while that

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of grass-consuming ruminant products such as red meat (except pork) increased from 7.8% to 9.9% ①.

In the past, China's agriculture was dominated by grain crop production. Although livestock husbandry had developed, the traditional crop production was still dominant and livestock husbandry only took a portion of less than 30% in agriculture. Therefore, the soaring demand for grass-consuming ruminant products exposed the shortage of domestic supply. In recent years, the import volume of ruminant products such as beef, mutton, liquid milk, and milk powder in China has remained high and been rising year by year. Meanwhile, the import volume of forage such as alfalfa, oat, and soybean was also increasing. The trade frictions between China and the United States and the subsidiary world trade disputes have increased the uncertainty of importing forage and dairy products from the international market into China. Since the No. 1 Central Document in 2015 pointed out to speed up the development of grass-based livestock husbandry (GLiH), the central government and multiple ministries have successively introduced a series of policies and measures. For example, the former Ministry of Agriculture (MOA) and Ministry of Finance of China issued the Notice on Conducting the Pilot Work of Transforming Grain Field to Forage Field ([2015]39); the former MOA issued the Guidance on the Restructuring of Maize Planting in the 'Sickle Bend Area' ([2015]4) which emphasized the development of silage maize, soybean, high-quality forage grass and ecologically functional plants; another file issued by the former MOA was the Guidance on Promoting the Development of Grass-based Livestock Husbandry ([2016]22), and pilot projects for the development of GLiH were organized in 37 counties of 12 provinces including Hebei. The development and issuing of policies indicate that the nation's agricultural structure adjustment is paying more and more attention to the role of grass and the GLiH development faces new opportunities.

1 The demand for ruminant products in China keeps growing

With the development of economy since the implementation of the reform and opening-up policy, the nutrition and health demand of Chinese residents have been continuously growing. Red meat has high protein content, low fat, and cholesterol content, rich essential amino acids, and important minerals, thus taking a growing portion in the diet of Chinese residents. From 1980 to 2018, China's red meat production increased from 0.714 million tons per year to 11.19 million tons per year, which was much faster than the increase of total meat production (from 12.05 million tons per year to 85.17 million tons per year). In the meantime, China's milk production also increased rapidly and the milk production in 2018 was 28 times of that in 1980 (Figure 1). The proportion of pork in total meat decreased from 94% to 63.4% while that of red meat increased from 6% to 13%. Despite the growing production, the red meat still cannot meet the growing demand of consumers. The import of beef, mutton, and liquid milk kept increasing from 2009 to 2018 (Figure 2). In 2018, 1.358 million tons of red meat were imported, which was 17 times of that in 2009; 700 000 tons of liquid milk were imported, which was 58 times of that in 2009.

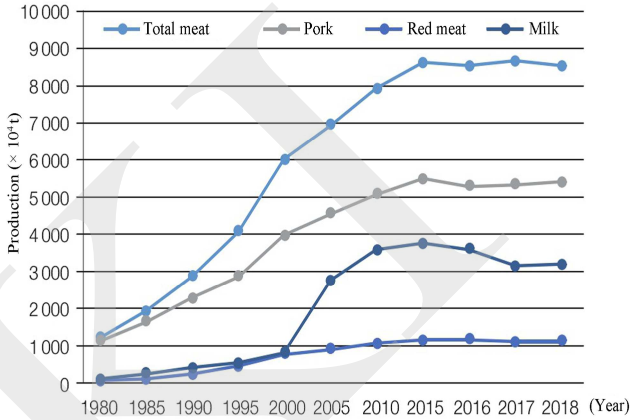

Figure 1 China's meat and milk production from 1980 to 2018

Data source: China Statistical Yearbook.

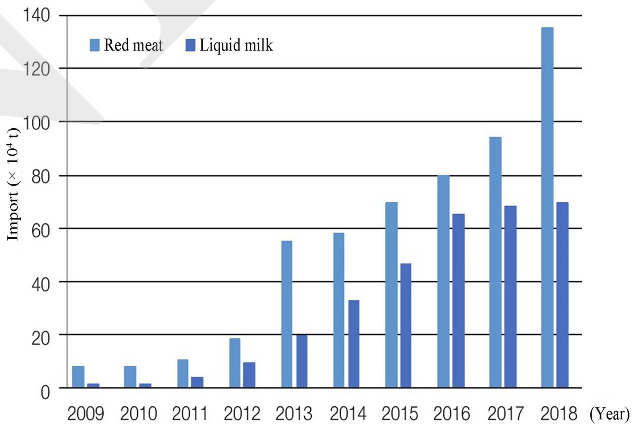

Figure 2 The import of beef, mutton, and liquid milk in China from 2009 to 2018

Data source: The website of Department of International Cooperation, Ministry of Agriculture and Rural Affairs, PRC.

The trend of red meat consumption in other Asian countries and regions promises the huge demand for red meat in China in the future. It is estimated that by 2030, the red meat consumption in China will reach 19.87 million tons. Based on the current level of ruminant breeding in China, the gap between demand and supply of red meat will broaden [1]. The

① Data source: China Statistical Yearbook.

current output value of China's crop production to GLiH bears a ratio of about 2:1. It is projected that the output value of China's crop (grain, cotton, and oil plants) production will be equal to that of GLiH by 2030 and the output value of GLiH will exceed that of crop production by 2050 [2], which reflects the promising developmental potential of GLiH.

The increasing production of ruminant products is bound to drive the rapid increase in the number of ruminant breeding. By the end of 2018, the total number of ruminants in China was 750 million sheep units ①. Ruminants are herbivorous. Considering the daily hay consumption of each sheep unit is 1.8 kg [3], the total demand for hay is 500 million tons per year in China, whereas the annual hay output of natural grassland is only 300 million tons. Therefore, there is a huge gap in forage grass. With the growing demand for grass-consuming ruminant products, China's forage shortage is sure to become increasingly serious. Therefore, it is a great challenge facing the development of GLiH in China to adjust the planting structure and increase the area of grass to make up for the forage gap.

2 Developmental potential of GLiH in low- and middle-yield fields in China

China has 1.8 billion mu (1 mu = 666.6 m^2) cultivated land. The total grain yield kept increasing in China and reached 650 million tons in 2018. However, with the dietary restructuring of Chinese residents, the ration grain consumption occupies a decreasing proportion in the total grain yield, while the feed grain consumption shows an opposite trend. According to statistics, about 50% (300 million tons) of total grain was taken as the raw materials for feed production in China every year [4]. Therefore, China's food security can be taken as feed security. However, since grain comprises less than 1/2 of the aboveground biomass of crops [5], using only grain as feed is like wasting at least 1/2 of the aboveground biomass, which is equivalent to wasting the water, soil, fertilizer, and pesticides used by the growing of straw. Moreover, some of the unserviceable straw can only be burned, which causes secondary pollution. The vegetative parts such as stems and leaves of grass can be harvested for utilization, which can thus realize the utilization of the whole plant biomass.

China's agricultural areas have a long history of livestock husbandry. Different from pasture areas that mainly raise herbivorous ruminants, smallholders in agricultural areas focus on the raising of farm animals, pigs, and poultry. Therefore, ruminant breeding in agricultural areas of China has always been a sideline industry in history and never really formed an industry to provide high-quality animal food with plenty of protein. Moreover, traditional breeding in these areas lacked scientific guidance and was mostly in an extensive mode using low-nutrient crop straw as feed. For instance, a major reason for the Melamine incident in 2008 was that the protein content was insufficient in cow feed, which caused the substandard protein content in milk. Adjusting the planting structure to ensure adequate supply of high-quality forage in agricultural areas and develop an integrated industrial mode of "planting, breeding, and processing" for GLiH is an important starting point for the reform of China's agricultural structure.

According to the statistics of the National Bulletin of Cultivated Land Quality Grades issued by the former MOA, 72.7% (1.328 billion mu) of China's farmlands have low to middle yield (Table 1). Traditionally, farmers plant crops for harvesting grain. In this mode, the production covers the entire growth period and the grain yield is restricted by geographical, seasonal and other factors [6]. Therefore, the development of crops in low- and middle-yield fields generally faces the problems of low yield, instability, and poor production efficiency, and the annual yield of low- and middle-yield fields is only 40%–60% of that in high-yield field [7]. Forage planting aims to harvest vegetative parts such as stems and leaves, which does not need the strict matching of climate and land resources with time during the growth period. It can make full use of climate, land and biological resources, thereby greatly improving the biomass per unit area [8].

Table 1 The quality of cultivated land in different regions of China (unit: 100 million mu)

Region	High-yield land area	Middle-yield land area	Low-yield land area	Proportion of low- and middle-yield land area (%)
Northeast China	1.44	1.68	0.22	56.89
Inner Mongolia and the area along the Great Wall	0.14	0.47	0.72	89.47
Huang-Huai-Hai region	1.18	1.67	0.61	65.90
Gansu and Xinjiang	0.29	0.26	0.38	68.82
Tibet	0.00	0.02	0.11	96.92
Loess Plateau	0.21	0.37	0.95	86.27
The middle and lower reaches of the Yangtze River	0.82	1.64	0.84	75.15
Southwest China	0.62	1.52	0.78	78.77
South China	0.28	0.54	0.50	78.79
Total	4.98	8.17	5.11	72.71

Data source: National Bulletin of Cultivated Land Quality Grades ([2014]1).

① One unit of sheep is defined as an adult ewe weighing 50 kg and consuming 1.8 kg standard hay per day; a cow/cattle is evaluated as 5 sheep units.

Since the No. 1 Central Document in 2015 pointed out to speed up the development of GLiH, China has increased the area of artificial grassland. At the end of 2017, the reserved artificial grassland in China was 180 million mu, and the area of the top 10 forage grasses (alfalfa, silage maize, perennial ryegrass, *Elymus*, oat, etc.) totaled 142 million mu, accounting for 78.7% of the total artificial grassland. The planting area of alfalfa, silage maize, perennial ryegrass, and caragana each exceeded 10 million mu (Figure 3). Due to the different climate, terrain, and soil conditions between northern and southern China, alfalfa, silage maize, and oat are mainly planted in northern agricultural areas, while perennial ryegrass and Italian ryegrass in southern areas [9].

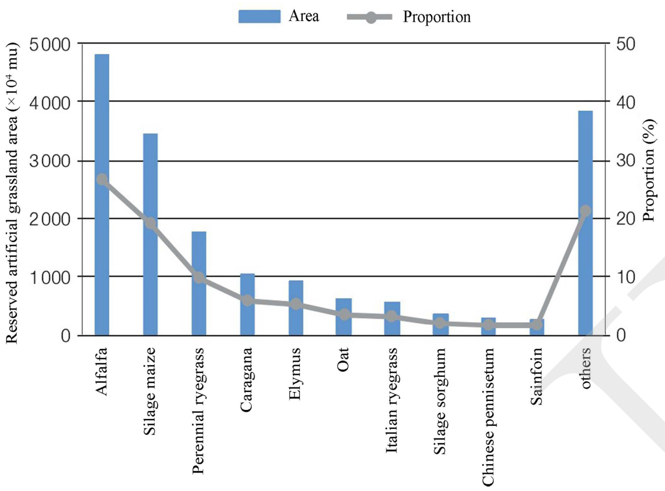

Figure 3 The major grasses and planting area in China, 2017 [9]

The low- and middle-yield fields have an area of 746 million mu in Northeast China, Inner Mongolia, Huang-Huai-Hai region, and the Loess Plateau, and 582 million mu in the middle and lower reaches of the Yangtze River, Southwest China, and South China. Three scenarios (6-year forage–cereal rotation: planting cereal for 5 years and forage for 1 year; 5-year forage–cereal rotation: planting cereal for 4 years and forage for 1 year; 4-year forage–cereal rotation: planting cereal for 3 years and forage for 1 year) have been projected for the potential of the exploitation of low- and middle-yield land for livestock production, which is equivalent to employing 17%, 20%, and 25% of the low- and middle-yield fields for GLiH. It means a yield reduction of 55 million to 83 million tons each year by the average grain yield of 250 kg/mu in low- and middle-yield fields in China. In the case of the planting ratio of alfalfa:silage maize:oat = 5:4:1 in northern China and mainly Italian ryegrass planted in southern China, the annual forage dry matter yield is estimated to be 225 million tons, 270 million tons, and 337 million tons in the three scenarios, respectively (Table 2). Assuming that 3 kg forage can replace 1 kg feed grain, the net increase in forage dry matter per year is 59–88 million tons after deduction of the reduced grain yield.

Assuming that the conversion rate of forage dry matter is 10:1 to mutton and 15:1 [10] to beef and the current production ratio of beef: mutton is about 6:4, the forage produced each year in middle-and-low-yield fields can give an annual red meat production of 17.98 million tons (6-year rotation scenario), 21.58 million tons (5-year rotation scenario), and

Table 2 Potential for the forage development in low- and middle-yield fields in three scenarios

Scenario	Region	Low- and middle-yield land area (100 million mu)	Forage area (100 million mu)	Grass	Forage yield per unit area (kg/mu)	Forage yield (100 million tons)	Total forage yield (100 million tons)
6-year forage–cereal rotation	Northern China	7.46	0.62	Alfalfa	471	0.29	2.25
			0.50	Silage maize	1551	0.77	
			0.12	Oat	752	0.09	
	Southern China	5.82	0.97	Ryegrass	1125	1.09	
5-year forage–cereal rotation	Northern China	7.46	0.75	Alfalfa	471	0.35	2.70
			0.60	Silage maize	1551	0.93	
			0.15	Oat	752	0.11	
	Southern China	5.82	1.16	Ryegrass	1125	1.31	
4-year forage–cereal rotation	Northern China	7.46	0.93	Alfalfa	471	0.44	3.37
			0.75	Silage maize	1551	1.16	
			0.19	Oat	752	0.14	
	Southern China	5.82	1.46	Ryegrass	1125	1.64	

Data source: National Bulletin of Cultivated Land Quality Grades ([2014]1); Reference [9].

26.98 million tons (4-year rotation scenario), respectively, which is 1.6, 1.9, and 2.4 times of the total red meat production in 2018. Therefore, implementing forage–cereal rotation in low- and middle-yield fields can significantly improve the self-supply of red meat in China.

3 The ecological effects of developing GLiH in low- and middle-yield fields in China

The low- and middle-yield land area takes up more than 70% of the total cultivated land area in China. Therefore, remediation of these fields is a major task of the country's agriculture, which generally concerns engineering and biological measures. Planting forage grass is one of the effective biological measures. Forage grass has strong abilities of soil fixation, water conservation, and fertility improvement. The rotation of cereal with forage grasses, especially leguminous grasses such as alfalfa, in low- and middle-yield fields plays an important role in the health and service functions of ecosystem.

(1) Improving saline-alkali land. After forage grass planting, the total salt content of soil is significantly lower than that of traditionally cultivated land. For example, after alfalfa cultivation for two years, the salt content in the 0–20 cm soil layer dropped from 0.22%–0.24% to 0.05%–0.06% [11]; in the 0–60 cm layer of the saline-alkali land where alfalfa was planted for 6 years, the total salt content decreased by 29.8% compared with that of the control [12]; after planting sesbania, sudangrass, alfalfa, and seepweed for six months, the desalination rate of 0–80 cm soil reached 26%–35% [13].

(2) Improving soil fertility. In the saline-alkali land growing alfalfa for 6 years, the organic matter and available nitrogen in the 0–60 cm arable layer increased by 4.5% and 10.7%, respectively [12]. In the field growing alfalfa for 4 years, the organic matter, total nitrogen, total phosphorus, and total potassium in the 0–10 cm soil layer were higher than those in the conventional fields, and the first three components were 47.7%, 20.9%, and 23.7% higher, respectively [14].

(3) Improving land productivity. The rotation of wheat after alfalfa was planted for 5 years increased the average yield of wheat by 67% to over 100% compared with the control [11,15]. Additionally, the rotation of cotton, foxtail millet, and maize after alfalfa increased the yield by 62%, 87%, and 7.4%, respectively [15]. Planting rice after milk vetch or ryegrass increased the rice yield by 6.8%–9.2% compared with continuous rice cropping [16].

(4) Improving physical properties of soil. For alfalfa fields that had not been plowed for 4 years, the soil bulk density of 0–60 cm layer decreased by 7.5%–7.9%, while the soil porosity increased by 8.8%–9.3% [14,17]. After 3–4 years growing of *Rumex patientia*, the soil bulk density of the arable layer decreased by 0.14–0.21 g/cm^3, and the total porosity increased by 1.89%–7.93% [18]. Generally, the soil permeability for water and air was improved, and the ability to conserve fertilizer and water was enhanced.

(5) Controlling pests and diseases. Continuous cropping can easily retain pests and pathogens in soil, while forage–cereal rotation can eliminate a large number of pests with single host and poor migration ability, thus effectively controlling infectious diseases and reducing the use of pesticides. After cereal–common vetch rotation in the Tibetan agricultural area, grubs and cutworms decreased by 12.6% and 18%, respectively, compared with those in the fields with continuous cropping of Triticeae crops; wheat aphids and *Mamestra brassicae* decreased by 79.1% and 73.6%, respectively, compared with those in the fields with continuous cropping of similar crops [11].

The application of forage–cereal rotation can increase the productivity per unit of arable land and improve low- and middle-yield fields, realizing both economic and ecological benefits. There were many successful cases including the saline-alkali land of Huanghua in Hebei, the Yellow River beaches in Zhengzhou, Henan, and Dingxi of Gansu, where the economic output per unit area was significantly improved by the cultivation of alfalfa in low- and middle-yield fields [10].

4 Potential of GLiH development in the Yellow River Delta

Saline-alkali soil is a major middle- and low-yield soil type in China and its productivity is closely related to the soil quality. The improvement and utilization of saline-alkali land, especially through biological measures like forage–cereal rotation and planting of forage grass with saline-alkali tolerance, have achieved significant economic benefits in other countries. Examples are the mixed planting of bermuda grass, sweet clover, and clover in the United States, the planting of fescue and tall wheatgrass in Argentina, and the utilization of *Kochia* and buffalo grass in Australia [19]. In China, there are many practical cases using forage cultivation to improve saline-alkali soil in Shandong, Ningxia, and Xinjiang [12,14,20]. China has a vast area of saline-alkali soil, especially in coastal zones where the land salinization and alkalization are severe. Due to the more than 6 million mu of saline-alkali land, high groundwater level, and lean soil, Yellow River Delta has low crop yield [21].

Shandong is a major animal-producing province in China. In 2018, the total production of red meat in Shandong was 1.132 million tons, accounting for 10% of the total red meat production in China and ranking the second only to that in Inner Mongolia [22]. However, the area of artificial grassland was 2.284 million mu in Shandong, only 1% of the artificial grassland area in China [9]. The mismatch of forage planting and ruminant farming will lead to a serious shortage of forage for livestock husbandry in Shandong. Therefore, developing GLiH in the saline-alkali land in the Yellow River Delta not only improves the saline-alkali land but also provides forage for the ruminants here.

The major forage grasses planted in Shandong are silage maize and alfalfa, which together account for 96.5% of the local artificial grass area. Other grasses planted sporadically include triticale, oat, silage sorghum, and legumes. To project the hay yield in Shandong Province, we assumed the current planting area ratio of silage maize: alfalfa = 9:1 and the per unit yield of forage in saline-alkali land being 80% of the average level in reality (the yield of silage maize: 850 kg/mu; the yield of alfalfa: 334 kg/mu). In the case of 50% of the saline-alkali land in the Yellow River Delta being employed for the growing of forage grass, 2.4 million tons of hay can be produced each year, equivalent to feeding 3.63 million sheep units. In the case of 30% of the saline-alkali land being employed for the development of forage grass, 1.44 million tons of hay can be produced each year, equivalent to feeding 2.18 million sheep units. The two major cities in the Yellow River Delta, Dongying and Binzhou, together kept 1.219 million mutton sheep in 2018. If 50% and 30% of the saline-alkali land in the Yellow River Delta are employed for forage cultivation, the equivalent sheep unit would be 3 and 1.8 times of the existing number in the two cities, respectively.

5 Suggestions for the development of GLiH in low- and middle-yield fields in China

Considering the weak foundation for the development of GLiH in China, it is an arduous task to develop GLiH in the low- and middle-yield fields, especially in the saline-alkali land. We suggest that the work in the following three aspects should be strengthened at present.

(1) Breeding and selection of forage grass varieties with saline-alkali tolerance. China is rich in halophyte resources which can be used as feed [23], whereas these resources are underdeveloped. From 1978 to 2018, there were a total of 559 nationally approved forage varieties, of which fewer than 20 were suitable for saline-alkali land. The previous breeding and selection of forage varieties mostly relied on experience, phenotypes, or biological detection technologies, lacking systematic methods. Nowadays, molecular breeding has been successfully applied to crops such as rice and maize. Establishing high-throughput molecular breeding method for forage can speed up the progress of forage breeding and even realize the cross-generation domestication.

(2) Establishment of a scientific forage–cereal rotation system. Experiments carried out in different regions have proved that forage grass planting on saline-alkali land helps to save water, conserve soil, and improve soil fertility. Forage–cereal rotation plays an important role in the health maintenance of ecosystem. Therefore, it is recommended to carry out scientific experiments on forage–cereal rotation systems for saline-alkali soil, design different forage–cereal combinations and rotation cycles to optimize the local planting mode, and promote the standardization and systematization of forage–cereal rotation.

(3) Construction of a scientific industrial chain of GLiH for saline-alkali land. According to the resources of different regions, the scale of livestock breeding and the planting area of forage grass can be planned through reasonable calculations, and then the planting structure can be optimized. A complete industrial chain of cereal–forage–livestock can be established by integrating elite grass varieties with saline-alkali tolerance, suitable rotation system, microbial agents for the processing of different forage grasses, and the diet formula for the whole life cycle of livestock, which can improve the saline-alkali land and ecological environment, enhancing both the quality and economic output of saline-alkali land.

In summary, with the rapid increase in the demand for red meat and 50% of the grain yield being used as feed, accelerating the development of GLiH has become an important starting point for the structural reform of agricultural supply in China. Adjusting the planting structure of low- and middle-yield fields such as saline-alkali land, increasing the area of artificial grassland, and replacing part of feed grain land with grassland to develop livestock husbandry will make great contributions to the security of general food including animal protein food in China.

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