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Sheepgrass (*Leymus chinensis*): An Environmentally Friendly Native Grass for Animals

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Gongshe Liu
Key Laboratory of Plant Resources,
Institute of Botany
Chinese Academy of Sciences
Beijing, China

Xiaoxia Li
Key Laboratory of Plant Resources,
Institute of Botany
Chinese Academy of Sciences
Beijing, China

Qingfen Zhang
Key Laboratory of Plant Resources,
Institute of Botany
Chinese Academy of Sciences
Beijing, China

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Foreword

It is with pleasure that I write this foreword to the new book by Professor Gongshe Liu.

Leymus chinensis (sheepgrass) is one of the most widely geographically distributed Triticeae grasses; it is an important forage and ecological restoration grass in China. Dr. Liu has a very broad understanding of *L. chinensis* across China and has been working on *L. chinensis* for over 20 years. His main interest is the system research and development of germplasm of *L. chinensis*. His research areas include forage genetic resources and molecular breeding and studies on the sexual reproduction mechanism and the molecular basis of biotic and abiotic stress tolerances of *L. chinensis*. Over the years, his research outcomes have been published in peer-reviewed scientific journals. He held 18 registered patents of invention and has developed new varieties of sheepgrass Zhongke Nos. 1, 2, and 3. He is author of two-volumed textbooks on *L. chinensis* germplasm as well as a textbook on practical techniques for *L. chinensis* plantation in China.

Now, *Sheepgrass (Leymus chinensis): An Environmentally Friendly Native Grass for Animals* will be a reference book that compiles all aspects of *L. chinensis*, such as basic knowledge, varietal development and utilization, sexual reproduction and seed traits, saline-alkaline resistance, nutrient and water absorption and applications, responsive mechanisms to defoliation, and gene resource mining and function research. It will be used widely in all provinces of China in the preservation and development of new cultivars and by those interested in grass systematics. This book will also be useful for forage breeders, Triticeae researchers, scientists, and graduate students interested in biosystematics, genetic resources management, natural resource management, and rangeland management.

German Spangenberg

Professor, School of Applied Systems Biology
La Trobe University
Bundoora, VIC, Australia

AgriBio, Centre for AgriBioscience
La Trobe University
Bundoora, VIC, Australia

Acknowledgment

Why do we study sheepgrass (*Leymus chinensis*)? Dating back to 1994, Professor Zhensheng Li, an academician of Chinese Academy of Sciences (CAS), who was its vice president at that time, paid particular attention to the food security in China and indicated “Building an ecologically sound North China grassland and animal husbandry is critically important for food security and as an Ecology Great Wall for China.” However, the lack of a suitable forage grass had been the major obstacle of the development of the herbivore husbandry in North China. Under such circumstance, he suggested that our research team at the Institute of Botany, Chinese Academy of Sciences should focus on the superior local native grass species, sheepgrass, and should select the germplasm resources of high quality for systematic research and further cultivation of new sheepgrass varieties. Professor Li’s proposal proved to be a feasible research field of great significance. With the supports and advice from him, there have been more than 50 researchers and graduate students contributing to the systematic study on sheepgrass in the last two decades, resulting in the plentiful achievements including 18 patents, 3 new varieties of sheepgrass, and 3 academic books. Professor Li is undoubtedly the guider of the research of sheepgrass germplasm resource in China.

Chinese scientists have achieved many outstanding progress and results in the sheepgrass research on germplasm resource, domestication, cultivation, physiological ecology, ecological restoration, etc. Numerous academic works have been published in Chinese. In 2004, *Yang-cao Biological Ecology* was published by Professor Tingcheng Zhu as the editor in chief. In 2011, Gongshe Liu et al. published *Studies on Germplasm Resources of Leymus chinensis (Volume 1)*. In 2015, Gongshe Liu and Xiaoxia Li as the editors in chief published *Studies on Germplasm Resources of Leymus chinensis (Volume 2)*. Also in 2015, *Seeds Ecological Research of Sheepgrass* was published by Professor Jixiang Lin and Chunsheng Mu. In 2017, *Questions and Answers of Sheepgrass Planting Technology* was published by Gongshe Liu et al. The publication of this present book, *Sheepgrass (Leymus chinensis): An Environmentally Friendly Native Grass for Animals*, is an additional contribution to the existing sheepgrass research. These basic and applied achievements on sheepgrass research contributed to the features and advantages of the native grass research in China.

Consisted mainly of research reviews, this book features the systematic and conclusive integrations based on the previous studies on sheepgrass. In order to have a full coverage on sheepgrass research in China, there is certain overlap between this book and the two previous volumes of *Studies on Germplasm Resources of Leymus chinensis* published in Chinese. In the convenience for the readers and also with respect for intellectual property, I cited the original publications as far as possible in this book in order to present the comprehensive knowledges and research works of sheepgrass to the English readers.

The authors of this book are nearly 30 scientists and experts from 17 institutes, including CAS Institute of Botany, *Institute of Soil and Water Conservation*, and Northeast Institute of Geography and Agroecology, Peking University, Lanzhou University, Shanghai Academy of Agricultural Sciences, Guangdong Academy of Agricultural Sciences, etc. Dr. Xiaoxia Li has contributed a great deal of time and efforts to organize the contents. Thanks to her tremendous efforts and continuous coordination, the book was edited in cooperation among authors. All of the authors worked hard with precision and motivation, and here, I deeply appreciate their contributions to this book.

This book is supported by the National Basic Research Program of China ("973" program), National High Technology Research and Development Program of China ("863" program), National Natural Science Foundation of China, Project of Agricultural Office Chinese Academy of Sciences, Funding Project of the Transformation of Scientific and Technological Achievements of the Ministry of Science and Technology of China, National Special Project for Transgenic Technology of China, Project of Ministry of Agriculture of China, etc., which I deeply thank.

Professor German Spangenberg, an academician of the Australian Academy of Sciences, is also the main founder and leader of the International Molecular Breeding of Forage and Turf Conference. He is very familiar with, and supports, the pratacultural science and high technology in China. I thank him very much for writing the foreword for this book despite his busy schedule.

I sincerely thank all the following colleagues who offered their help and support: Jizhou Ren, Zhibiao Nan, Jingyun Fang, Zhicai Wang, Zongli Wang, Weiwei Li, Xinshi Lu, Xiu-Qing Li (Canada), Zengyu Wang (USA), Alan Stewart (New Zealand), etc. I will always remember their pursuit in prataculture and their support for the sheepgrass research and industrial development.

My greatest gratitude goes to my wife, Yanyan, and my son, Yifei. Along with my many relatives and friends, they are the strong backups for my work and life. I sincerely thank them all.

I would also like to thank the staff at Springer for their help and support.

Beijing, China Gongshe Liu
2018.11.30

Abstract

Sheepgrass (*Leymus chinensis* (Trin.) Tzvel) is a key species in the eastern part of the Eurasian steppe and is widely distributed in North China. It has extensive adaptability, high animal husbandry value, and ecological environment value. In the past 30 years, Chinese scientists collected and evaluated thousands of wild sheepgrass germplasm resources. A large amount of basic research about sexual reproduction, high yield, quality, and abiotic stress had been carried out. Various new varieties for different regions have been developed and are in utilization. This book summarizes the latest research results of sheepgrass both here and abroad and introduces the basic knowledge at different levels. The content of this book includes the distribution and origin, breeding, cultivation, and sexual reproduction of sheepgrass. It also includes the research progress of sheepgrass on nutrient and water absorption and applications, grazing resistance mechanism, and gene resource mining.

Contents

About the Author

Liu Gongshe was born in 1958 in a small village of Shaanxi Province in China. He is a PI and PhD supervisor of Chinese Academy of Sciences (CAS). He majored in agronomy in Northwest Agriculture and Forestry University during 1978–1981, pursued advanced studies in the University of Clermont-Ferrand II and CNRS in France during 1982–1986, and earned his Ph.D. in Plant Physiology. During 1986–1988, he was doing postdoctoral work in the team of Academician Wang Fuxiong in CAS. Since 1989, he was dedicated to his research work in the Institute of Botany, CAS, till now, where he is currently the group leader of the Center of Plant Genetic Resources and Molecular Breeding. His research areas include forage genetic resources and molecular breeding, sexual reproduction mechanism, and molecular basis of the resistance of sheepgrass. His main interest is the system research and development of germplasm of sheepgrass. His representative research results were published in *Plant Biotechnology Journal*, *Plant and Cell Physiology*, *BMC Genomics*, and *Acta Prataculturae Sinica*. He has also published the books *Study on Germplasm of Leymus chinensis*, Volumes 1 and 2 and *Question and Answer on Practical Technique for Sheepgrass Plantation*. He held 18 registered patents of invention and has developed Zhongke Nos. 1, 2, and 3, the new varieties of *Leymus chinensis*. Concurrently, he is the chairman of Biotechnology Committee of Chinese Grassland Society, and his group has won the first prize of science and technology from Chinese Grassland Society in 2014–2015.

Xiaoxia Li majored in pratacultural science in Lanzhou University during 2002–2009 and received her bachelor's and master's degrees. During 2009–2013, she studied in the Institute of Botany, Chinese Academy of Sciences, and earned her Ph.D. Since 2013, she was dedicated to her research work in the Institute of Botany, CAS, till now. Her research orientation is forage genetic resources and the molecular basis of resistance and seed germination of sheepgrass. Her representative research results were published in *Journal of Experimental Botany*, *Plant Biotechnology Journal*, *Plant and Cell Physiology*, *BMC plant biology*, *Plant Physiology and Biochemistry*, *Acta Prataculturae Sinica*, and so on. Moreover, she has published the book *Study on Germplasm of Leymus chinensis, Volume 2*, together with Liu Gongshe.

Qingfen Zhang born in May 1980, is doctoral graduate student of the Institute of Botany, Chinese Academy of Sciences, expert of Renewable Energy Center of Energy Research Institute of the National Development and Reform Commission and Internet Society of China, and special expert of China Quality Certification Center. He engaged in the research of technology and policy in the related fields of biological industry over 10 years. As the main head of the project and the key member of the national and provincial level projects, he participates in the research on more than 50 major strategic planning and policy issues. He cooperated and participated in writing of more than ten books and more than ten papers which are published in the core journals and completed nearly million words of research reports. In addition, he won the third prize of the People's Government of Beijing Science and Technology Research, second prize of the National Energy Administration Soft Science Research, and other provincial and ministerial level scientific and technological achievements awards.

Chapter 1
Basic Knowledge of Sheepgrass (*Leymus chinensis*)

Gongshe Liu, Dongmei Qi, Xiaobing Dong, Hui Liu, and Shu Liu

Abstract Sheepgrass (*Leymus chinensis* (Trin.) Tzvel) is the key species which is widely distributed in eastern Eurasia steppe. It is a perennial gramineous plant belonging to *Leymus*, Triticeae, and Poaceae. As a very important forage grass of great value in animal husbandry, sheepgrass is well known for its abundant foliage, high palatability, and high nutritive content. Sheepgrass is also valuable in grassland repair and reservation since it is a perennial grass with a rhizome network to fix the soil and can survive well in stressful environments. Based on the sufficient morphological and developmental knowledge, the cultivation and plantation of sheepgrass had become the focus of many grass breeders. In recent decades, a variety of new cultivars of sheepgrass such as "Zhongke" series were verified for the grass and seed production. In the artificial grassland establishment of sheepgrass, proper watering and essential fertilizers assure the plant growth and the production of grass and seed. As a fine grass with resistance to various stresses, multiple scientific studies on development and stress tolerance of sheepgrass have drawn the attention of many researchers.

1.1 Value and Distribution of Sheepgrass

1.1.1 Derivation of the Name Sheepgrass

Sheep prefer to eat many varieties of forage crops, which are not necessarily called sheepgrass. Sheepgrass, a botanical species similar to wheat and maize, has the Latin and scientific name of *Leymus chinensis* (simplified Chinese, 羊草; and Pinyin, Yáng Cǎo). As a high-quality forage crop, sheepgrass is nutritious and palatable; sheep and goats particularly like to eat sheepgrass. Thus, this plant deserves

G. Liu (✉) · D. Qi · X. Dong · H. Liu · S. Liu
Key Laboratory of Plant Resources, Institute of Botany, Chinese Academy of Sciences, Beijing, China
e-mail: liugs@ibcas.ac.cn

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the name of sheepgrass (a grass for sheep). In Northeastern China with chernozem containing carbonate minerals and in other areas with saline-alkali pastures, sheepgrass is often referred to as an alkali-tolerant grass because of its strong saline-alkali resistance.

In Chinese studies of sheepgrass, *L. chinensis* was termed "Yangcao" by Mr. Tingcheng Zhu in some international conference papers according to the pronunciation in Chinese directly. Dr. Gongshe Liu and his group used sheepgrass in their research papers published on various international academic journals. In some academic works, sheepgrass is also called Chinese Lymes.

1.1.2 Relatives of Sheepgrass

Sheepgrass is a perennial gramineous plant belonging to *Leymus*, Triticeae, and Poaceae. Common species of *Leymus* includes the following: *L. chinensis*, a forage crop of superior quality; *L. racemosus*, which is a sand-controlling plant and a good parent cultivating improved variety of wheat; *L. secalinus*, which is well adapted to a wide range and belongs to a medium-quality forage crop plant; *L. tianschanicus*, which originates from Xinjiang, China, grows on the upper part of the pasture belt of Mount Tianshan and is distributed in the Soviet Union and in Central Asia; *L. angustus*, *L. multicaulis*, *L. racemosus*, and *L. mollis*, which grow on sandy coasts and have rhizomes that can fix quicksand for grazing when it is small and tender; and *L. ovatus*, *L. paboanus*, *L. akmolinensis*, *L. arenarius*, *L. cinereus*, *L. hybrid*, *L. karelinii*, and *L. salinus*. These species are tetraploid, hexaploid, octagonal, and diploid, with the number of chromosomes up to $12 \times 7 = 84$, and are an inexhaustible gene pool for genetic improvement of important crops, such as wheat. Studies have been conducted on the origins of *Leymus*, which consists of 38 species worldwide. Furthermore, plants belonging to *Leymus* have the genomic constitution of $N_sN_sX_mX_m$ and the chromosome constitution of $2n = 4\times = 28$. N_s are probably rooted in *Psathyrostachys nevski*. However, the origin of the X_m genome of *Leymus* remains unknown.

1.1.3 Distribution of Wild Sheepgrass

Sheepgrass is widely distributed at around 36–62° North latitude and 120–132° East longitude. This species is mainly distributed and probably originates at the east end of the Eurasian steppe, which altitude is about 600–2400 m. In China, sheepgrass is mainly distributed in the Northeastern provinces, including Heilongjiang, Jilin, Liaoning, Inner Mongolia, Hebei, Shanxi, Beijing, Tianjin, Shaanxi, Ningxia, Gansu, Qinghai, and Xinjiang. Sheepgrass also grows in Russia, Mongolia, the Democratic People's Republic of Korea, and Japan. Sheepgrass is distributed worldwide in an estimated area of 280 million ha, half of which is in China. Sheepgrass is mainly distributed in eastern pastures of Inner Mongolia and in the Songnen Plain in Northeastern China (Figs. 1.1, 1.2, 1.3, and 1.4).

Fig. 1.1 Hulunbuir Prairie is a natural gene pool of sheepgrass

Fig. 1.2 Sheepgrass – the key species of the Xilin Gol Prairie

1.1.4 Cultivation Areas of Sheepgrass in China

Collection and cultivation of wild sheepgrass in China originated from the Songnen Plain and Eastern Inner Mongolia. After germplasm collection and long-term breeding, the artificial cultivation of sheepgrass gradually started in the other areas

Fig. 1.3 Bashang Prairie in Hebei Province

Fig. 1.4 Prairie of wild sheepgrass in Heilongjiang Province of Northeastern China

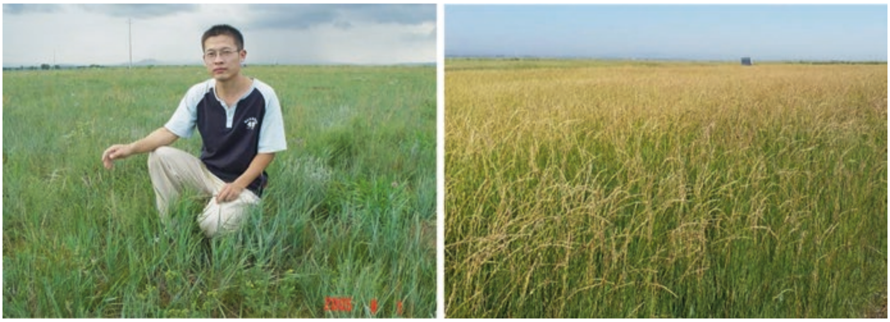

Fig. 1.5 Wild sheepgrass on the Bashang Prairie and artificially cultivated "Zhongke" series sheepgrass

of China. With breeding and promotion of new varieties of "Zhongke" series in recent years, sheepgrass has been subjected to large-scale artificial cultivation in China, covering Inner Mongolia, Xinjiang, Hebei, Gansu, Ningxia, and Heilongjiang (Fig. 1.5).

1.1.5 Animals Preferring to Eat Sheepgrass

Sheepgrass has a unique herbaceous aroma, which makes it palatable, and a very high nutritive value. Thus, many animals, such as horses, cattle, sheep, rabbits, and geese, are in favor of sheepgrass. However, since excessive grazing caused the pastures to exceed the ecological carrying capacity of the prairie, severe environmental issues such as the degeneration, desertification, and salinization of the prairie occur.

1.1.6 Advantages of Sheepgrass

Sheepgrass exhibits the following advantages compared to other forage crops:

1. Sheepgrass is a perennial herbaceous plant. Once it finishes planting, it may be used for several decades, resulting in relatively low production cost.
2. This specie is strongly resistant to stress including drought, cold, saline, alkali, and grazing and able to recover quickly after the grass harvesting.
3. Sheepgrass is palatable, nutritious, and conducive for healthy growth and development of grass-feeding livestock.
4. This species is extensively distributed, has high productivity, and can meet the requirements of large-scale intensive production.
5. It is non-deciduous, easy to process and store, and characterized by long harvest time and low nutrient loss, thereby saving harvesting and storage costs.

6. Sheepgrass can grow in the arid saline land of Northern China and can also provide high-quality forage, improve soil quality, and restore vegetation. Thus, sheepgrass has a very wide range of application.

1.1.7 Nutrient Components of Sheepgrass

Sheepgrass is widely distributed in famous prairies of China, including the Hulunbuir Prairie, the Xilin Gol Prairie, and the Songnen Plain. Sheepgrass has always been hugely popular among herbivores especially as staple food and fine kernel for cattle, horses, and sheep, etc. This species is also rated in the first class among all types of forage crops. Sheepgrass grows well in the cold and semiarid zones, with a relatively high production, regrowth in earlier spring, relatively late withering and yellowing in autumn and strong resistance to grazing. In addition, sheepgrass is recognized as a highly adaptable plant. Finally, sheepgrass with large foliage volume is nutritious, palatable, conducive to animal growth and development, and favored by livestock throughout the year. These excellent features make sheepgrass comprehensively valuable in animal husbandry.

Zhao et al. (2016) found that sheepgrass has a fecal energy of 10.11 MJ/d, urinary energy of 0.88 MJ/d, methane energy of 1.29 MJ/d, digestive energy of 9.76 MJ/d, and metabolic energy of 7.59 MJ/d. The aboveground part of sheepgrass can be used as feed. As a premium forage crop, sheepgrass is nutritious, mainly containing crude protein, crude fat, crude fiber, nitrogen-free extract, trace elements, calcium, phosphate, and vitamin E. Among them, crude fiber is indispensable from the gastrointestinal health of grass-feeding livestock. In the hays of sheepgrass, the content of crude protein is 13.35%, crude fat is 2.58%, crude fiber is 37.57%, nitrogen-free extract is 31.45%, and the ash content is 5.11%. Furthermore, sheepgrass is rich in minerals and carotene, and the content of carotene in its dry matter ranges from 49.5 to 85.87 mg/kg. Vitamin E is one of the essential vitamins that animals need, and its content in a forage crop is the main manifestation of feeding value. The content of vitamin E in the dried sample of *Silphium perfoliatum* L. is about 65 mg/kg, while that in the powdered sample of alfalfa is 98–144 mg/kg. Researchers have determined the contents of vitamin E in the dried leaves of sheepgrass of 18 varieties. The results showed that the content of vitamin E in sheepgrass was 448 mg/kg on average, varying within the range of 229.71–1187.58 mg/kg, suggesting a large space for breeding improvements. Moreover, the content of vitamin E in the grayish-green sheepgrass is higher than that in the yellowish-green type. At the heading stage, the content of vitamin E in the rhizome of sheepgrass is higher than that in the leaf, stem, or young panicle.

1.1.8 Nutritional Changes of Sheepgrass at Different Stages of Growth

The growth of sheepgrass can be divided into the following different stages: seedling, jointing, heading, flowering, milking, wax ripeness, and ripening. The contents of nutrients in sheepgrass, such as crude protein, crude fat, crude fiber, ash content, calcium, and phosphate, vary with the growth stage, of which the basic rule is as the growth stage changes from the jointing stage, the content of crude protein reduces gradually. However, those of crude fiber and acid detergent fiber (ADF) ascend slightly. The content of crude fat reaches the peak at the milking stage and is relatively lower at the seedling and flowering stages, while the ash content decreases during the vegetative growth of sheepgrass. The content of calcium is gradually increasing during the vegetative growth, reaches the peak at the heading stage, and then decreases gradually. The phosphorus content reaches the peak during the period from the jointing stage to the heading stage. The variations in the nutritional components and contents of sheepgrass at different stages can guide its grazing, mowing, and feed production.

Su (2016) found that on an experimental base of "Zhongke" series sheepgrass in Ningxia, the content of crude protein decreases with the extension of the growth period. For instance, fertilizing by 180 kg·hm^{-2}, the content of crude protein is 18.1% at the jointing stage and 11.9% at the harvesting stage (Fig. 1.6). As the

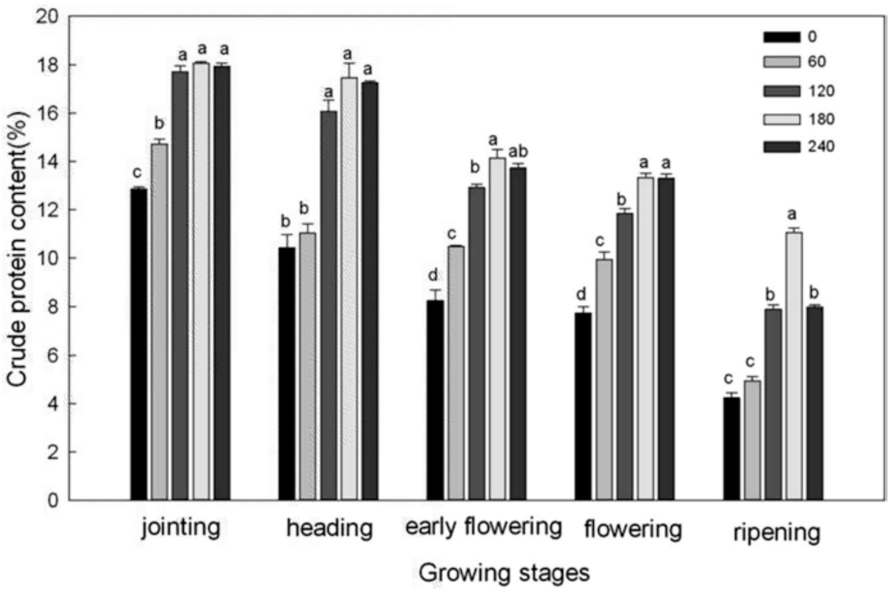

Fig. 1.6 Crude protein content in sheepgrass at different mowing stages under different nitrogen fertilizing rates. Note: Different fertilizing rates at the same growth stage are indicated by columns in different colors

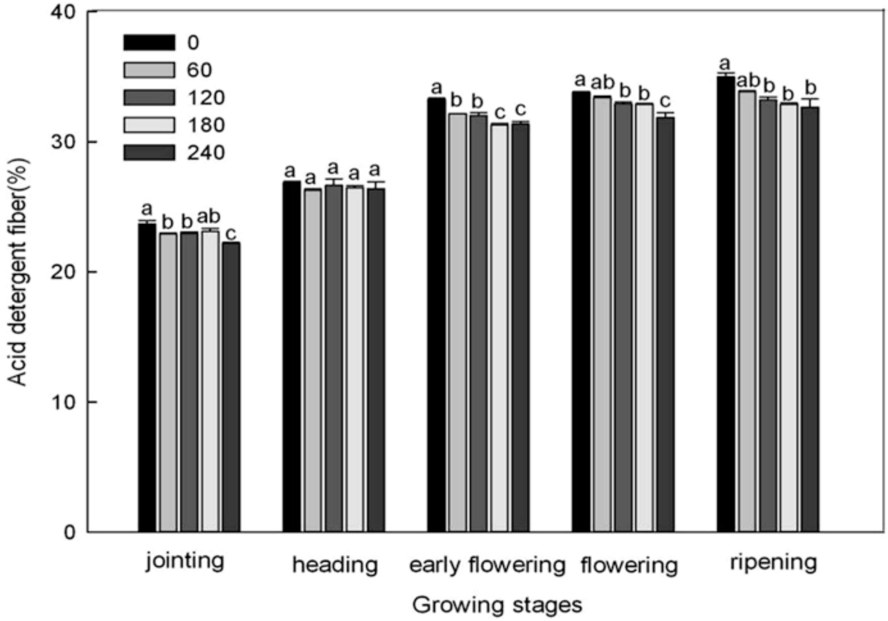

Fig. 1.7 ADF content in sheepgrass under different fertilizing rates during different development stages. Note: 0–240 represent different fertilizing rates and fertilizing rates at the same growth stage are indicated by columns in different colors

growth period extends, the ADF content increases, and the digestibility of forage crop is lowered. Taking the control group for an example, the ADF content is 23.7% at the jointing stage and 35.0% at the harvesting stage (Fig. 1.7). Moreover, the crude fat content reaches the peak at the jointing stage, accounting to 2.71–2.85%, and the valley at the flowering stage, accounting to 1.42–1.51% (Fig. 1.8). However, there is no significant difference in the content of crude fat between the flowering stage and the maturity stage.

1.1.9 Value of Sheepgrass in Grazing and Feeding

Feedstuff in animal husbandry is generally divided into concentrates and roughages. Concentrated feed is characterized by high contents of nutrients per unit weight, with low crude fiber content and high rate of digestion. Concentrates include bean cake, cottonseed cake, corn, and bran. Roughages, on the other hand, have low water content and high crude fiber and are mostly fed to the livestock dried. Forage crops and stalks fall into roughages. Roughages that are often used in animal husbandry include alfalfa, oats, sheepgrass, and corn silage. Particularly in animal husbandry on the prairie, sheepgrass is staple food for grass-feeding livestock. Secondly, the natural green hay in Chinese commercial grass is composed mainly of

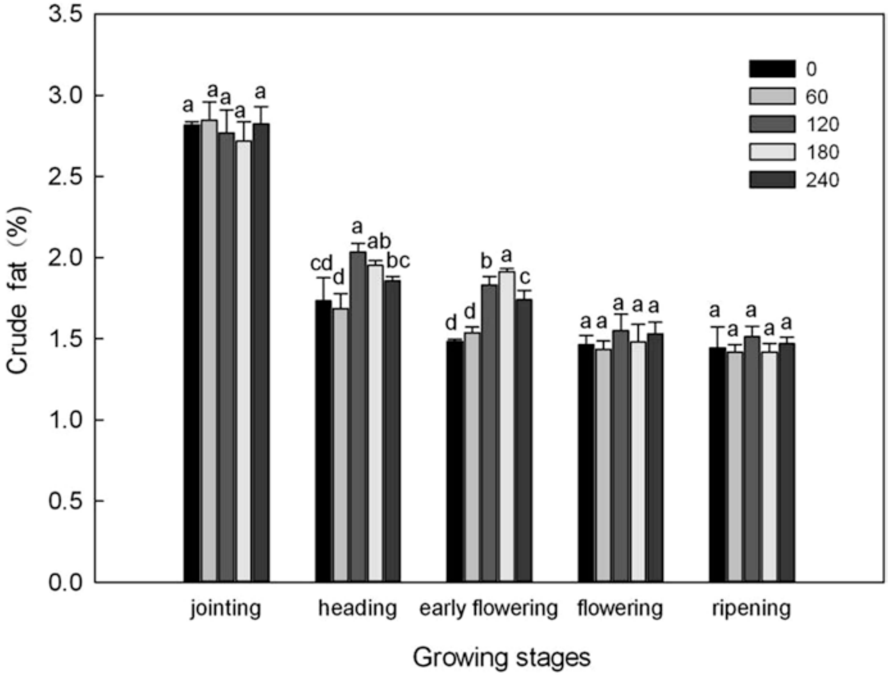

Fig. 1.8 Crude fat content of sheepgrass under different fertilizing rates during different development stages. Note: Different fertilizing rates at the same growth stage are indicated by columns in different colors

sheepgrass, resulting in higher trading volume than other forage crops. In addition, sheepgrass is nutritious and palatable. Therefore, it is necessary to adopt superior varieties for the standardized cultivation and production of sheepgrass. Sheepgrass could be referred to as "the king of forage grasses," since it had become the major component of roughages in the foraging and pasturing in China. However, in the previous production and marketing of natural sheepgrass, green hays contained some of the harmful weeds, such as *Stipa baicalensis* Roshev., *Stipa capillata* L., and wormwood, which greatly reduced the nutritive value and the feeding efficiency of the roughages titled and sold as sheepgrass. As a result, the reputation of sheepgrass has been questioned in animal husbandry.

1.1.10 Domestic and Foreign Demands for Sheepgrass

According to the data obtained from the China's pasture statistics of the National Animal Husbandry Station (Ministry of Agriculture), the production area of sheepgrass in China has been calculated as about 667 thousand ha in total. The "Zhongke" series sheepgrass is entering a larger-area demonstration and promotion in China, covering the provinces of Ningxia, Inner Mongolia, Xinjiang, Hebei, and also Northeastern China. In the next decade, the potential demand of sheepgrass in Northern China is estimated to reach about 30–60 million ha, while the probable international market potential is reckoned to reach 120 million ha. Since 1980, China has begun to export substantial amount of sheepgrass to Japan, South Korea, and other countries, and the export amount of sheepgrass hays from Heilongjiang to Japan had reached 25,600 tons by 1985, with an annual export amount of 4267 tons.

1.1.11 Purpose of Fresh and Dried Sheepgrass

Generally, it is better to feed the animals with fresh sheepgrass, which could be accomplished by directly grazing and forage-feeding. Grazing in the pasture allows fresh sheepgrass to retain more available water and nutrients for livestock. Higher water content makes fresh sheepgrass more palatable and extra supplements to animals. In addition, fresh sheepgrass is comprehensively richer in nutrients. The natural drying of sheepgrass leads to loss of water, but the living plant cells that have not died are still breathing and keep consuming the inherent nutritive matter of sheepgrass in the process. Therefore, considering the nutritive value of feeds, fresh sheepgrass is evidently superior to the dry grass. However, in the practical activities of animal husbandry, the feeding demand goes far beyond the supply of fresh sheepgrass especially during particular seasons, and dried grass presents the advantages obliged in transporting and storage. Therefore, both the dried and fresh sheepgrass in the forage industry as well as the pasture activities should be applied depending on comprehensive consideration. In the past few decades, the haymaking methods and techniques of sheepgrass are relatively well developed, which is substantially significant for grass production and animal husbandry.

1.1.12 Other Value of Sheepgrass

As a high-quality forage crop, sheepgrass may be used for grazing and haymaking. Moreover, sheepgrass is a plant that can be used for environmental restoration. Given that the rhizome of sheepgrass has strong penetration ability, it can form a strong root network that may play important roles in the conservation of water and soil, preventing water loss and soil erosion, which makes it significant for dust prevention and sand fixation. The biodiversity of sheepgrass also has certain ecological value. Prairie soil animals are important parts of the prairie ecosystem, playing important roles in the formation and aging of soil and in the energy conversion and material circulation of the ecosystem. Studies have shown that soil animals in the community of sheepgrass are relatively multifarious, having certain ecological value. Furthermore, the stems of sheepgrass have good value to be used as a source of fiber. In addition, sheepgrass also has certain landscape value. Large area of sheepgrass can show the unique landscape that "sheep and cattle emerge when the wind downs grass" and can make the environment beautiful while using it for environmental restoration.

1.1.13 Usage of Sheepgrass to Prevent Water Loss and Soil Erosion

The root system of sheepgrass is very strong, with well-developed rhizome underground that can hold soil well. The rhizome network of sheepgrass firmly fixes soil; thus soil cannot leave from the root system of sheepgrass easily. In addition, sheepgrass has developed asexual reproduction characteristics. On the prairie, the density of sheepgrass plants is high, thereby avoiding any water loss or soil erosion caused by high wind and other weather conditions to some extent. Arguably, the rhizome characteristics and the growth density enable the sheepgrass plant to effectively hold soil and to prevent water loss and soil erosion (Figs. 1.9, 1.10, and 1.11). Li (2011) found that the application of N, P, and K fertilizer may effectively increase the density of leaves and roots by 1884/m^2 and 11,429/m^2, respectively. The biomass of the aboveground part of sheepgrass in double harvests is 16.84 t/hm^2, while that of the underground part is 5.32 t/hm^2 (Table 1.1).

Fig. 1.9 One seed producing hundreds of tiller buds in 1 year through vegetative propagation

Fig. 1.10 The root network of sheepgrass, including the fibrous root system and the rhizome

Fig. 1.11 Sheepgrass gradually covering the ground surface, preventing soil erosion caused by wind and desertification (relying upon the rhizome and tiller expansion)

Table 1.1 Dry matter weight for the above and underground parts

	Grass weight (aboveground part)			
	Sample 1	Sample 2	Total Weight	Root weight (underground part)
Weight (kg/m^2)	1.084	0.564	1.648	0.564
	1.116	0.58	1.696	0.516
	1.096	0.556	1.652	0.544
	1.124	0.568	1.692	0.528
	1.184	0.556	1.74	0.516
Average weight (kg/m^2)			1.684	0.532

1.1.14 Usage of Sheepgrass for Wind Prevention, Sand Fixation, and Dust Suppression

Sheepgrass mostly grows in arid and sandy areas, and its root system has a sand-sleeve structure. Sand-sleeve structure is a cylindrical sleeve-like structure formed by the agglomeration of sand, which can bond sand. Moreover, the well-developed rhizome system of sheepgrass supports vegetative propagation, with the rhizome sticking out of soil and distributed at random. Planting sheepgrass can effectively reduce soil drifting; however, it would result to having significant differences with varying coverage. The annual average amount of soil drifting of natural pasture on the Bashang Plateau is 37,410 kg per ha; this amount of soil drift is effectively reduced after planting sheepgrass. When the coverage after planting sheepgrass is 20%, 60%, or 100%, the annual amount of soil conservation is 7390.5, 28432.5, or 35,502 kg per ha, respectively. Moreover, the soil holding capacity of *sheepgrass* varies with the soil type. With lower coverage, the soil-holding effect of sheepgrass on loam is greater than that on sandy soil.

1.1.15 Benefits of Sheepgrass Feeding Animals

Studies have shown that the "Zhongke" series sheepgrass is productive, high-quality, and palatable. Given its lower production costs, the market price may be lower than alfalfa. Using "Zhongke" series sheepgrass for feeding cannot only meet the nutritional requirements of livestock but also reduce the production costs. Studies have shown that using "Zhongke" series sheepgrass as a substitute for alfalfa in feeding Tan sheep does not affect the growth and carcass traits of Tan sheep. However, it improves the mutton quality and economic benefits of Tan sheep. The artificial rumen fermentation results of sheepgrass and its combination diets have shown that the appropriate proportion of sheepgrass is better for producing the combined effect of feedstuffs than oats. Therefore, in the actual production, using sheepgrass instead of oats can improve the feed efficiency and reduce costs. On the other hand, goose has certain ability to use sheepgrass as one of its sources of dietary fiber.

1.2 Morphology and Development of Sheepgrass

1.2.1 Plant Height of Sheepgrass

Under normal circumstances, the aboveground part of sheepgrass has two nodes to four nodes and three nodes to six nodes calculated from the tillering node. Under natural conditions, the reproductive branches of sheepgrass reach the peak value during the period from the flowering stage to the seed maturity stage, and at the moment the spike height is 40–60 cm. At the same time, the height of the adjacent vegetative branch is 20–60 cm. The spike height of some germplasm is over 175 cm, and its vegetative branch height goes beyond 185 cm. For sheepgrass cultivated in a greenhouse, the vegetative branch can grow indefinitely, and it sometimes exceeds 230 cm in length, at least having 18 nodes. For new varieties of the artificially cultivated "Zhongke 1" sheepgrass, the spike height is about 100–160 cm, while the height of the vegetative branch is 60–80 cm under normal cultivation conditions. If mown 3–4 times a year, the plant height is more than 200 cm in total, exhibiting a very high yield as a forage crop (Fig. 1.12).

Fig. 1.12 Plant heights of sheepgrass varying significantly from 41 to 89 cm and to 230 cm

1.2.2 Root System of Sheepgrass

Sheepgrass is a rhizomatous forage crop of the family Poaceae, of which the rhizome is an important reproductive organ (diameter = 2–3 mm) and turns from ivory into yellow and then brown with the extension of the growth stage. The root system of sheepgrass is well-developed. While encountering sheepgrass in the wild, we may try to pull it up. However, uprooting sheepgrass is difficult, which is directly related to the root characteristics of sheepgrass. The root of sheepgrass is prone to producing adventitious roots at the tillering node, forming fibrous roots. Meanwhile, the rhizodermis has more root hairs. The root system of sheepgrass is commonly found 5–20 cm deep in soil, with well-developed underground rhizome. Sheepgrass may utilize rhizome for vegetative reproduction. The rhizomes of two adjacent plants of sheepgrass are occasionally linked together underground, thus forming a dense and compact root network underground. Thus, the sheepgrass plant is hard to uproot. In addition, the fibrous root of sheepgrass has a sand-sleeve structure that can bond the sandy soil. The field sowing was conducted in Chifeng, Inner Mongolia, in July 2016. The sample was taken in May 2017, with one plant of sheepgrass producing 31 tiller buds and has rhizome length of 142 cm (Fig. 1.13a). One seed was potted in Beijing in July 2015, and the root was densely covered with hairs when it was examined in September 2017 (Fig. 1.13b).

1.2.3 Sheepgrass Stem

Sheepgrass stem is upright and cylindrical, with the height of 30–120 cm; it often has two nodes to five nodes, which is similar to bamboo. Sheepgrass is composed of internodes and protruding nodes that are often marked in red. The node on the spike growing on the top of sheepgrass is called the spike internode and is generally the longest; however, the lower stem nodes get shorter. In sheepgrass stem, the vascular bundles are regularly arranged in two circles. The sheepgrass stem is especially

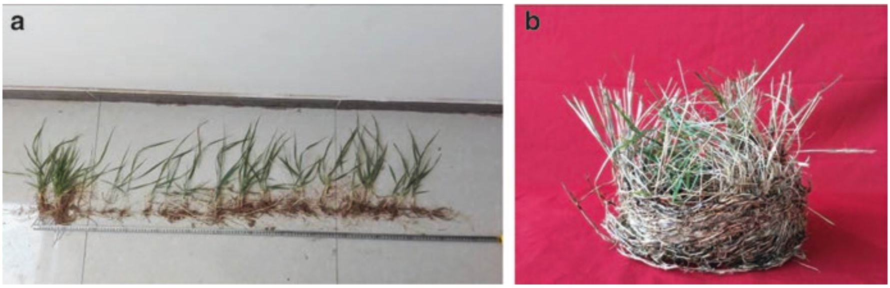

Fig. 1.13 (**a**) Field-planted sheepgrass with the rhizome at full stretch; (**b**) Potted sheepgrass with tangled rhizomes

prone to producing tillering node(s) underground or close to the ground surface, with internode compression enlargement, which is the start site of the tillering of sheepgrass.

1.2.4 Sheepgrass Leaves

The leaf structure of sheepgrass is composed of three parts, namely, blade sheath, ligule, and blade. The leaf sheath surrounding the leaf base acts like a sheath protecting the bud and enhancing the stem support. The leaf sheath of sheepgrass is relatively smooth, and its basal part is fibrous, colored in pale yellow. The ligule is a membranous protrusion at the junction of the blade and the leaf sheath, which can prevent moisture, insects, bacteria, and spores from falling into the sheath. The ligule of sheepgrass is relatively smooth with slits on the top. The leaf blade of sheepgrass is narrow and long, similar to the other members of Poaceae (7–19 cm long and 0.3–0.6 cm wide), and is flat or curly inward, with thick and hard texture. The upper surface is rough, while the lower surface is smooth. The leaf blade is usually gray-green or yellow-green, which is related to the size of waxy matter on the blade surface. The siliconized cells of leaf epidermis of some sheepgrass resources have bristles and small thorns produced on the blade edge, with a discernible sense of touching on the blade surface (Fig. 1.14).

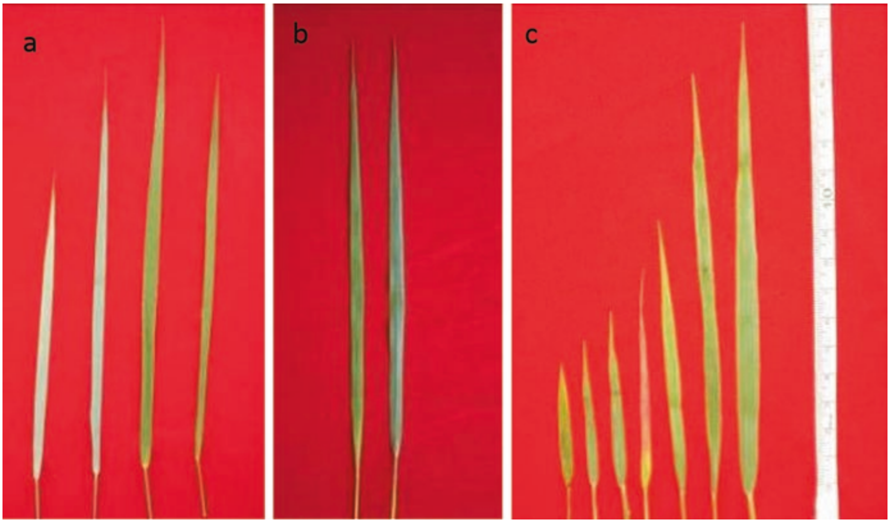

Fig. 1.14 (**a**) Front blade surface with more wax on the left and less on the right; (**b**) Rear blade surface, with less wax on the left and more on the right; (**c**) The flag leaf is very different