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Research Progress on Forage Production, Processing and Utilization in China

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Introduction

China is the largest forage consumption country in the world. Every year, more than 2 billion herbivorous livestock need more than 350 million tons of forage, but the supply each year is only 250 million tons at present. There is a huge gap in forage supply and great contradiction between grass and livestock. The domestic forage is low quality and has safety problems, resulting in poor animal production performance. The degree of localization of forage processing machinery and equipment is low, and more than 80% protein feed relies on import; the market share of cultivated forage species is not high, and independent innovation and transformation capabilities of scientific research achievements need to be further improved. Due to these factors, the forage industry in China cannot be developed in a healthy way for a long time.

The No.1 documents released by the Central Government in 2015–2017 emphasized "speeding up the development of grassland and animal husbandry and strengthening coordinated development of the ternary planting structure of grain, cash crops and forage materials," "optimizing livestock and poultry breeding structure and developing herbivorous animal husbandry," and "vigorously fostering the modern forage industry system"; in 2018, it also proposed to "implement the rural revitalization strategy" so as to improve the quality of agricultural supply. In addition, for the purpose of accelerating agricultural supply-side structural reform, the Ministry of Agriculture and Rural Affairs has carried out the conversion of grain to feed in the border area of Inner Mongolia Autonomous Region and the main maize production area beside the Yellow Sea and Huaihai Sea. At the same time, whole plant silage maize has been promoted, and a new agricultural relationship has been developed with the combination of planting and breeding and a balance between grain and grass, which effectively strengthened the development of herbivorous animal husbandry and increased the income of farmers and herdsmen.

With the policy and financial support of the Central Government, the forage industry in China has been developed rapidly, great progress has been made in the science and technology in forage production, processing, and utilization, and its influence has been increased in the world. In order to promote international exchange and cooperation between forage practitioners and scientific workers, widely publicize the achievements of forage development, and further enhance its international impacts, the author compiled this book by mobilizing all the research forces in the field of forage grass in China and under the leadership of China Agricultural University, Lanzhou University, and Sichuan Academy of Grassland Sciences with the support of other related universities and research institutes.

This book is the first book on forage science written in English in China. It is composed of 11 chapters which systematically introduce the latest achievements in scientific research and technological application of the forage industry in China and also covers the laws and polices related to forage production. Due to the limited knowledge of the author, there might be mistakes and flaws in this book, please do not hesitate to point out for correction in reprinting.

Beijing, China Fuyu Yang

Contents

Chapter 1
The History of Forage Industry Development in China

Qizhong Sun, Ya Tao, and Yukun Sun

Forage has played an important role in the origin and development of China's primitive animal husbandry and agriculture (Guo 1930; Jian 1946). *Liu Tao Bao Tao Niao Yun Ze Bing* (Jiang 2016) states that "The three-armed forces are unprepared, cattle and horses have no feed, and soldiers have no grain. In this case, just cheat the enemy and withdraw the troop rapidly." This shows that forage and food are equally important and are considered military supplies similar to cattle and horses. In ancient China, many techniques and methods for processing and utilizing forage were invented, and some techniques are still in use today. China is also the first country to cultivate *Medicago sativa*, which was first cultivated in the Han Dynasty and has a history of cultivation and utilization for more than 2000 years (Sun, *Medicago sativa* Classic 2016, *Medicago sativa* Investigation 2018; Brief History Draft of *Medicago sativa* 2020).

1.1 Origin and Development of Forage Cultivation in China

1.1.1 Germination and Utilization of Forage in the Primitive Society

1.1.1.1 Motivation for Forage Cultivation in the Primitive Society

Lewis Henry Morgan (1818–1881) (Fig. 1.1) pointed out in *Ancient Society* (Morgan 1971) that plants were originally cultivated because of the need of raising livestock: "At the beginning of gardening, it seems that it was not so much to meet the needs of human beings but rather to meet the needs of livestock."

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Fig. 1.1 Morgan (Lewis Henry Morgan)

In *Introduction to Ancient Chinese Society*, Guo (1930) highlighted (Fig. 1.2) that the transition from a primitive clan society to one of slavery in China must have been started with the discovery of livestock and ended with the development of agriculture. Humans discovered livestock through fishing and hunting; because livestock breeding was flourishing, there had been a panic over the shortage of forage. This panic led to the cultivation of fodder grass (forage for cattle and horses). The cultivation of grains was further developed based on the cultivation of fodder grass. Li (1962), who wrote the *Economic History Draft of Pre-Qin and Han Dynasties* (Fig. 1.3), believed that "because of the increasing number of livestock raised in the era of herding livestock, the need for fodder grass had become more and more urgent. Initially, people lived near water bodies and grass areas (i.e., nomadism); however, eventually, they were concerned about insufficient fodder grass even living a nomadic life. Therefore, they began to manually enclose regions and cultivate fodder grass.

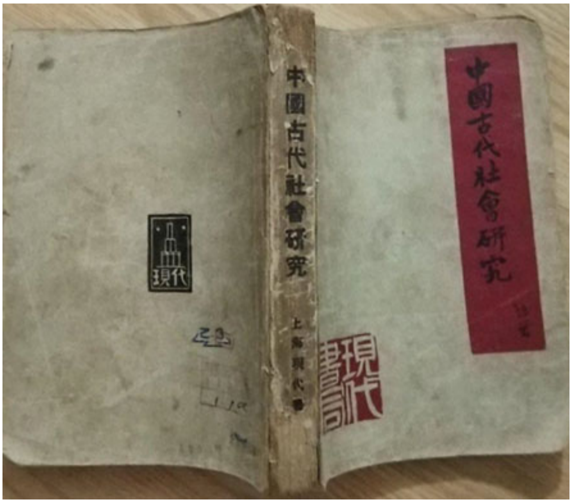

Fig. 1.2 Research on ancient Chinese society

Fig. 1.3 Economic history draft of Pre-Qin and Han Dynasties

Discovering grains for human food through cultivating wild fodder grass is also a possible origin of agriculture."

Initially, when animal husbandry was introduced, weeds were the only source of livestock forage; therefore, most pastoral nomads lived near water bodies. As a result, nomads migrated frequently, which was very inconvenient. Ancient herders gradually adopted the requirement of settling down and planting forage. After they settled down and the livestock had consumed all the surrounding forage, herders had to address the forage problem, particularly the shortage of forage in winter (Hidetoshi 1991). Initially, forage was cultivated by encircling a certain area of land and cultivating wild plants to be used as forage. Thus, during this process, grains suitable as human foods were discovered (Zhang and Zhu 1986). Huang (1963) highlighted that raising livestock required a large amount of forage. However, the amount of wild forage was limited and was particularly scarce in winter, so it was necessary to accumulate and store it. Following the accidental discovery that new forage grew where it was accumulated and stored, people eventually thought of the idea to plant forage, and the knowledge of planting was gradually acquired through observation and imitation. This is perhaps the embryo of arboriculture and grain agriculture. Shi (1953) also believed that the livestock's demand for forage is far greater than a human's demand for grain, thus necessitating forage accumulation and storage, especially in winter when grass is scarce.

During the nomadic era in prehistoric times, people grazed everywhere and originally did not need to cultivate forage. Forage cultivation emerged because of the gradual population growth of humans and proliferation of livestock thereafter. In order to avoid the restrictions of local natural environments, people might have gradually migrated away from the warm zone and toward the north where the climate is characterized by four distinct seasons. With great temperature differences between the summer and winter seasons, grass grew abundantly in the spring, summer, and autumn but withered everywhere in the winter, during which livestock were in danger of running out of food. In response to this, forage cultivation emerged (Wang 1975).

1.1.1.2 Cereal Forage Cultivation in Primitive Society

Millet is one of the oldest cultivated plants in China. It was cultivated in the Yellow River valley as early as 7000–8000 years ago. It was gradually cultivated from its wild type, *Setaria viridis*. Millet seeds were also unearthed from Banpo, Xi'an (Song et al. 1983). Approximately, 7000–8000 years ago, raising livestock was popular among the agricultural tribes in the Yellow River Basin. This is consistent with the time of planting millet in this area, which suggests that millet was used as food for both humans and livestock in the cultivation process, and undoubtedly, at least the stems and leaves of the grains served as very good forage sources. Li et al. (1979) believed that it took a very long time for *Setaria viridis* to evolve to the cultivated millet varieties (Huang et al. 1982), during which it was possibly used as forage for livestock because the branches and leaves of millet have been very good forage up until the present.

1.1.2 Forage Cultivation and Utilization in the Xia, Shang, and Western Zhou Dynasties

1.1.2.1 Xia and Shang Dynasties

China transitioned from a primitive society to a slave society in the twenty-first century BC and successively established three slavery dynasties: the Xia Dynasty (approximately 21st to seventeenth century BC), Shang Dynasty (approximately 17th to eleventh century BC), and Zhou Dynasty (approximately eleventh century to 256 BC). Animal husbandry in China was mostly developed during the Xia, Shang, and Western Zhou Dynasties (Guo 1976).

Shang Shu Duo Tu (2012) states that "Our ancestors in Yin kept books and records." The original Chinese character for field (Tian) does not mean a field where rice, millet, glutinous millet, or wheat was cultivated later but rather a field where forage was cultivated for grazing and hunting. Zhang pointed out that plants such as grass, millet, and glutinous millet, which were originally cultivated in the fields, were used as forage, and it was very common for horses to consume grains in the slave society. Abundant grass and weeds attracted animals to the fields, which was convenient for hunting. Therefore, planting forage at that time could not only increase forage but also facilitate hunting. Before the Yin Dynasty, the character "You" referred to an area of land enclosed for cultivating forage or planting fruit trees. According to its glyph, it can be inferred that wild birds and beasts could easily breed in places with abundant vegetation. Therefore, enclosed grazing land can be used for grazing, obtaining forage, and hunting (Li 1962).

The final years of the Yin Dynasty accounted for the most developed period of livestock husbandry and the period when agriculture emerged. Guo (1930) pointed out that “with increasingly prosperous livestock, the forage for livestock inevitably became a problem; this presented the main opportunity for agriculture to emerge. At the time when livestock husbandry was invented, the forage for livestock possibly only depended on natural weeds; thus, people lived near water bodies and grass areas at that time, and the development of ancient nationalities mostly went down along rivers. However, when the quantity of livestock was too high, and natural weeds were no longer sufficient. However, repeated migration was troublesome, so herders at that time gradually began to grow forage.” Therefore, to develop cattle husbandry, in addition to grazing cattle in the wild in the summer and autumn when grass flourished, people in the Yin Dynasty ensured sufficient forage supply in all seasons by specifically cultivating forage on their farms to graze cattle thereon or to obtain the forage needed in winter.

Besides grazing livestock on it, the planted forage needed to be reaped frequently to be transported to corrals, where forage was stored and transported during winter when grazing was impossible, and forage was particularly important. In oracle inscriptions from the Shang Dynasty, “Qiang Chu” refers to those who cut grass and fed horses (Xie 1959). In the period of indoor feeding, in addition to a considerable amount of roughage such as dried reaped grass, it was necessary to supplement some concentrated feed, such as grain. The characters “Lao, Xin, Jia, and Jiu” on oracle bones indicate that livestock were fed indoors at that time. In addition, emperors and nobles had gorgeous livestock houses, and even their dogs and horses were decorated with brocade, which showed that the improvement of the level of feeding management was already emphasized in ancient times. “Chu” refers to forage that has been reaped and processed, and “Mo” refers to concentrated feed. Millet and soya (beans) were the main forage (Xie 1986).

1.1.2.2 Western Zhou Dynasty

Although the prosperity was mainly because of agriculture, animal husbandry was still very important in the economic life of the Western Zhou Dynasty, and new progress was made in raising livestock. Common livestock and poultry included horses, cattle, sheep, dogs, pigs, chicken, geese, and ducks. Livestock and poultry were housed in livestock and poultry houses. In *Shi Jing Da Ya Gong Liu* (2015), “Zhi Shi Yu Lao” means “tying pigs in pigpens and feeding them with reaped grass,” and “Lao” is a barn for captive livestock, so there were houses for pigs. Horse stables were called “Jiu” (e.g., “Cheng Ma Zai Jiu (keeping carriage horses in stables)” in *Shi Jing Xiao Ya Yuan Yang*, etc.). All of these characters reflect the practice of captive breeding in the Western Zhou Dynasty. Captive breeding was bound to promote forage production.

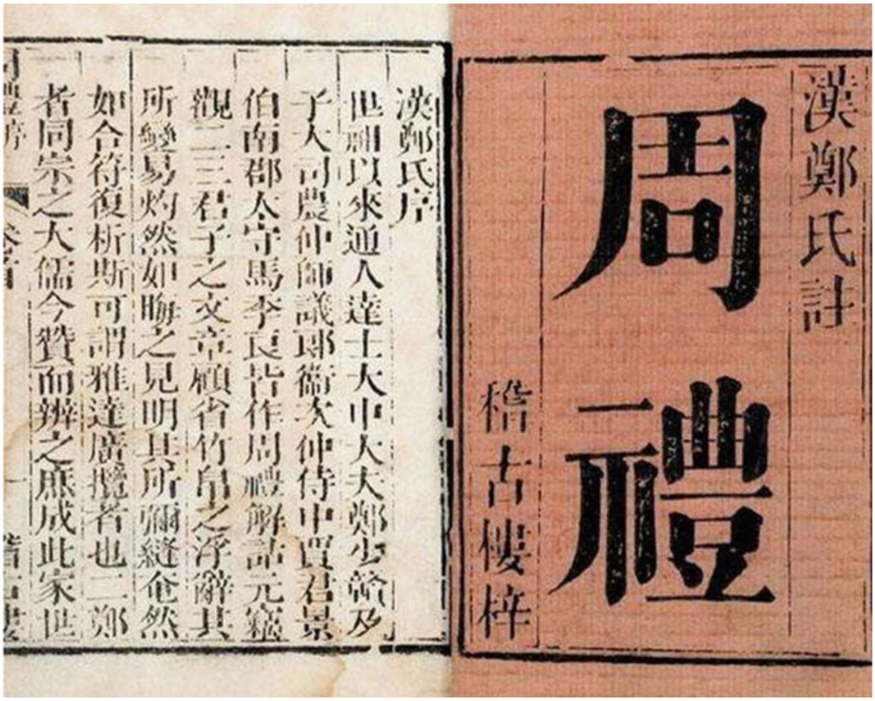

Fig. 1.4 Zhou Li

Zheng (1936) stated in *Zhou Li Tian Guan Da Zai* (Fig. 1.4) that “There are nine ways to save money and supplies… the seventh way is Chu Mo.” Zheng Xuan annotated that “Chu Mo refers to grains for raising cattle and horses.” Thus, in China, the practice of feeding grains to horses originated during very ancient times.

In *Zhou Li Xia Guan Yu Shi*, it has been stated that the word “Yu Shi,” meaning a person in charge of raising and grazing horses, is also used to refer to a horse keeper in general terms. For example, “Yu Shi teaches people to raise horses; specifically by removing their straw mattress, smearing their blood on the newly-built stable, and starting to graze them in the spring; cooling them in a semi-open house in the summer; and offering them as tribute in the winter. Their skin can be used to enhance the quality of the target for shooting and cut to seal the walls of thatched huts.” Here, grazing should have occurred in the spring and summer and stabling in autumn and winter; there were straw mattresses in the stables, so they should have be cleaned out when grazing began in the spring. Indoor raising required the supply of forage, and forage needed to be chopped, implying a requirement of iron cutting boards.

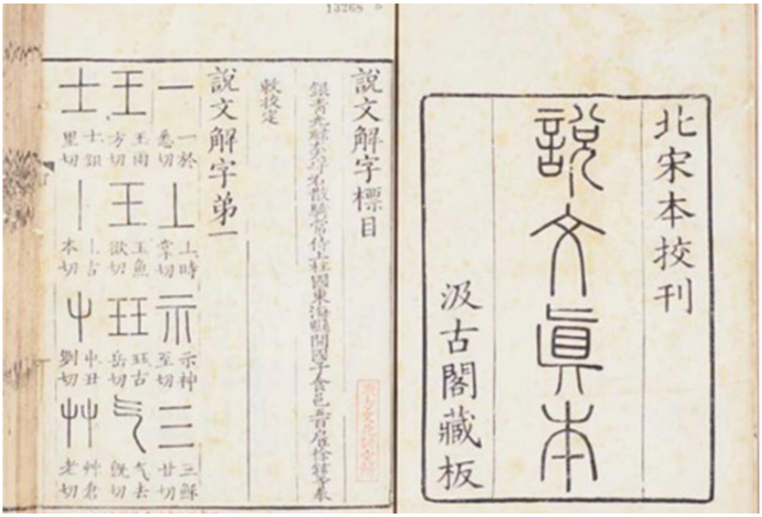

Fig. 1.5 Shuo Wen Jie Zi

1.1.3 Forage Cultivation and Utilization During the Spring and Autumn Period and Warring States Period

1.1.3.1 Early Spring and Autumn Period and Warring States Period

During the Spring and Autumn Period and the Warring States Period, with the development of animal husbandry, forage planting and utilization also developed to some extent. Xu (2013) has stated in *Shuo Wen Jie Zi* (Fig. 1.5) that "Chu means raising cattle with reaped straw." In ancient times, millet and soya (beans) were used as the main concentrated feed, which were collectively called "Mo." Millet is a feed with high carbohydrate content, whereas beans are rich in proteins. The rational combination of carbohydrate and protein feeds, as well as roughage and concentrated feeds, shows that China had a relatively scientific feeding technology before the Spring and Autumn Period and the Warring States Period. After entering the Spring and Autumn Period and the Warring States Period, farmers raised cattle not to produce milk and meat but to pull carts and cultivate fields. Vegetable fields were gradually utilized as farmlands; thus, the forage for cattle also began to change: from grass, dry reaped straw, and cowpea to grain by-products, such as stalks and chaff.

1.1.3.2 Late Spring and Autumn Period and Warring States Period and Early Qin Dynasty

After the reform of the Qin State by Shang Yang, farmers had to pay a fixed amount of tax every year according to the number of fields granted, including He Jia (grains), Chu (forage), and Mo (crop stalks). The Qin bamboo slips unearthed from the Qin Tombs in Shuihudi, Yunmeng County, Hubei Province are the writings of the Qin State and Qin Dynasty, and there are many records of "Chu Gao." "[The tax payer] enters and pours in the Chu and Gao, with the amount based on the area of fields he is granted and whether they are cultivated or not; he pours in three dan of Chu and three dan of Gao" (Bamboo slips sorting group of Qin Tombs in Shuihudi 1978a, b). The bamboo slips sorting group of Qin Tombs in Shuihudi (1978a, b) explained that "Chu means forage, and Gao means crop stalks. Bamboo slips and ancient books often use the word 'Chu Gao.'" *Qin Lyu Cang Lyu* (bamboo slips sorting group of Qin Tombs in Shuihudi, 1978a, b) also stipulates that "Once He Jia, Chu, and Gao enter the granary, records should be noted in the granary registry, and these should be reported to Nei Shi" (Yang 2003).

In *Qi Guo Kao* (Fig. 1.6), Ming also recorded the cattle fields and vegetable fields in the Qin State: "*Guo Ce* states that in the Qin State, cattle are used to plough the farm, and water channels are used for transporting grains," and "a person who is granted 300 vegetable fields is called Guo Lao." To strengthen the management of forage fields, the Lu state specially set up the official position of Cheng Tian in the Spring and Autumn Period to take charge of the livestock. *Shi Ji Tian Guan Shu* (Sima 2006a, b) states that "Wei is the heavenly warehouse, and its southern stars are forage warehouses." In *Shi Ji Ji Jie*, Pei Yin cited Ru Chun's words: "Chu Gao are accumulated to form a granary." Zhang Shoujie explained that "the six stars of Chu Gao are to the west of Tianyuan and govern the accumulation of Gao grass."

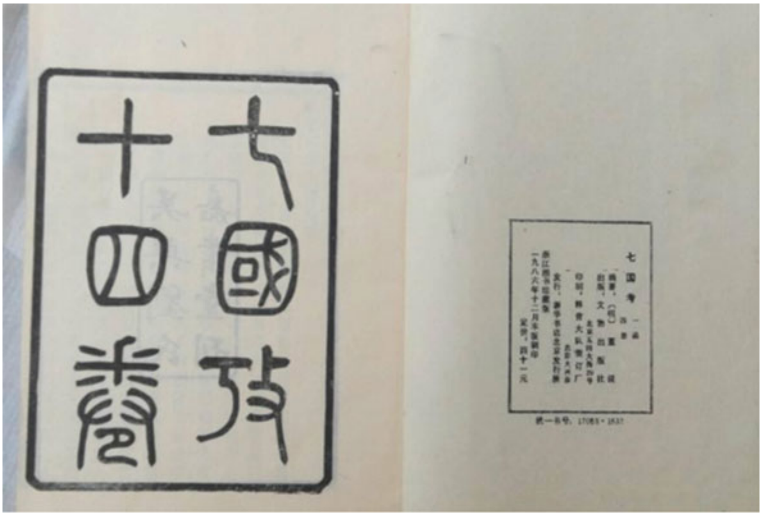

Fig. 1.6 Qi Guo Kao

1.2 Forage Processing and Preparation Technology in Ancient China

1.2.1 Overview of Forage Processing and Preparation Technology

The ancient Chinese laboring people were aware of the importance of forage preparation. They had long known that forage preparation can improve its nutritional value and invented seven types of forage preparation methods: (1) sun exposure; (2) fermentation; (3) cutting and chopping; (4) grinding, crushing, and mashing; (5) sieving, winnowing, and sifting; (6) steaming and boiling; and (7) mixing (Table 1.1). These processing and preparation methods still occupy a considerable position in modern livestock breeding science.

Table 1.1 List of forage processing and preparation techniques in ancient China

Preparation approach	Forage to be prepared	Characteristics of preparation method	Livestock suitable for feeding
Sun exposure	Green hay, i.e., *Medicago sativa*, dried in the wild	Sun drying	Sheep, cattle, donkeys, and pigs
Fermentation	*Portulaca oleracea* and *M. sativa*	Fermentation by microorganisms	Pigs, cattle, horses, and sheep
Cut, chop, shear, and slice	Hay, straw, and bean stalks	Cut and chop with a knife and hay cutter	Cattle, sheep, horses, mules, donkeys, chickens, and ducks
Grind, scrunch, crush, and mash	Grain, beans, dried leaves, and salt	Crush or scrunch with heavy objects such as stone mill, stone muller, and stone roller or mash with a pestle	Cattle, pigs, and chickens
Sieve, winnow, and sift	Hay and grain beans	Use bamboo utensils to winnow out stones and soil	Horses
Steam and boil	Grain beans, oak, chestnut, wild vegetables, *M. sativa*, duckweed, melon, amaranth, potato, taro, leaves of paper mulberry, elm and catalpa, wheat, barley, and rice	Boil in water and heat with steam	Pigs, horses, cattle, chickens, and geese
Mix	Grass and fodder (grain beans)	Mix with water or draff water or dry mix	Cattle, sheep, chicken, and pigs

Fig. 1.7 **a** Jia Sixie, **b** *Qi Min Yao Shu*

1.2.2 Hay Preparation Technology

The sun drying and exposure technique involves using sunlight to dry and expose the feed to make it convenient for storage. *Medicago sativa* hay, wild hay, and various leaves must be dried before storage. Jia and Qi (1936) (Fig. 1.7a) recorded in *Qi Min Yao Shu* (Fig. 1.7b) that *M. sativa* hay and soybean hay can be used to feed cattle, sheep, and donkeys. *M. sativa* hay powder is used to feed pigs, and it needs to be sun-dried before grinding. The grass must also be exposed to the sun to prevent it from decaying. This step allows forage to be stored for a long time without spoiling. In particular, the method of drying and grinding *M. sativa* into hay powder is an important invention of the laboring people in China 600 years ago. This is the best supplementary feed for young livestock such as calves, piglets, lambs, foals, and chicks in the winter. Western countries produce more than one million tons of *M. sativa* hay powder every year, which is used to feed chickens, pigs, calves, horses, and mules as supplementary forage for vitamins. In the future, China can also summarize the advanced experience of the ancient laboring people in China and develop this feed industry to meet the needs of developing animal husbandry in China.

1.2.3 Fresh Grass Storage Technology

The fermentation or green forage fermentation method is a method for preparing forage that was invented by the laboring people in China more than 600 years ago, which is especially suitable for raising pigs. During the fermentation process, many fermentation bacteria are propagated in the forage, which produce many bacterial proteins and improve the nutritional value of the forage. In addition, the fermented forage is slightly fragrant and sour. It is helpful to improve the flavor and palatability of the forage. In ancient China, the green forage fermentation method was described as early as in the Yuan Dynasty's *Wang Zhen Nong Shu* (1912) (Fig. 1.8) more than 700 years ago. The content is as follows: "The land to the north of the Yangtze

Fig. 1.8 Wang Zhen Nong Shu

River can be used to plant *Portulaca oleracea,* … reap them, … chop them, and soak them in big tanks with fermented grains to make them sour and yellow or mix them with bran to feed [pigs].” More than 200 years ago, Yang (1960) in the Qing Dynasty summarized the advanced experience of the laboring people at that time and introduced the method of fermentation with *M. sativa.* Specifically, this process involved cutting the planted *M. sativa*, putting it into a cellar with rice swill or distiller’s grains and bean flour, making it sour and yellow, mixing it with bran and sundries, and feeding it to the pigs. At present, fermented green forage is widely used to feed pigs in Shaanxi, Shandong, and Northeast China, and good growth and development have been obtained. Forage fermentation invented in the Yuan Dynasty more than 700 years ago, which is the rudiment of modern silage technology, has played an important role and been widely used in preparing all types forage.

1.2.4 Forage Cutting Technology

In the Western Zhou Dynasty, forage was already processed before utilization, and livestock farming had reached a refined level, which was mainly reflected in the fine processing of forage and the matched feeding of forage materials. Because this can reasonably provide all types of nutrients required by domestic animals, a special grassland was used in the Zhou Dynasty to reap straw for domestic animals. When used for feeding, the forage must be first chopped, and concentrated materials such as corn should be added. For example, *Shi Jing Xiao Ya Yuan Yang* states that "For carriage horses raised in stables, chop the forage." The character "Cui" is the same as "Cuo." *Shuo Wen Jie Zi* (2013) states that "Cuo means chopping forage. Chop the forage. The chopped forage is Cuo. Cuo is used to feed horses." This shows that in the early Western Zhou Dynasty, roughage (i.e., forage) was generally used to feed horses; however, concentrated feeds were used as well. Forage processing in China had already begun at least in the Western Zhou Dynasty. Duan (1981) in the Qing Dynasty stated in *Shuo Wen Jie Zi Zhu* that "Mo means the grains used to feed horses. Horses are fed with grains." In addition, Zhou Nanchuan quoted that "Mo means feeding."

Qi Min Yao Shu (1936) first introduced feeding horses with Cuo Chu (green straw chopped to a shorter length). *San Nong Ji* (1986) also mentioned that "every grass should choose new grass and be fine." Regarding feeding cattle, the appropriate article on animal husbandry and service in *Chen Fu Nong Shu* (1981) pointed out that "clean grass should be taken and chopped into fine pieces." There is an example of "chopping bean stalks into pieces" and feeding them to cattle in Nong Sang Jing (1982). The grazing method was generally adopted for raising sheep, and finely cut straw was used only when fattening the sheep by indoor raising. Chopping was also used when pigs were fed with green forage, such as *Portulaca oleracea* or green *M. sativa*. Forage was easier to digest after chopping to become finer and shorter. The utilization efficiency of forage could also be improved.

1.2.5 Crushing Technology

This method involves crushing forage by using heavy objects and passing it through moving machines. The heavy objects used included grinders, treadmills (Fig. 1.9),

Fig. 1.9 Roller

wheels, pestles (Fig. 1.10), etc., which made the forage easy to digest after crushing or breaking it and could improve the utilization rate of the forage. Chen (1981) pointed out in *Mu Yang Yi Yong Zhi Yi Pian* that "beans can still be crushed" (1957). *Nong Pu Bian Lan* suggested that when farming cattle, one should "grind one sheng of beans for each and mix them with grass for feeding." There are also records of crushing beans, paper mulberry, mulberry, cudrania, and potato leaves and feeding them to cattle. When fattening sheep, the beans should be ground before feeding. When storing winter forage for pigs and preparing *M. sativa* hay powder, we can grind dried *M. sativa* into fine powder to fatten the pigs. *Qi Min Yao Shu Vol. 6, Pig Raising* (1936) states "Take three sheng of castor beans, pound them with a pestle more than one thousand times, cook them into soup, add one sheng of salt, mix in three hu of bran, and feed it to the pigs, which will make them become fat." If buckwheat leaves are used to feed pigs, they must also be mashed into fine powder and then fed with bran, lees, and swill. When chickens are fed with meat bones, the meat bones must be crushed before feeding. To feed the chickens with grains and glutinous rice, they must be ground into flour and mixed with wheat bran and cooked *M. sativa* before feeding. This kind of preparation method can be used to prepare bean forage and grain forage. When feeding cattle, sheep, pigs, and poultry, this method can be used to prepare grains and beans.

Cleaning techniques include screening, winnowing, and sifting. Screening is the same as sifting (Fig. 1.11), which implies that "the coarse material can be removed, and the fine material can be obtained using bamboo utensils." Winnowing means "winnowing rice from chaff." Screening and winnowing can remove stone and soil impurities and coarse grass knots from the forage, making it more digestible. It has been particularly highlighted in *Xin Ke Ma Shu* (1981) that "every grass should choose fresh grass to be fine and sift out stone and soil," and then, it can be fed to horses. Whether feeding horses with grass or materials, the materials must be screened and

Fig. 1.10 Cleaning technology

Fig. 1.11 Screening

winnowed to remove stones, soil, ash, and sand. Horses are often prone to indigestion and hernias due to the consumption of unclean forage. Therefore, attention must be particularly paid to the cleanliness of forage.

1.2.6 Maturation Technology

Ripening techniques include boiling and steaming. The purpose of cooking forage is to make it soft and easy to chew and to change the properties of the protein and starch for easier digestion. Yang (1960) stated in *Bin Feng Guang Yi* (Fig. 1.12) that young pigs and lambs should be fed with cooked grain. Supplemented cereals are difficult for young pigs to digest if they are not cooked. It is common to feed pigs and poultry and to prepare forage by cooking it. According to the records of San Nong Ji by Zhang (1989) in the Qing Dynasty, oaks, young leaves, and wild vegetables collected from mountainous areas must be cooked and then fed to pigs ("boiled to feed them"). When feeding chickens with *M. sativa*, the *M. sativa* must be chopped, boiled, and steamed before feeding. Chickens and ducks that have just hatched must also be fed with cooked wheat or millet.


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Fig. 1.12 Bin Feng Guang Yi

1.2.7 Forage Mixing Technology

Forage mixing usually involves combining grass with other materials and can be classified into two types: wet mixing and dry mixing. Wet mixing refers to combining grass and materials with water. In the Yuan Dynasty, Sinong quoted in *Nong Sang Ji Yao* Han's direct introduction to the method of mixing forage for feeding cattle. The description reads as follows: "After [the cattle] finish drinking and come to the trough, mix forage with water in three portions. For the first portion, use more grass and less forage. For the second portion, use half of the grass used the first portion. For the third portion, use half of the grass used in the second portion. All forage is then mixed. After the cattle eat up the feed, harness these animals for plowing." Water-mixed forage has two functions. The first is to improve the palatability of grass. The palatability of the mixed forage is usually good. Generally, the palatability of grass, particularly of the stalk, and hay is poor. Mixing good ingredients with grass can improve the palatability of the grass. The second function is to lure cattle to eat more grass. Cattle need food and grass; however, if you provide the feed first and then the grass or if you do not mix the grass with feed, cows will not be interested in eating the grass after feed consumption. The dry mixing method was recorded in *Bin Feng Guang Yi Vol. 3* (1960): Mix *M. sativa* hay powder with bran when feeding pigs in the winter, and stir fried soybean and fried chicory into fine material for fattening pigs. When raising chickens by feeding *M. sativa*, the feed can be mixed with wheat bran, minced flour, glutinous rice flour, or millet beans. Mixing forage in this manner serves mainly to diversify the forage in the diet to improve its palatability. The above-mentioned forage mixing method is a feeding method to ensure that cattle eats more forage.

1.3 Cultivation and Research of M. Sativa in Ancient China

1.3.1 Origin of M. Sativa

1.3.1.1 Background of the Introduction of M. Sativa into the Han Dynasty

At the beginning of the Western Han Dynasty, Liu Bang, Emperor Gaozu of the Han Dynasty, attacked the Huns and was besieged by the Huns in Baideng. The war between the Han Dynasty and the Huns ended with the defeat of the Han Dynasty. Afterward, the Han Dynasty was defensive when dealing with their relationship with the Huns in the north. After the rule of Emperors Wen and Jing and during the rule of Emperor Wu, the Han Dynasty society consensually decided to defeat the Huns by force and to maintain the security of the northern border. To deal with the Huns, Emperor Wu of the Han Dynasty planned to join forces with Yuezhi and Wusun in the Western Regions; thus, he sent Zhang Qian to the Western Regions (Fig. 1.13). Zhang Qian went to these regions twice, in the third year of Jian Yuan (138 BC) and the fourth year of Yuan Shou (119 BC), and returned to Chang'an in the third year of Yuan Shuo (126 BC) and the second year of Yuan Ding (115 BC), respectively. Although Zhang Qian's two missions failed to achieve the goal, he objectively understood the customs, social economy, and ecological environment of the Western Regions and Central Asian countries, opened up the Silk Road, and strengthened the ties between China and foreign countries (Sun 2020).

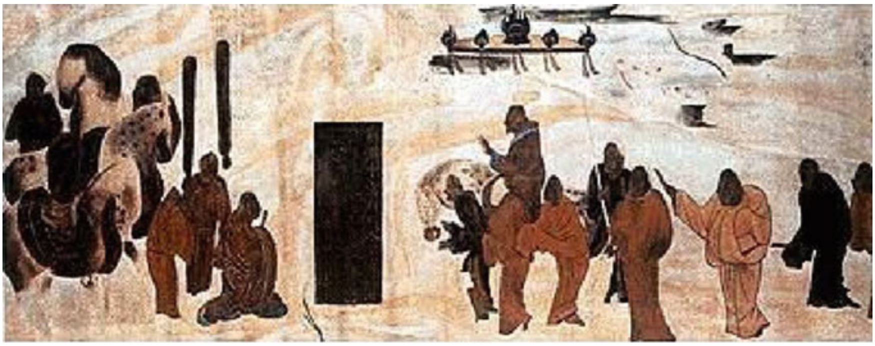


Fig. 1.13 Zhang Qian's mission to the Western Regions (Dunhuang frescoes)

1.3.1.2 Introduction of M. Sativa into the Han Dynasty

M. sativa cultivation in China began in the Han Dynasty, i.e., in 126 BC (the third year of Yuanshuo). The Han envoys sent to the Western Regions by Emperor Wu of the Han Dynasty (Fig. 1.14) brought in *M. sativa* seeds (Sun 2018). According to *Shi Ji Da Wan Lie Zhuan* by Sima (1933) (Fig. 1.15a), "Grapes were used to make wine in Wan, and the rich kept more than 10,000 shi of wine. Wine can be stored for dozens of years. Common people are addicted to alcohol, while horses are addicted to *Medicago sativa.* The Han envoys brought back their fruits. Then, the emperor started planting *Medicago sativa* and grapes to make the lands fertile. The Tianma horses (prized horses) multiplied, and foreign envoys came. When people left the palace, they got an eyeful of grapes and *Medicago sativa* planted all around." Ban (2007) recorded in *Han Shu Xi Yu Zhuan* (Fig. 1.15b) that "The Han envoys brought back seeds of grapes and *Medicago sativa.* The Emperor owned many Tianma horses. Many foreign envoys visited and got an eyeful of the grapes and *Medicago sativa* planted around the palace."

Fig. 1.14 Emperor Wu of the Han Dynasty, who first advocated the planting of *Medicago sativa*

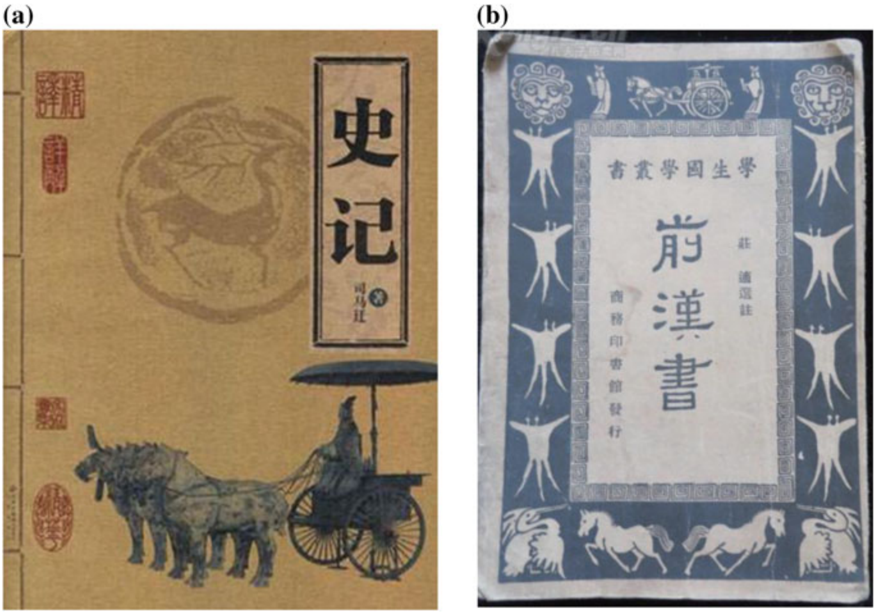


Fig. 1.15 **a** Shi Ji. **b** Qian Han Shu. The earliest history books recording *Medicago sativa*

1.3.2 Cultivation and Utilization of M. Sativa in Ancient Times

1.3.2.1 The Han Dynasty to the Wei, Jin, Southern, and Northern Dynasties

When *M. sativa* was introduced in China, it was simply a precious plant in the Han Palace garden, mainly used for feeding horses. During the reign of Emperor Wu of the Han Dynasty, Chinese envoys introduced *M. sativa* seeds from the Western Regions and attempted to cultivate them inside the palace in the capital (Chang'an) and was used as feed for horses. Subsequently, *M. sativa* reached the common folk, entire Guanzhong, and then Ningxia and Gansu (Sun, 2016). Yan (1955) pointed out in *Han Shu Xi Yu Zhuan* that "Within the old jurisdiction of Anding in the northern provinces today (referring to the Tang Dynasty), *Medicago sativa* was often found, which was planted in the Han Dynasty." Research has shown that southern Xinjiang and Dawan are connected by roads and have convenient communication. It is likely that *M. sativa* was cultivated in southern Xinjiang during the Han Dynasty. According to the records in Kharosthi books unearthed from the southern margin of Tarim Basin, *M. sativa* was cultivated in southern Xinjiang from the Eastern Han Dynasty to the Wei and Jin Dynasties. According to the bamboo slips unearthed in Loulan, many *M. sativa* plants were planted in the south of Loulan, and these grew vigorously because of convenient irrigation (Sun, 2020).

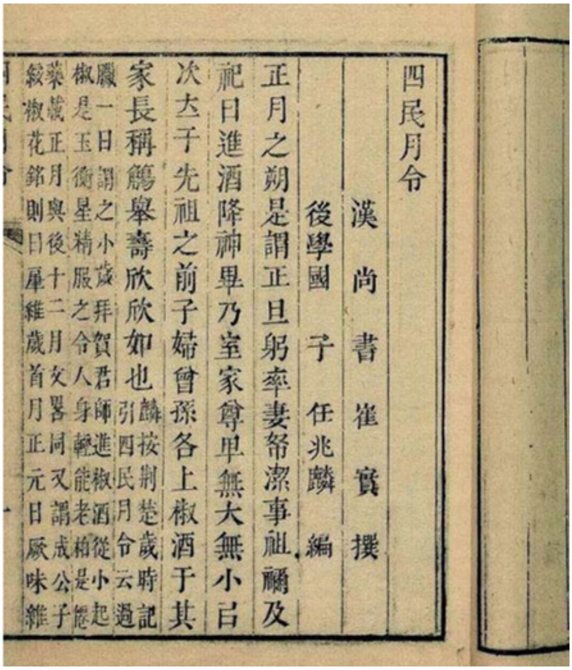

四民月令
漢尚書崔寔撰
後學國子任兆麟編
正月之朔是謂正旦躬率妻帑潔事祖禰及
祀日進酒降神畢乃室家尊卑無大無小
次太子先祖之前子婦曾孫各上椒酒于其
家長稱觴舉壽欣欣如也麟按荊楚歲時記引四民月令云過
臘一日謂之小歲拜賀君師進椒酒從小起椒是玉衡星精服之令人身輕能老栢是㦬
藥歲正月與後十二月文畧同又謂戎公子敘椒花銘則曰肇維歲首月正元日厥味雜

Fig. 1.16 The earliest record of *Medicago sativa* farming activities in *Si Min Yue Ling*

The earliest record of *M. sativa* cultivation techniques is in *Si Min Yue Ling* (Fig. 1.16), written by Cui (1965), which has detailed records of *M. sativa* planting seasons. Except for the first month of the lunar calendar, in the seventh and eighth months, there were *M. sativa* farming activities (sowing); in the fifth, seventh, and eighth months, it can be "reaped as forage." In the Northern Wei Dynasty, Jia and Qi (1936) had a deeper understanding and detailed record of *M. sativa* cultivation and utilization technology in Qi Min Yao Shu: "The land should be cultivated land. Plant it in the seventh month, and irrigate it with water, just like growing chives. Also fertilize the land with manure each time after reaping, harrow the soil, and then irrigate with water…It can be reaped three times a year, and one harvest should be used for obtaining seeds. At the beginning of spring, when it has already grown to medium length, it can be reaped for eating raw or making soup, which has a nice aroma. When it has grown long, it can be fed to horses. Horses are especially fond of it, and those who plant it need to labor only once and harvest the evergreen. It is good to plant it around city walls."

1.3.2.2 Tang and Song Dynasties to Yuan Dynasty

By the Tang Dynasty, *M. sativa* had been widely cultivated. For example, plans were needed for cultivating *M. sativa* for feeding post horses. Xin Tang Shu Bai Guan Zhi (1975) stated that "Every post horse will be assigned four hectares of land for planting *Medicago sativa*." It showed that four hectares of *M. sativa* must be cultivated to feed each post horse. According to Xin Tang Shu Bing Zhi (1975), "The fields in Bafang, 1230 ha, are cultivated by people recruited to produce forage." In this area, 1230 ha were set aside as fields, people were recruited for farming, and their harvest was used exclusively for forage. *Long You Jian Mu Song De Bei* states that "In Long You Pastoral Area, '1900 ha of naked oats and *Medicago sativa* were planted to be dried and stored for use in winter.' These feeds were dried in the sun and cooled, which is called Jiao." "Yi Jiao Xu Yu Dong" means to store dried feed for the needs of the livestock in winter.

The Yuan Dynasty paid even more attention to the cultivation of *M. sativa*. *Yuan Shi Shi Huo Zhi* (1945) states that "In the seventh year of the Yuan Dynasty, the system of agriculture and mulberry was issued, which ordered every community to plant *Medicago sativa* in case of hunger," which was the government's decree on planting *M. sativa*. *Yuan Shi Bai Guan Zhi* (1945) states that "*Medicago sativa* gardens should have three members to be in charge of planting *Medicago sativa* to feed horses, camels, and cattle." In the 23rd year of the Yuan Dynasty (1286), the court formulated a "Tiao Hua," which stipulated that "*Medicago sativa* should be planted with the community. It is not necessary to reap it in the early years, and seeds should be obtained in the next year and should be widely planted (Yuan Dian Zhang, Nong Shang Quan Nong Li She Shi Li)." Most of the Shanglin Department of the left-behind company also had a "*Medicago sativa* garden" for "planting *Medicago sativa* to feed camels and horses," and even had an official for *Medicago sativa* planting to feed camels, horses, and sheep.

1.3.2.3 Ming and Qing Dynasties

M. sativa has been recorded in detail in many classics of the Ming and Qing Dynasties. For example, *Qun Fang Pu* (1985) contains the experience of the mixed sowing of *M. sativa* and buckwheat, taking seeds and buckwheat seeds in the summer, taking root when reaping buckwheat, and self-growing the next year. There is not only the method of mixed sowing *M. sativa* and buckwheat but also the benefit of ensuring a continuous supply. Furthermore, the valuable experience that *M. sativa* can improve soil, can be used as the previous crop, and can be used for planting grain in fertile land has been summarized. This vividly shows that the laboring people in the north have accumulated rich experience in the cultivation and utilization of *M. sativa* in the long-term production practice (Sun 2018).

In the Qing Dynasty, in *Guang Qun Fang Pu*, Wang (1935) also recorded that "It flourished in the three Jin Dynasties, followed by Qin, Qi, and Lu, and followed by Yan and Zhao, whereas people to the south of the Yangtze River did not know it." We can see the distribution of *M. sativa* in China since the former Han Dynasty. *Guang Qun Fang Pu* (1935) instructs "In summer, take the seeds (*Medicago sativa*) and plant them with buckwheat. When reaping buckwheat, *Medicago sativa* takes root. It grows by itself the next year. It can only be reaped once and then three times a year after 3 years. For those who want to store the seeds, skip one reaping. Remove the roots after 6 or 7 years and plant the seeds instead. If the bamboo planting method in Zhejiang area is used, half of the roots in each acre will be removed in the first half of the year, and the other half will be removed in the third year. If you rotate in this way, you can let it grow for a long time and never bother to plant more. If grains are planted the following year after the cultivation, double the harvest will be obtained, because the leaves that accumulated over several years are rotten and thicken the plough layer. Therefore, people in the Three Jin States reap the grass for 3 years, then cultivate the fields as farms, and they are eager to plant grains in the fertile land." In ancient times, the rotation of *M. sativa* and spring grains had become the norm.

In the Qing Dynasty, almost every farm in northwest and northern China planted it. Yang (1963) recorded in Nong Yan Zhu Shi that "In the second month of the year, people were taught to hoe wheat. Those who have a lot of grass in the land should carefully hoe. Hoe *Medicago sativa*, then sometimes hoe rapeseed, lentils, and peas." This is not only the rotation of wheat and *M. sativa* but also the rotation of wheat and rapeseed, lentils, and peas.

1.3.3 Botanical Research on M. Sativa in Ancient Times

1.3.3.1 Study on the Botanical Characteristics of *M. sativa* in the Ming Dynasty

Jiu Huang Ben Cao (Fig. 1.17) by Zhu (1959) in the early Ming Dynasty states that "*Medicago sativa* came out of Shaanxi, and now it is everywhere. The seedlings are more than one chi long, and the thin stems are bifurcated. The leaves are like peas, which are quite small. Every three leaves emerge in one place, with purple flowers and corners. There are seeds in the corners, with the size like a millet and shape like a kidney." This is the profound understanding and description of the *M. sativa* plant morphology in the ancient times.

Wang Xiangjin (1561–1653) was an agronomist in the Ming Dynasty. The characteristics of *M. sativa* plants were described in *Qun Fang Pu* (1985) (Fig. 1.18): "Zhang Qian brought it back. The height of the seedlings is excessive, and the slender stems diverge. The leaves are like peas. Every three leaves emerge in one place, with purple flowers and corners. There are seeds in the corners, with the size like a millet and shape like a kidney. It flourished in the Three Jin Dynasties, followed by Qin, Qi,

Fig. 1.17 Zhu Su (1361–1425) Picture of *Medicago sativa* in *Jiu Huang Ben Cao*. Zhu Su and a picture of *Medicago sativa* in *Jiu Huang Ben Cao*

Fig. 1.18 Qun Fang Pu

and Lu, and followed by Yan and Zhao, while people to the south of the Yangtze River did not know it. In summer, take the seeds (*M. sativa*) and plant them with buckwheat. When reaping buckwheat, *M. sativa* takes root. It grows by itself the next year and can only be reaped once. It flourishes after 3 years and can be reaped three times a year thereafter. For those who want to keep the seeds, skip one reaping. Remove the roots after 6 or 7 years, and plant with the seeds instead. If the bamboo planting method in Zhejiang area is used, half of the roots in each acre will be removed in the first half of the year, and the other half will be removed in the third year. If you rotate in this way, you can let it grow for a long time and never bother to plant more. If grains are planted the following year after cultivation, the resulting grains can be harvested twice because the leaves that accumulated over several years are rotten and the land is cultivated deeper. Therefore, people in the Three Jin States reap the grass for 3 years, then cultivate the fields as farms, and they are eager to plant grains in the fertile land."

1.3.3.2 Study on the Botanical Characteristics of M. Sativa in the Qing Dynasty

Cheng Yaotian (1725–1814) was a famous scholar in the Qing Dynasty. He made a detailed observation and study on the characteristics of *M. sativa* plants in *Shi Cao Xiao Ji* (2008). He spent 5 years observing and studying before and after and introduced the research results in *Shi Mu Xu Ji E Jian Tu Cao Mu Xi* in his work *Shi Cao Xiao Ji* and drew the plant maps of *M. sativa* and *Melilotus officinalis* (Fig. 1.19). The research results are as follows:

(1) *M. sativa* (seed) is very different from the former (*Melilotus officinalis)* seed, and its shape is kidney-like. On the 21st day of the second month, 2 days before Grain in Ear, it was seen that its flowers were small, like *Cryptotaenia japonica*, with a length of about three fen, with four pale purple flowers.
(2) *Melilotus officinalis*: (seed) is as big as millet, round, flat and slightly sharp, black, not firm, and slippery. It is a yellow flower in June, surrounded by one stem, with more than 10 flowers, and the stem is straight up, and the flowers are drooping.

Wu Qixun (1789–1847) was a famous botanist in the Qing Dynasty. *Zhi Wu Shi Ming Tu Kao* (1919), written by him, was the first of modern Chinese flora and occupies an important position in the history of Chinese botany. The botanical characteristics of *M. sativa* were described in *Zhi Wu Shi Ming Tu Kao*, and the plant maps of *M. sativa* and two kinds of *M. denticulate* were drawn (Fig. 1.20).

Fig. 1.19 *Medicago sativa* and *Melilotus officinalis* (Cheng 2008)

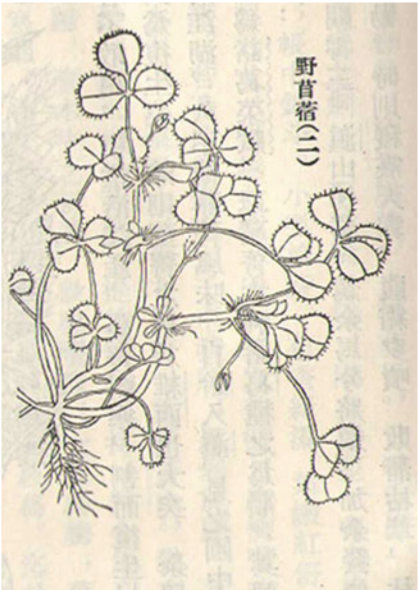
Song Tian Dingjiu (1907), a famous Japanese botanist, pointed out that the three *M. sativa* species mentioned in *Zhi Wu Shi Ming Tu Kao* are as follows:

(1) *M. sativa* L., which is planted on the border of northwest China, has snow-white perennial roots, green leaves, and greens with wheat in early spring and is regarded as a cloud with wind in Gansu, so the belief is not false. In summer, the purple calyx stands upright, reflecting the sun for glory.
(2) *M. denticulate* (1) is *M. falcata* L., which has three petals of yellow flowers but turns purple and black when dry. It grows by dragging the seedlings to spread on the ground and cannot stand upright.
(3) *M. denticulate* (2) is *M. denticulate* Wild., growing in the south of the Yangtze River, with long vines touching the ground, one branch with three leaves, notches in the round leaves, small yellow flowers in the stems, and no pickers. Li Shizhen often refers to the yellow flowers of *M. sativa* but not to *M. sativa* in the northwest (Shi Zhen also stated that the pods have thorns, which obviously refers to this wild variety).

This fully demonstrates the scientific nature and accuracy of Wu Qixun's research on *M. sativa*, and Wu's research results are also adopted in Zhong Guo Zhi Wu Zhi (Institute of Botany, Chinese Academy of Sciences 1998).

A. *Medicago sativa*

B. *M. falcata* (I)



C. *M. denticulate* (II)

Fig. 1.20 *Medicago sativa* and *M. denticulate*

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Chapter 2
Development of Forage Industry in China

Xuebing Yan, Lu Gan, and Minghui Chen

Forage grass is an important part of crop production and the foundation of modern livestock development, which plays an important role in agricultural system in most countries. China's forage industry has gradually risen since the mid-twentieth century, experiencing the slow development from 1978 to 1998, the rapid development from 1999 to 2003, the adjustment stage from 2004 to 2008, and the achieving development stage from 2009. The yield of high-quality forage grass has been greatly improved, providing the solid foundation for the rapid development of the animal husbandry. After nearly 30 years of development, China's forage industry chain has transformed from barely existing into near perfection. It is mainly composed of forage seed industry, forage cultivation, production and processing, forage efficient utilization and intensive processing industry, etc.

Analysis of Forage Requirement

As people's living standard in China improves, food consumption pattern has undergone major changes. From 1985 to 2017, the proportion of total rations in the grain consumption structure dropped sharply from 71.9 to 27.3%. At the same time, residents' annual consumption of meat, eggs, milk, and other animal foods increased from 15.2 kg per capita to 57.7 kg per capita, up 3.8 times. In addition, due to the population growth in China, residents' demand for the total consumption of meat, eggs, and milk was also exploding. In terms of the meat' consumption structure, the proportion of pork decreased from 83 to 62%, while the proportion of herbivorous livestock products such as beef and mutton increased from 7.8 to 9.9%. The increasing need for livestock products inevitably lead to a rapid increase in the number of cattle and sheep breeding.

Until the end of 2019, the total number of large domestic animals was 98.777 million in China, and the number of sheep was 300.7214 million (data source:

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F. Yang et al. (eds.), *Research Progress on Forage Production, Processing and Utilization in China*, https://doi.org/10.1007/978-981-16-7542-3_2

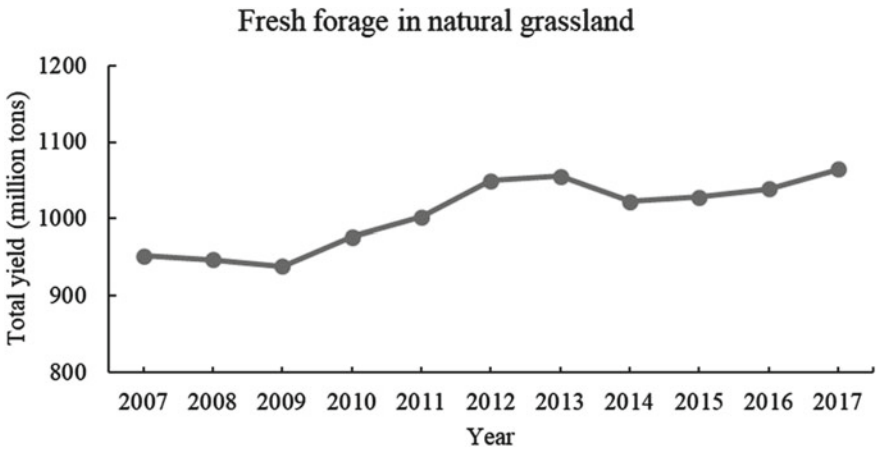

Fig. 2.1 Total yield of fresh forage grass of natural grassland in China from 2007 to 2017 (*Data resource* NBS)

National Bureau of Statistics, NBS). Cattle and sheep are mainly herbivorous livestock. Assuming that the conversion rate of dry pasture to mutton and beef is 10/1 and 15/1, respectively, it means that 500 million tons of hay is needed to feed the livestock in China every year. However, the National Grassland Resources Monitoring Report of 2017 showed that the total yield of fresh grass in natural grassland in China was 1064.91 million tons (Fig. 2.1), equivalent to about 328.42 million tons of hay, so the current domestic forage output is far from the needs of herbivorous livestock industry. Although the area of cultivated grassland and the import of forage hay have been expanding, the demand-supply gap is still large. Therefore, there is an increasing need for forage grass and grassland in China to satisfy the ever-growing need for feeding the livestock.

2.1 General Development of Forage Industry

2.1.1 Forage Farming

From world-wide perspective, forage industry, as the symbol of agricultural modernization, is an important part of crop production and agricultural system in the developed agricultural countries like the United States, Canada, France, the Netherlands, Ireland, Australia, New Zealand, etc. In the United States (the U.S.), the proportion of the grassland in total land area is 55%, and then the cultivated area of pasture accounts for more than 60% of its cultivated land. The resulting economic value of forage industry accounts for 60–70% of its total agricultural output. Among them, alfalfa is the fourth largest crop after wheat and corn, with planting areas of 25 million hectare and annual output of more than 140 million tons of high-quality hay (Putnam 2013). Hence, the total output value of pasture planting was 28 billion dollars combined with alfalfa seeds. In addition, Canada, Australia, New Zealand, and others are major countries in forage production. The area of planted pasture in Canada 2019 was 7.379 million hm^2, which produced grass of 30.432 million tons. In Australia, the output of all kinds of hay exceeds 6.5 million tons, and the output of high-grade silages is about 2.2 million tons.

In China, the area of artificial pastures has expanded since 2015 after the call for "accelerating the development of grass husbandry" by the No. 1 Document of the Central Committee. According to the statistics of China Grassland Development Report (2017) and other relevant data (The Ministry of Agriculture of the People's Republic of China 2017), the area of artificial pastures planting was 180 million hectares until 2017. The top 10 of forage grass in planting area include alfalfa, silage corn, perennial ryegrass, wheatgrass (*Elymus dahuricus*), oat, etc., with a total area of 142 million hectares, accounting for 78.7% in total the artificial region (Fig. 2.2). Most of the artificial alfalfa grassland is located in Shaanxi, Gansu, Xinjiang, and the area of the northeast and the yellow river delta.

In recent years, the production area of commercial forage grass in China showed a downward trend. As shown in Fig. 2.3, in 2012, the planting area of commercial grass was about 1.16×10^6 hectare, and reached a peak with 3.178×10^6 hectare in 2013. However, by 2018, the production area of commercial forage declined to 1.36×10^6 ha. Despite the decline of planting area, the yield of commercial grass from 2015 to 2018 remained mostly stable, and the output of commercial grass industry in 2018

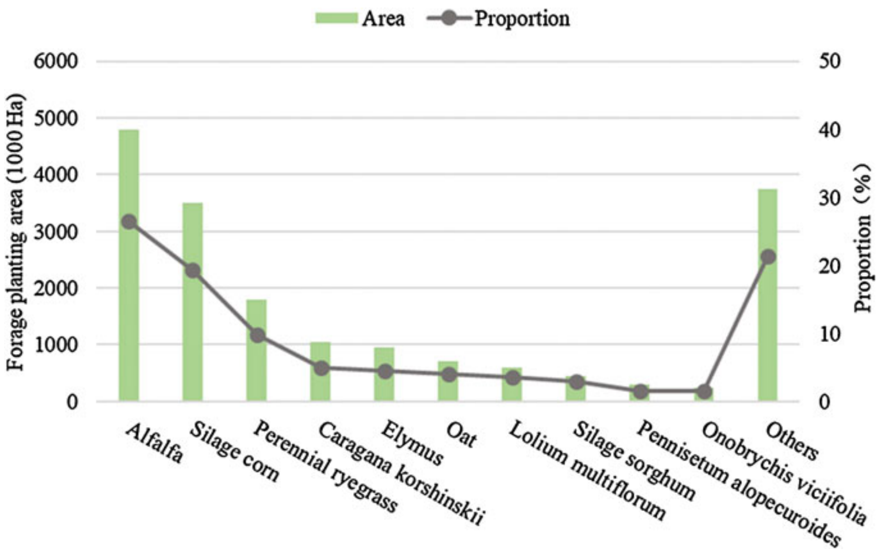

Fig. 2.2 Area and proportion of planting forage and its species in China 2017 (*Data resource* National Bureau of Statistics)

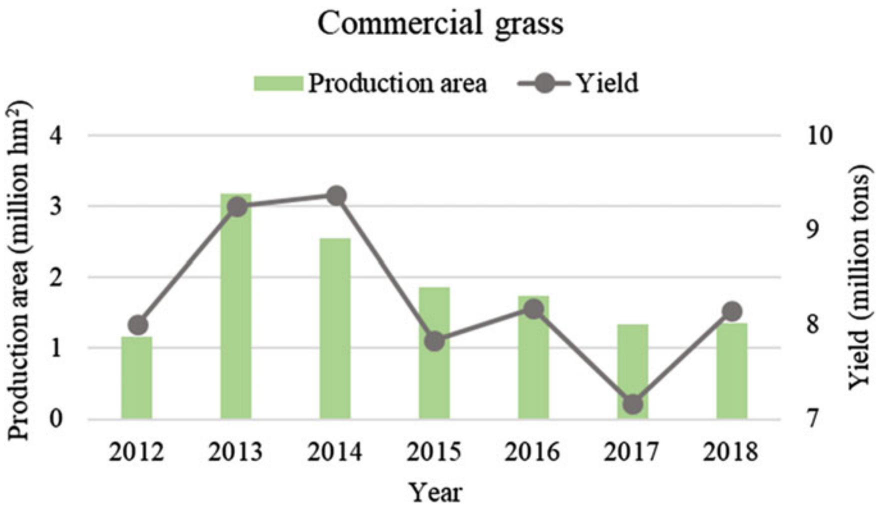

Fig. 2.3 The production area and yield of commercial grass in China from 2012 to 2018

was about 8.15 million tons which increased by 2.39% compared with 7.96 million tons in 2017(Fig. 2.3). The relatively stable change of the total supply indicates that the planted pattern of pastures in China has gradually developed into the stage of higher-quality and fast-growing forage. It implies that the yield per unit has increased, which offsetting the adverse effects caused by the decrease of planted area.

2.1.2 Forage and Pasture Seeds

The development of grassland husbandry cannot be separated from the grass seed industry. For example, the system of grass seed industry was excellent in the most developed countries, like the United States, Canada, Denmark, New Zealand, Australia, and other countries were an important exporter of forage seed production in the world. North America is currently the world's largest producer of forage and turfgrass seed, with most of them coming from Oregon, lowa, Washington State in the western United States and four provinces in southwestern Canada, whose commercial seed production accounts for about 50% of the world's commercial seeds. According to the statistics of USDA (United States Department of Agriculture (2017), there was 2999.9 km^2 of grass seed fields in the United States in 2017, most of which *Fescue* species had the largest seed field (74.93%) of all grass seed fields (Fig. 2.4a). Then, the total number of grass seeds in the United States in 2017 was 354,851.1 tons with higher quantity of ryegrass, fescue, and alfalfa seeds (Fig. 2.4b). Europe is the second largest producer of grass seeds in the world, mostly from Netherlands and Denmark in the north-central part of Europe, most of which were planting ryegrass

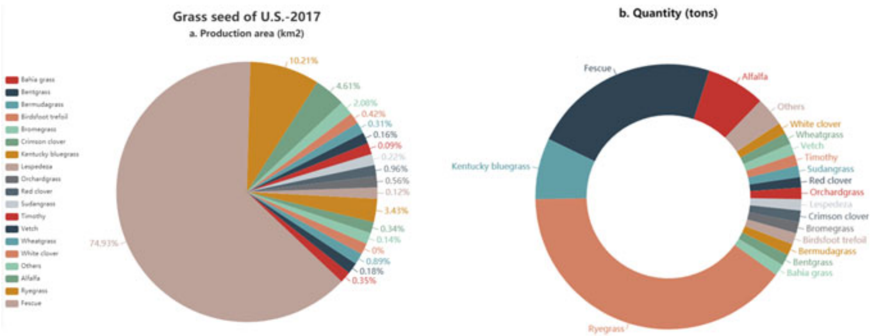

Fig. 2.4 The production area (**a**) and quantity (**b**) of various grass seeds of the United States in 2017 (*Data resource* Census of Agriculture in US-2017)

(1,398,770 ha), alfalfa (84,700 ha), fescue (57,700 ha), clover (64,785 ha), wild pea (25,415.7 ha), etc. (Fig. 2.5).

For China, the total field of forage seed production in 2017 was 851.36 km^2, and the quantity of grass seed was 70,900 tons, mainly including oats, alfalfa, *Elymus* grass, Triticale and Sudan grass (Fig. 2.6). These seeds are mainly produced in northern part of China, among which Gansu, Qinghai, Ningxia, and Inner Mongolia are the top four supply areas. Their annual supply of forage seeds accounts for 37.82%, 19.61%, 12.68% and 9.35% of China's total output in 2017, respectively (National Animal Husbandry Station 2018).

In term of forage breeding variety in China, there were 379 varieties registered by the National Grass Variety Approval Committee from 2001 to 2019, of which 134 were bred (Fig. 2.7). However, the promotion and application for the bred varieties of forage seeds are very limited, and most of the forage seeds in the domestic market

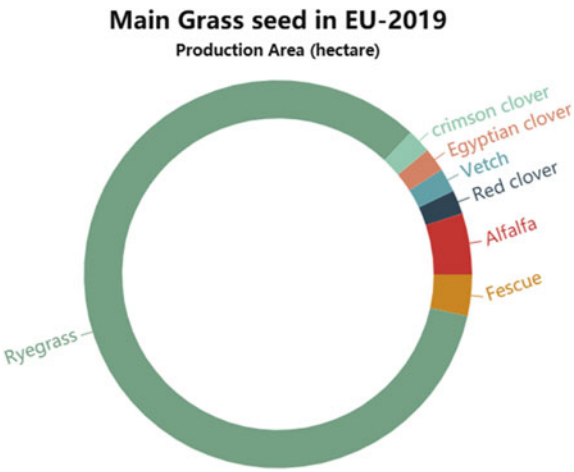

Fig. 2.5 The production area of main grass seed of the Europe in 2019 (*Data resource* European Seed Certification Agencies Association)

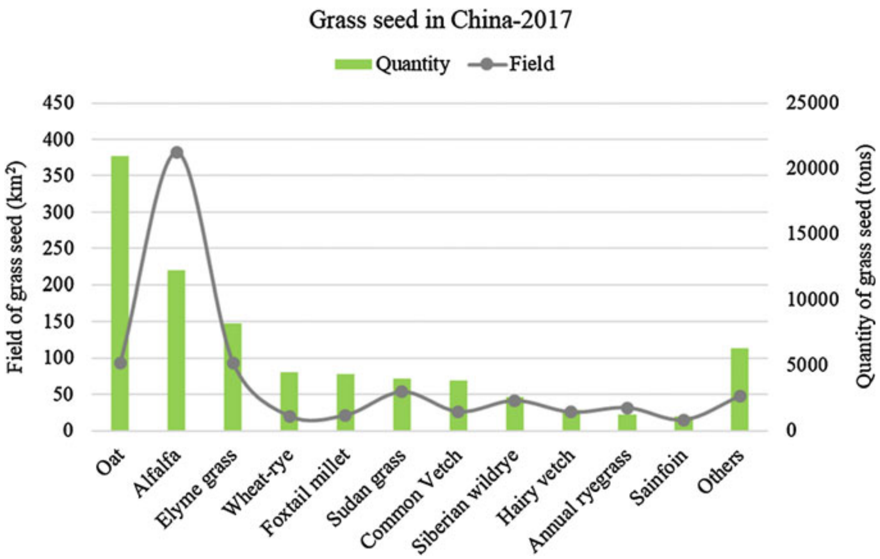

Fig. 2.6 Production area and quantities of grass seed of China in 2017 (*Data resource* Statistics of Grass Industry in China (2017))

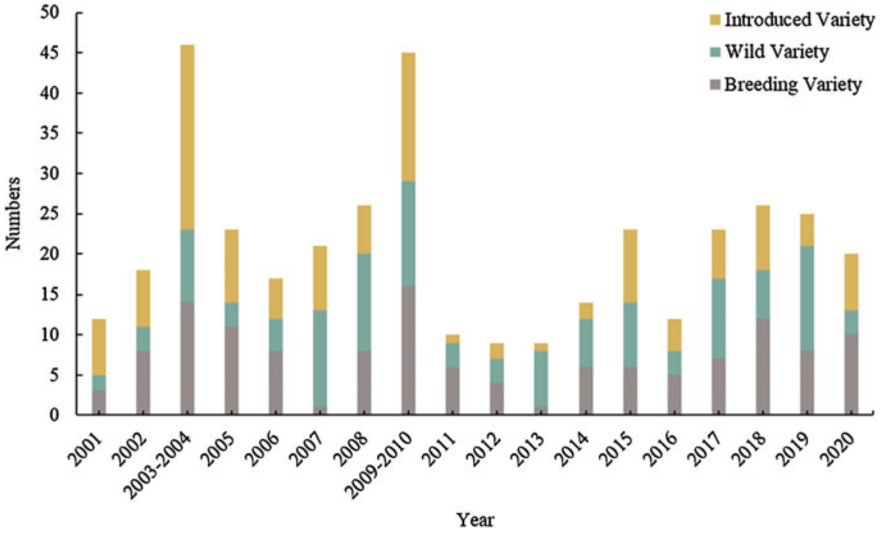

Fig. 2.7 Forage varieties registered by the National Grass Variety Approval Committee from 2001 to 2019

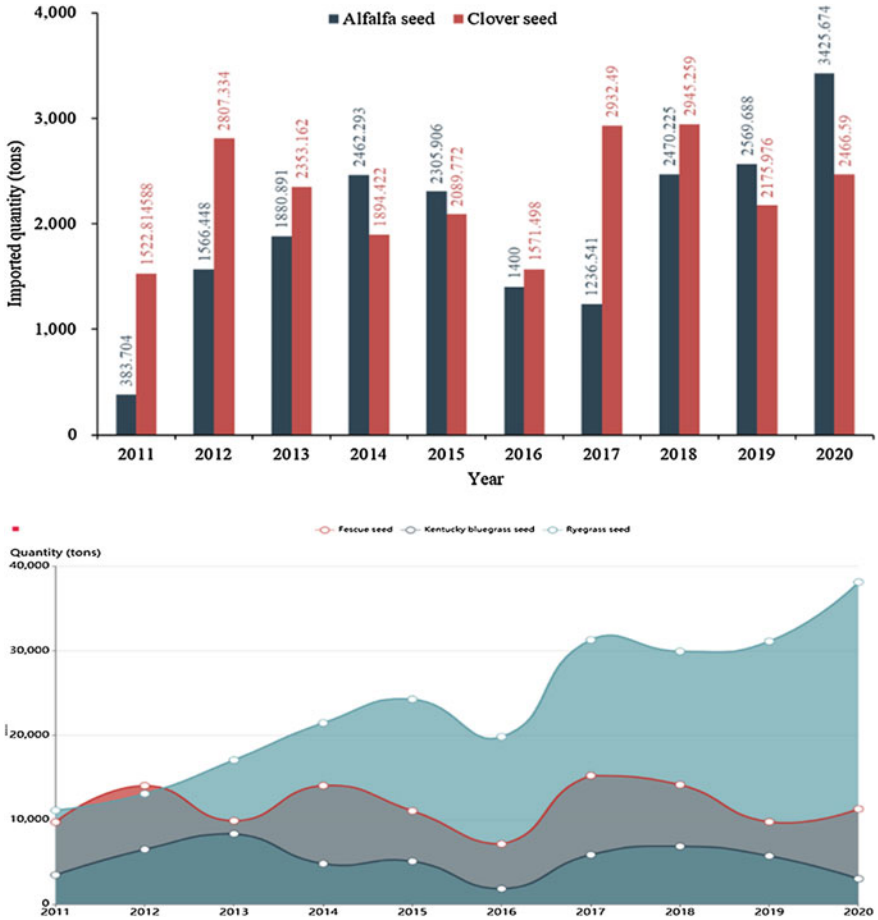

Fig. 2.8 The import quantities of various grass seeds of China from 2011 to 2020 (*Data Source* China customs data)

are imported seeds. In recent years (2011–2020), the total imported grass seeds from different countries have increased annually. In 2020, the total imported grass seeds reached 38,100 tons valued at 107 million U.S. dollars, among which the seed of ryegrass seeds, fescue, and Kentucky bluegrass are the main imported species (Fig. 2.8).

2.1.3 Forage Production

There are various categories of forage production in the world, mainly include hay, haylage, grass silage, greenchop, and leaf protein. The international forage trade

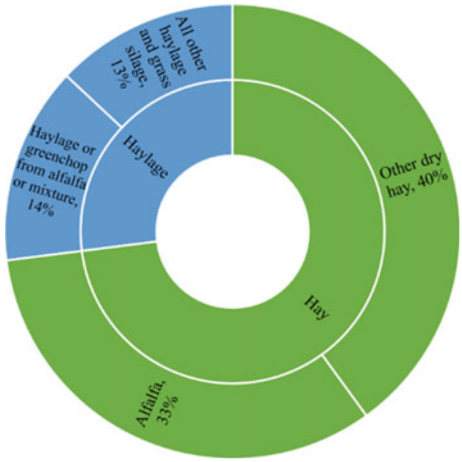

Fig. 2.9 Quantity of forage product of the United States in 2017 (*Data Source* USDA)

reached 6.944 million tons and the value of trade accounted for 2.289 billion U.S. dollars in 2008, which increased nearly 87 times compared to 1962. There are more and more countries actively participated in the trade of forage products, from 60 in 1962 to 180 in 2008. At present, dry hay of grass are the main product form in the international market. According to the USDA, the forage quantity were 163 million tons in 2017, among which hay accounts for 73% of forage products (alfalfa hay at 33% and others at 40%) (Fig. 2.9).

The main varieties of forage products in China are alfalfa and wildrye, of which alfalfa accounts for more than 90%. In the product structure of forage, 77% are bales, 2% are blocks, 8% are particles, 7% are powder, and 6% are other grass products. According to relevant statistics of forage industry, sales volume of domestic forage was 7.16 million tons in 2017, of which the quantity of alfalfa bales was about 1.72 million tons. The yield of these domestic alfalfa hay is far from the level of developed countries and the needs of livestock industry in China. In order to meet the demand of livestock industry development, the demand for alfalfa is increasing rapidly, at the same time, the import of forage products was also increased. From 2014 to 2016, the total import of forage products were raised and reached 1.71 million tons in 2016, of which the import quantity of alfalfa hay was 1.46 million tons. However, during 2017–2020, the total amount of forage imported was stable at about 1.7 million tons with an average price of 360 dollars/ton (Fig. 2.10). It implies that the linkage of grass and livestock in recent years has promoted the rapid development of forage industry in China.

With the development of forage industry, the regional situation of alfalfa industrial belt, the production area of wild rye and ryegrass in southern China has been formed. At present, there are more than 30 companies processing forage products with more than 3000 hectares in the alfalfa industrial belt. By 2017, there were 840 companies of processing forage products in China, which processed 7.327 million tons of forage products including hay, silage, powder, etc. These companies or factories are located

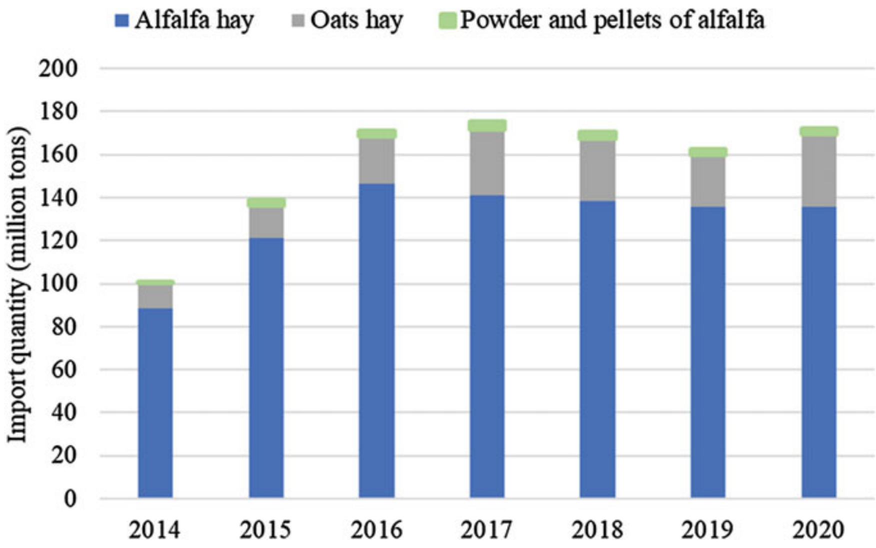

Fig. 2.10 Import quantities of various forage products from 2014 to 2020 in China (*Data Source* china customs data)

in 23 provinces, among which Gansu has 296 companies with 2.702 million tons of forage production. However, most domestic forage processing companies are small in scale, and the quality of various grass products is poor, so it is necessary to further improve the processing technology and ability of forage products.

With the growing demand for forage grass products in China, the development of herbage mechanical engineering and feed additive of forage have been rapidly promoted. However, the herbage machineries and forage additives used by domestic forage product processing companies are mainly imported from abroad. At present, domestic herbage machinery is mainly supplied by Japan's Shidal Company, New Holland Company, Germany's Class Company, France's KUHN Company, etc. Compared to Europe and America, most herbage machinery companies in China have some competitive disadvantages in terms of mechanical quality, type, and technology. However, some herbage machinery companies, such as Huade Grass Machinery Co., Ltd., and Huanong Machinery Co., Ltd. in Inner Mongolia, have make technological breakthroughs in herbage machinery, and some mechanical products have comparative advantages in price.

In terms of feed additives in forage, most products in China are imported from Europe and America. In recent years, the types of additives registered and sold in China are increasing, indicating that the demand for feed additives in forage is also increasing. It implies that the sales volume of feed additives in China will grow in the future, due to the demand of high-quality forage production.

2.1.4 Efficient Utilization and Intensive Processing of Forage Grass

European and American countries have attached great importance to the research and production of extracting effective substances from cultivated pastures, such as leaf protein, cellulose, chlorophyll, unsaturated fatty acids, and β carotene. The application of these substances can achieve higher economic benefits. At present, the French alfalfa production complex is the largest commercial producer of forage leaf protein in the world. Countries such as Britain, Denmark, New Zealand, Australia, Russia, Brazil, and India also have different scale factories processing leaf protein condensate. For example, the 'green protein' produced in New Zealand and Australia is called Quintessence, which has high nutrition, equivalent to soybean protein and casein. In terms of improving production technology, Britain, America, Russia, and other countries have researched and designed a helix prescriber, which can complete the processes of crushing and pressing at the same time. It can not only produce a series of concentrated protein of green feed, forage cake, and residue, but also extract single cell protein from its fluid.

Apart from leaf protein, the extraction and industrial production of active substances is also an important field of intensive processing of forage grass in the world. At present, there are many studies on the utilization of flavonoids in red clover. The isoflavones extracted from red clover is known as a botanical drug with excellent effect on climacteric syndrome. Th sale volume of these drug has been ranked among the top 10 botanical drugs in the United States, and a large number of them are exported to China every year. After intensive processing, the value of forage production has been greatly improved. For example, the price of red clover hay is 0.2 dollars per kilogram, while that production of red clover with 8% total flavonoids is 23–38 dollars/kg, that production of red clover withe 20% total flavonoids is 100–130 dollars/kg, even that of red clover isoflavones is 230 dollar/kg.

Although there have been studies on extracting and intensive processing of leaf protein from alfalfa in China, most of them are in the laboratory stage and not in the commercial production stage. However, these high-value forage extraction, like leaf protein, dietary fiber, plant pigment, saponin, flavone, polysaccharide, etc., can be used not only for feeding herbivores, but also for diets of monogastric animals, such as pigs and poultry. This application can not only improve the quality of animal products, but also save feed grain. Therefore, the industrial chain of forage utilization and intensive processing can be extended to grain-consuming animal husbandry, replacing part of the feed grain and improving the quality of livestock products. The various types of forage utilization and products of intensive processing will trigger the upgrading of traditional forage industry and provide better opportunities for the development of forage industry in China.

2.2 Problems and Challenges of Forage Industry

2.2.1 Improved Breeding Varieties of Grass Seeds is not Mature and Relies Too Much on Imports

After the launch of artificial grassland construction and the breeding of new forage varieties, the production of forage seed in China has experienced a process from scratch. Although the industrialized production of forage seeds took off at the end of 1990s, there are still so much deficiencies compared to those in the developed countries. For example, the disadvantage of organization and technical research limit the further development of forage seed industrialization in China. In terms of the production unit, most farmers in China rely on self-produced seeds and specialized seed producers is severely lacking. There were a total of 379 varieties registered by the National Grass Variety Approval Committee from 2001 to 2019, of which 134 were bred. However, most of the approved and registered varieties were not used for production and promotion, or excellent varieties were ignored and resulted to the gradual degradation under extensive production conditions. Most of the grass species used in major ecological conservation and restoration project are imported species. From 2011 to 2020, the imported species of pastures and turfgrass in China mainly include alfalfa, clover, fescue, Kentucky bluegrass, perennial ryegrass, annual ryegrass, and other feed crops. Especially, the import quantity of alfalfa seeds has increased greatly in recent years, with the import volume of alfalfa seeds reaching 3425.7 tons in 2020, an increase of 88% compared with 2011.

2.2.2 The Standardization and Quality of Forage Production is Low, and the Regional Production is Unbalanced

Like other industries, the sustainable and healthy development of forage industry cannot be separated from industry standards and policies to guide scientific production. At present, the corresponding standards for production of forage seeds and processing has been not established in China. Also, there are no specific operating procedures for fertilization, harvesting, drying, storage, etc. Eventually, it leads to many outstanding problems, such as impurities in seeds, weeds in grass, poor quality of grass products, which greatly affects the domestic sales and export of forage products. According to related investigation and statistics, the quality of alfalfa bales in China is low. More than half of the crude protein content cannot meet the secondary standard, and there is almost no top grade of alfalfa hay. Besides, the research and development, the popularization and application of forage additive products are one of the urgent problems to be solved in the development of forage industry in China. In addition, the imbalance between the distribution of forage industry and livestock industry should be highlighted. Using the alfalfa hay as an example, Gansu, Heilongjiang, Inner Mongolia and Ningxia are the main producers of commercial grass. In 2017, the yield of commercial grass in Gansu Province was the highest, reaching 2.7 million tons, but the dairy farming stock ranked 10th and the milk yield ranked lower, which reflect extreme imbalance.

2.2.3 The Integration of Forage and Livestock is not High and Closely

At present, the integration of forage and livestock in husbandry cannot meet the requirements of modern husbandry production. On one hand, the backward feeding mode of “straw + concentrate” still exists in reality, and farmers don’t pay enough attention to the fact that “high-quality pasture is the fundamental guarantee of high-quality and safe livestock and poultry products”. On the other hand, forage producers only take pasture as the primary production to obtain a small profit, resulting in the absence of industrial extension for livestock and poultry. Also, the benefits of simply planting grass are very limited, but the potential benefits of grass can be effectively increased with the combination of pasture farming and livestock. The development of herbivorous husbandry has been accelerating, while the supply of forage products is still seriously insufficient for feed. For example, based on the calculation that each cow needs 1 ton of alfalfa hay every year, as there were nearly 15 million cows of China in 2012, 15 million tons of alfalfa hay are needed. At present, the annual circulation of alfalfa hay in the market in China is less than 1 million tons, which is far short of the demand.

2.2.4 The Mechanical Equipment of Forage Processing is not Improved, and Mainly Depends on Importation

Compared to developed countries, there are deficiencies and gaps in the technology and process of herbage machinery in China, and most of them are lagging decades behind. Since 1980s, the investment in grassland and forage industry has been seriously insufficient, causing many companies of herbage machinery to switch or stop production. In addition, there are a host of problems in these companies, such as the low machine quality and poor reliability. Reciprocating mower needs sharpening after working for half a day, and its reliability is less than 80%. The machines of raking grass from international companies work for 400 hectares, and the ratio of broken tooth is only about 4%, while the broken tooth rate of domestic products is about 25% for the same amount of work. Under the same operation conditions, the workload of forage picking and stacking in China is half that of similar models from the developed countries. In addition, the models and combination of various herbage machinery in China is poor. On the basis of introduction and digestion of foreign machinery in China, the operation process system of loose grass, square bale, round bale, piling, and secondary pressure packing has been initially formed. However, most of the models can only handle one of the process but not multiple processes. At the same time, most domestic manufacturers can only produce simple models such as lawn mowers and shredders, but cannot produce high-grade models such as the combination of mowing and flattening machines, thus, many herbage machines can only rely on imports.

2.2.5 Intensive Processing of Forage Products is Insufficient and Low-Value

Leaf protein from forage grass not only contains the main amino acids needed by livestock, but also be closer to milk proteins easily absorbed by human beings. Therefore, these leaf proteins can be processed into intensively processed substrates of consumption and application for both livestock and human. If the direct feed utilization rate of alfalfa is only 20–30%, the utilization rate of intensive processing could be as high as 80%. In the European market, the value of leaf protein from alfalfa is 10–100 times higher than that of animal protein. Up to now, the process of forage grass in China is still dominated by primary production with few intensive processing products.

Summary

On the development of forage grass and livestock, we firstly focus on advancing the development of forage farming, the processing of forage product, and its related herbivore industry. Secondly, the added value of agriculture, forage and livestock industry will be increased by combining farming, production, and processing. Then, we should enhance the relationship between efficient production system of forage products and the modern ecological agriculture system, thus promote the adjustment that make traditional agriculture in the direction of combining grassland with modern agriculture. These aforementioned improvements will play an important role in ensuring the healthy development of food safety in China.

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Chapter 3
Research Status of Forage Seed Industry in China

Yunwei Zhang, Junmei Kang, Manli Li, Zan Wang, Shangang Jia, Xiqing Ma, Hui Wang, and Huifang Cen

3.1 Forage Germplasm Resources in China

Forage germplasm resources are the basis of the original innovation in grass industry and forage breeding, and strategically important to ensure the national security of food, ecology and seed industry. After more than 20 years' rapid development and establishment in forage germplasm resources in China, it has made remarkable achievements in collection and preservation, evaluation and identification, and exploration of gene resources.

3.1.1 Collection and Preservation of Forage Germplasm Resources in China

The national collection and preservation of forage germplasm resources in China was led and organized by the National Animal Husbandry Service since 1997. The investigations on forage germplasm resources mainly focused on endemic, wild, rare and endangered species, and wild relatives of the major cultivated forage germplasms in China. Moreover, we also tried to figure out the relationship of these key forage germaplasm resources depending on their classifications, qualities, distributions and descriptions in literature review. Until now, eight lists of key protected forage species, including "List of Endemic Species of Forage Plants in China", "List of Wild Types

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and Wild Relatives of Major Cultivated Forage in China", and "List of Major Plants in National Grassland Nature Reserves", were published. A serial of descriptive specifications and standards for forage germplasm resources are being compiled and issued. These efforts have provided scientific basis and technical support for guiding the implementation and priority determination of collection and protection of forage germplasm resources in China.

Collection of forage germplasm resources is carried out mainly through field survey, domestic acquisition and foreign introduction. By the end of 2016, a total of 65,660 forage germplasm resources had been collected. Based on the climate zones and distribution of forage germplasm resources in China, National Forage Germplasm Genebank of China (Beijng), two backup germplasm banks (Backup Genebank of Temperate Forage, Hohhot, Inner Mongolia; and Backup Genebank of Tropic Forage, Danzhou, Hainan), and 17 germplasm nurseries have been built up, which established a nationwide conservation system for forage germplasm resources. In total, 54,728 accessions of 2,593 species across 772 genera of 116 families were stored in the three Genebanks. Based on the SQL Server 2005 system, an open and national forage germplasm resource management system (http://www.digitalgrass.cn) is already available, which realizes the standardization, digital management and information sharing of the stored forage germplasm resources.

3.1.2 Evaluation and Identification of Forage Germplasm Resources in China

The evaluation and identification of germplasm resources which is essential to know and utilize them, includes phenotyping and genotyping.

The phenotyping of germplasm resources generally refers to the charaterizations of agronomic, qualitative (e.g. general forage quality and special functional components), biotic and abiotic stress resistant (e.g. drought, waterlogging, salinity, heat, cold, heavy metal, disease, insects, etc.). Under different regions and soil conditions, Chinese scientists combined identification in natural field and simulation in artificial greenhouse to characterize the biotic and abiotic resistance during the seed germination, seedling and full growth stages of alfalfa, ryegrass and other major forage plants. The germplasm materials with high yields, high qualities and excellent adaptabilities were screened out, which provided the material basis for developing new forage varieties. Scientists from China Agricultural University characterized about 1,500 alfalfa accessions under drought, salt and cold stresses, and screened out a batch of excellent resources. Scientists from the Institute of Botany of the Chinese Academy of Sciences screened out a batch of germplasms with early germination and fast vegetative growth in the sowing year from thousands of germplasms to speed up the sexual reproduction of *Leymus chinensis*. Scientists from Lanzhou University evaluated more than 600 siberian wildrye (*Elymus sibiricus*) germplasm resources and screened out 10 ones with low seed shattering. Sichuan Agricultural University evaluated about 300 orchardgrass (*Dactylis glomerata*) germplasm resources for rust resistance, and identified about 20 resistant ones. The near-infrared method was used to establish an isoflavone content prediction model for red clover (*Trifolium pratense*) in China Agricultural University.

Genotyping is also an important item of forage germplasm identification. With the advancement of genome sequencing technology, genotyping has entered a period of rapid development. Due to the complex genetic backgrounds, most of forage species still do not have reference genomes except for alfalfa, white clover (*Trifolium repens*), red clover, perennial ryegrass (*Lolium perenne*), and orchardgrass. At present, the studies on genotyping of forage plants is far behind that of the main crops. Genetic diversity and population structure studies on 336 alfalfa accessions collected worldwide were performed at the genome level in China Agricultural University, which supported the two-origin hypothesis of alfalfa and revealed that the genotypes from China were distinct from those collected from other regions the world after the earlier introduction and long-term domestication. A total of 88 core collections of *Stylosanthes* were constructed using the phenotypic and EST-SSR marker data in Chinese Academy of Tropical Agricultural Sciences and Hainan University. Three chloroplast genes (*matK*, *rbcL* and *trnL-trnF*) and one nuclear gene (*ITS*) were used for sequencing and constructing a phylogenetic tree of *Melilotus*. It was confirmed for the first time that the evolution mode of *Melilotus* was monophyletic inheritance, and barcode sequences and identification methods for different species of *Melilotus* were developed in Lanzhou University. China Agricultural University has established *matK*, *trnH-psbA* and *matK*$^+$*trnH-psbA* as ideal DNA barcodes for identification of *Vicia* species.

3.2 Research Advances in Forage Breeding

3.2.1 An Overview of Forage Breeding in China

Breeding of forage and fodder crops in China started late, whose developmental process has roughly experienced three stages. The first stage is introduction. Since the 1930s, a variety of forage germplasm resources have been introduced from abroad, mainly including alfalfa, clover, birdsfoot trefoil, perennial ryegrass, timothy, yellow sweet clover and so on. Subsequently, large-scale introduction experiments were carried out across the country, which laid a foundation for cultivation of new forage varieties. The second stage is screening and evaluation stage. After extensive introduction, evaluations, and selections, a large number of local varieties adapted to local ecological conditions have been screened out, such as Xinjiang Hetian alfalfa, Shaanxi Guanzhong alfalfa and so on. The third stage is the all-round development stage since the 1980s, forage breeding developed comprehensively and rapidly. In 1986, the National Pasture Breeding Committee and the National Pasture Variety Approval Committee established, and the registration for pasture and feed crops

Table 3.1 Statistical table of types of approved and registered forage grasses from 1987 to 2019

Variety type	Grass species (family)	Number (piece)	Total (piece)	Percentage of registered species (%)
Bred varieties	Leguminosae	89	217	37.2
	Gramineae	113		
	others	15		
Introduced species	Leguminosae	65	175	30.0
	Gramineae	97		
	Others	13		
Landrace	Leguminosae	37	61	10.4
	Gramineae	16		
	Others	8		
Wild	Leguminosae	31	131	22.4
	Gramineae	80		
	Others	20		
Total		584		

began. Through selection and breeding of forage and fodder crops, sorting of local varieties, introduction of excellent foreign varieties, domestication of wild forages, new varieties of forage and fodder crops have been bred. Up to 2019, there were 584 forage varieties registered by the state, including 217 bred varieties, accounting for 37.2% of the total; 175 introduced varieties, 30.0% of the total; 10.4% local varieties; and 131 wild cultivated varieties occupying 22.4% of the total (Table 3.1). According to human demands, there are mainly mainly divided into feeding, ecological (urban greening and environmental protection) and ornamental types.

In 2008, the national grass variety regional trial started, and 53 district pilot projects were built, basically covering the main forage grass planting areas in the country. The regional trial plan for 146 grass varieties has been formulated. In 2013, the DUS (Distinctness, Uniformity, Stability) test content of grass varieties were added to the regional test projects, and DUS test evaluations of grass species such as alfalfa, chinese wildrye, multiflorum ryegrass, zoysia grass, dahuria wildryegrass, white clover, orchard grass, bermuda grass, etc. were completed.

3.2.2 Advances in Perennial Forage Breeding (Current Registered Perennial Forage Varieties and Characteristics)

According to statistics, there are about 26 families, 159 genera and 425 species of forage grass species in China (cited from the National list of forage and forage crop varieties). Among them, the number of species and cultivation area of Gramineae and Leguminosae are absolutely dominant and they are the core part of forage resources in China. Currently, 584 forage varieties belonging to 194 spiecies, 107 genera, and 19 families have been registered (Table 3.2), 488 ones of which are perennial forages, accounting for 83.6% of the total. Among these perennial forage varieties, there are 37 genera and 210 varieties in the Gramineae at most, mainly including *Festuca* L., *Dactylis* L., *Elymus* L., *Pennisetum* Schumach., *Bromus* L., *Leymus* Hochst., *Agropyron* J. Gaertn, *Cynodon* L., etc.; followed which is Leguminosae with a total of 26 genera and 208 varieties, mainly including *Medicago* L., *Trifolium* L., *Stylosanthes* Sw., *Vicia* L., *Hedysarum* L., *Cassia* L., *Lespedeza* Mich., etc.; while the remaining 56 forage varieties are registered in other 17 families (Table 3.2).

3.2.3 Main Perennial Forage Varieties and Suitable Planting Areas

Perennial forage plays an important role in the development and ecological construction of grass husbandry in China. Among registered forage varieties, the top ten grass species for promotion and planting area are alfalfa, dahuria wildryrgrass, sibirian wildryegrass, sainfoin, chinese lemus, kentucky bluegrass, erect milkvetch, perennial ryegrass, orchardgrass and clover.

3.2.3.1 Characteristics of Registered Medicago L.

Medicago spiecies are legume perennial herbs, including the main cultivated species *alfafa (M. sativa* L.*)*, sickle alfalfa (*M. falcata* L.), russian fenugreek (*M. falcata* L.), california burclover (*M. ploymorpha* L.), black medic (*M. lupulina* L.), etc. Among them, alfalfa is the most widely distributed one. At present, the most registered species is alfafa with 104 varieties, accounting for 17.8% of all registered forage varieties. If only taking bred varieties into consideration, 47.1% of the registered ones are alfafa. Alfalfa is widely cultivated in China. According to the “Alfalfa Planting Regionalization and Variety Guide”, Chinese alfalfa growing areas are roughly divided into six planting areas including Northeast China, Inner Mongolia Plateau, Huanghuaihai Plateau, Loess Plateau, Qinghai-Tibet Plateau and Xinjiang. Kinds of alfalfa varieties are suitable for different planting areas. For example, Gongnong series and Longmu series prefer the environment in Northeast China. Zhongcao series, Grassland series and Zhongmu series grow better in Inner Mongolia Plateau. Zhongmu series fit in Huanghuaihai region, while Gannong series and Xinmu series behave better in Loess Plateau, Qinghai Tibet Plateau and Xinjiang.

Varieties of Gongnong series and Longmu series Some varieties of *Medicago* L. harbor advantages of cold resistance, high quality and yield, like Gongnong series (*Medicago sativa* L. cv. Gongnong No.1, *Medicago sativa* L. cv. Gongnong No.2,

Table 3.2 Statistical table of families, genera and species of approved registered pasture species (1987–2019)

Serial number	Family	Genus	Species	Variety	Serial number	Family	Genus	Species	Variety
1	Gramineae	48	97	306	11	Azollaceae	1	1	2
2	Leguminosae	31	63	222	12	Apocynaceae	1	1	1
3	Amaranthaceae	1	4	8	13	Liliaceae	2	2	2
4	Compositae	5	5	11	14	Convolvulaceae	1	1	1
5	Chenopodiaceae	3	5	7	15	Anatidae	1	1	1
6	Euphorbiaceae	1	1	7	16	Iridaceae	1	1	1
7	Polygonaceae	3	3	3	17	Plumbago	1	1	2
8	Cruciferae	2	3	5	18	Cannaaceae	1	1	1
9	Rosaceae	2	2	2	19	Urticaceae	1	1	1
10	Cucurbitaceae	1	1	1	Total		107	194	584

Medicago varia Martin. cv. Gongnong No.3, *Medicago varia* Martin ‘Gongnong No.4’, *Medicago sativa* L. ‘Gongnong No.5’) and Longmu series (*Melilotoides ruthenicus* L.) Sojak × *Medicago sativa* L. cv. Longmu No.801, *Medicago sativa* L. × *Melilotoides ruthenicus* (L.) Sojak cv. Longmu No.803, *Medicago sativa* L. × *Meliloides ruthenica* (L.) Sojak. cv. Longmu 806, *Medicago sativa* L. cv. Longmu No.807, *Medicago sativa* L. ‘Longmu No.808’, *Medicago sativa* L. Longmu No.17, *Medicago varia* cv. Longmu No.14) and *Medicago sativa* L. cv. Zhaodong. These varieties are mainly utilized to establish high-yield artificial grasslands and no-tillage reseeding on natural grasslands, with about 600,000 mu in cultivation area.

Zhongmu series varieties The varieties named as Zhongmu series have been cultivated largely in saline-alkali and medium–low-yield fields in 10 provinces including Shandong, Hebei, Henan, and Inner Mongolia. These varieties become the main cultivated ones in alfafa industry in North China due to their significantly ecnomic, social and ecological benefits, with cumulative planting area of more than 30 million mu.

Zhongcao series and Caoyuan series varieties These varieties are suitable for cultivated in cold, arid and semi-arid areas of northern China, especially in Inner Mongolia and its surrounding areas. ‘Zhongcao No.3’ is mainly planted in Inner Mongolia, Shanxi, Shaanxi, and northern Hebei, with a cumulative cultivation area of about 1 million mu.

Gannong series and Xinmu series varieties The varieties called Gannong series (*Medicago varia* Martin. cv. Gannong No.1, *Medicago varia* Martin. cv. Gannong No.2, *Medicago sativa* L. cv. Gannong No.3, *Medicago sativa* L. cv. Gannong No.4, *Medicago sativa* L. ‘Gannong No.5’, *Medicago sativa* L. ‘Gannong No.6’, *Medicago sativa* L. ‘Gannong No.7’, *Medicago sativa* L. cv. Gannong No.9) and Xinmu series (*Medicago varia* Martin. cv. Xinmu No.1, *Medicago sativa* L. cv. Xinmu No.2, *Medicago varia* Martin. cv. Xinmu No.3, *Medicago sativa* L. ‘Xinmu No.4’), are drought-resistant, high-yielded, and insect-resistant, with a cumulative area of nearly 300,000 mu since 2008.

Alfalfa varieties introduced abroad According to the climatic and soil charateristics, 20 alfafa varieties which are excellent in quality, yield, stress-reisistance, and suitable for cultivating in different ecological areas, have been introduced to China and screened. As a result, *Medicago sativa* L. cv. AC Caribour and *Medicago sativa* L. cv. AmeriGraze401+Z are suitable for planting in North, Northwest and Northeast China, while *Medicago sativa* L. cv. Eureka, *Medicago sativa* L. cv. Magna601, etc. are suitable for planting in hilly areas in the middle and lower reaches of the Yangtze River.

3.2.3.2 Elymus Varieties and Planting Areas

Elymus varieties mainly belong to *Elymus sibiricus*, *Elymus dahuricus*, *Elymus nutans* and *Elymus breviaristatus.* 15 Elymus varieties were registered totally, including *Elymus breviaristatus* Keng cv. Tongde, *Elymus nutans 15 Elymus varieties were registered totally,* Griseb. cv. Kangba, *Elymus nutans* Griseb. 'Aba', *Elymus submuticus* Keng f. 'Tongde', *Elymus sibiricus* L. cv. Qingmu No.1, *Elymus sibiricus* L. cv. Tongde, *Elymus sibiricus* L. 'Aba', *Elymus sibiricus* L. 'Kangba', etc. They are mainly cultivated in Qinghai-Tibet Plateau, northwest of Sichuan, Sichuan Aba, Qinghai Plateau cold temperate zone and similar habitats.

3.2.3.3 Leymus Chinensis Varieties and Planting Areas

At present, 7 *Leymus chinensis* varieties were registered. *Leymus chinensis* (Trin.) Tzvel. Zhongke No.1 shows a hay yield of 400–600 kg per mu, 35% increase in seed gremination rate, and strong cold, drought, salt and alkali tolerance and disease resistance. *Leymus chinensis* is suitable for the establishment of artificial grasslands, the improvement of degraded grasslands, and the ecological management of soil erosion areas in northern regions such as Xinjiang, Gansu, Ningxia, Inner Mongolia, Hebei, Henan, and Heilongjiang.

3.2.3.4 Perennial Ryegrass Varieties and Planting Areas

There are 33 registered varieties of perennial ryegrass, including *Lolium multiflorum* (18 varieties), *Lolium perenne* (10 varieties), hybrid ryegrass (2 varieties) and festulolium (3 varieties). *Lolium multiflorum* Lam. cv. Changjiang No.2 is suitable for planting in the warm and humid areas of the hills, flat dams and mountains in the upper and middle reaches of the Yangtze River, while *Lolium multiflorum* Lam. 'Chuannong No.1' is suitable for planting in the warm and humid hills, flat dams and mountains in the Yangtze River Basin and its south. There are 3 introduced varieties, namely *Lolium multiflorum* Lam. cv. Lipo, *Lolinm multiflorum* var. Westerwoldicum cv. Tetragold and *Lolium multiflorum* Lam. cv. Spendor.

3.2.3.5 Dactylis Varieties and Planting Areas

Since 2000, 14 varieties of *Dactylis* have been registered, including 3 wild cultivated varieties (*Dactylis glomerata* L. cv. Chuandong, *Dactylis glomerata* L.'Dianbei', *Dactylis glomerata* L.) and 11 introduced variesties (*Dactylis glomerata* L. cv. Anba, *Dactylis glomerata* L. cv. Porto, *Dactylis glomerata* cv. Ambassador, *Dactylis glomerata* L. 'Donata', *Dactylis glomerata* L. 'Wana', *Dactylis glomerata* L. 'Athos', *Dactylis glomerata* L. 'Crown Royale', *Dactylis glomerata* L. 'Endurance', *Dactylis glomerata* L., *Dactylis glomerata* L., Intensiv). They are mainly planted in the Yangtze River Basin, in the cool and humid areas of southwest and southern China.

3.2.3.6 Clover Varieties and Planting Areas

There are 15 varieties of clover were registered, including red clover (6 varieties), white clover (7 varieties), Kenyan white clover (1 variety) and wild clover (1 variety). At present, the most popularized varieties are *Trifolium pratense* L., *Trifolium pratense* L. ‘Emu No.5’, and *Trifolium repens* L. cv. Emu No.1.

3.2.3.7 Stylosanthes Varieties and Planting Areas

At present, a total of 13 *Stylosanthes* varieties have been registered, belonging to 4 species, named *Stylosanthes guianenesis* Sw, *Stylosanthes*, *Stylosanthes hamata* (L.) Taub, *Stylosanthes scabra.* At present, the most cultivated varieties are mainly *Stylosanthes guianensis* Sw. cv. Reyan No.2, *Stylosanthes guianensis* Sw. cv. Reyan No.5, *Stylosanthes guianensis* Sw. ‘Reyan No.20’, *Stylosanthes guianenesis* Sw. ‘Reyan No.21’ and *Stylosanthes guianenesis* Sw. ‘Reyan No.25’. Stylosanthes varieties are mainly utilized in mowing leguminous grassland and intercropping with forest (fruit) and grass. Hainan, Guangdong, Guangxi and parts of Yunnan and Sichuan are the main cultivation areas for them, with a cumulative promotion area of about 3 million mu.

3.2.3.8 Pennisetum Varieties and Planting Areas

There are 6 species and 15 varieties of *Pennisetum* registered. Including *Pennisetum americanum*, *Pennisetum americanum* × *P. purpureum*, *Pennisetum clandestinum*, *Pennisetum polystachyon*, *Pennisetum purpureum*, *Pennisetum purpureum* Schum. cv. (*Pennisetum Americanum* × P. purpureum) × P. purpureum Schum. cv. *Pennisetum* has a wide range of cultivation in tropical, subtropical and warm temperate zones. According to whether it could overwinter safely, *Pennisetum* is easily distinguished into perennial and annual.

3.2.4 Advances in Annual Forage Breeding

Ninety-six annual forage plants were registered until the end of 2019 in China, accounting for 16.4% of all. These annual forage species are mostly gramineous herbs, including oats, sorghum, triticale, annual *Setaria*, *Pennisetum*, etc.

3.2.4.1 Characteristics of Oat Varieties

Registered oats include Longyan No.3, ABA, Qingyin No.3, indimit and aiwo oats. Longyan No.3 owned dark green leaves, strong tillering ability and more effective tillers, compact plant architecture and strong stems. It is a late maturing variety with high hay and seed yields, which is mainly suitable for cold areas in Gansu Province. ABA oat, a local variety, has strong resistances to drought, cold, barren, also aphids and rust. It has tender grass quality and high digestibility. It is an early maturing variety, which is suitable to be planted in southwest high mountains like Qinghai Tibet Plateau with an altitude of 2000–4500 m. Qingyin No.3 naked oat with fibrous root system and stems, was introduced from Canada. It is tolerant to poor fertility, resistant to drought and lodging, and has strong adaptability, rich nutrition and good palatability. It is mainly suitable for planting in the high-altitude area of 1700–3000 m.

3.2.4.2 Characteristics of Sorghum

Eight sorghum varieties have been bred in recent ten years, Mengnong Qingsi 3, Xinsu 3, Jicao 2, Jicao 6, Jinmu 1, Shucao 1, Xincao 1 and Sumu 3. Jicao series have compact plant architecture, fibrous and developed root system, stout and juicy stems, wide leaves, strong tillering ability after cutting, drought resistance, salt tolerance, leaf disease resistance, lodging resistance and good palatability. They can be planted in the areas suitable for sorghum and sudangrass cultivation in all parts of the country. Mengnong Qingsi No.3 is very tall, lodging resistant, drought resistant and salt tolerant, with tender stems and leaves, large amount of leaves and high nutritional value. Xinsu No.3 has strong regeneration ability, strong drought resistance, salt and alkali resistance, but it is not cold resistant. It has low requirements for soil and likes warm and humid climate. It is mainly planted in the areas with frost free period of more than 130 days in the south or north of China and irrigation conditions. Jinmu No.1 has developed root system, erect plant type, thick stem, strong tillering ability, strong regeneration ability after cutting, good quality, shorter vegetative growth period in southern China, earlier heading date, strong salt and alkali tolerance, drought resistance, purple spot disease resistance, lodging resistance, and good palatability, which is suitable for silage or forage.

3.2.4.3 Characteristics and Planting Areas of Triticale

There are two main series of Forage Triticale. Shida No. 1 has strong stem, strong lodging resistance, early turning green in spring, fast growth rate, immunity to powdery mildew, rust resistance, salt and alkali resistance. It is suitable for preparing hay or silage. It is mainly suitable for growing in Northwest China winter wheat area and winter and spring wheat planting area. Zhongsi 1048 triticale plant is tall and luxuriant, having many tillers, large leaves, strong winter resistance, disease resistance, lodging resistance, drought resistance, high yield and quality, which is suitable for planting in Huanghuaihai region, Northwest China and Jiangnan region. Zhongsi 1877 is resistant to had strong immunity to stripe rust and powdery mildew, drought and cold tolerance, lodging resistance. It is suitable for autumn sowing in Huanghuaihai and Northwest China, and can be planted in winter in South China.

3.2.5 Breeding Methods

Distant hybridization refers to cross between different species, sub-species, genera, which is beneficial to break species limits, increase genetic variation, and combine the biological characteristics of existing species. It is an important method which widely used as a tool of chromosome manipulation in forage crop improvement. There are many new forage crop varieties bred using the method in China. Among the alfalfa varieties bred, Gannong No. 3 and Tumu No. 2 were bred by crossing *M. sativa* subsp x varia cvv. Caoyuan No. 1 and 2, Tumu No. 1, and Gannong No. 1 were developed by crossing subsp. *Medicago sativa* and subsp. *Medicago falcata*. Longmu No.801 and 803 were bred through intergeneric reciprocal hybridization of wild diploid *M. ruthenica* and tetraploid *M. sativa* on the basis of radiation mutagenesis techniques. Reyan No. 4 (*Pennisetum purpureum* × P. tyhoideum cv.) and Guimu No. 1 (*Pennisetum americanum* × P. purpureum) × P. purpureum Schum. cv.) with high yield, robust root system and lodging resistance were developed by interspecific hybridization.

Heterosis is a well-known phenomenon whereby hybrid offsprings resulting from cross pollination show greater vigor than both parents. Heterosis requires male sterile lines. Studies on the alfalfa heterosis began in 1978 in China. Six male sterile lines were selected from *Medicago varia* Martin. cv. Caoyuan No. 1 in Inner Mongolia Agricultural University. The correlations of genetic distance, combining ability, photosynthetic physiological characteristics and heterosis effects of alfalfa male sterile lines and hybridized combination were analyzed, laying a theoretical foundation for how to make full use of heterosis. In 2008, four alfalfa sterile lines were found by Institute of Grassland Research, Jilin Academy of Agricultural Sciences, subsequently the “three-line” hybrid breeding system of alfalfa was preliminarily established, and the new variety of alfalfa developed though male sterile line technology is participating in the regional trials of national grass varieties.

Space mutation breeding, regarded as a new breeding technique, provide excellent materials containing genetic variations for breeding new varieties. The technique takes advantage of special space environment and various mutagenesis factors to induce physiological changes in plant for creating materials with genetic variations, from which new cultivars were developed though identifying and selecting these mutagenic materials carried back by recoverable spacecraft. In China, space mutation breeding has been started since recoverable satellite for scientific experiment was launched successfully in 1987. In recent decades, callus, tissue culture plantlet and seeds of alfalfa (*Medicago sativa*), switchgrass (*Panicum virgatum*), Russina wildrye (*Psathyrostachys juncea*), sainfoin (*Onobrychis viciifolia*) and other forage species were carried by the Shenzhou No. 3, No. 8, No. 10 and No. 11, Tiangong No. 1, Practice No. 8 and No. 10 spacecraft, and the mutagenic effects and mechanisms of carried materials were studied. The research results indicated that there were many types of variations in spacecraft carrying, which caused increased biomass, stress resistance and quality compared with the control seed on the ground. Plant architecture of mutagenic lines also were different from the control plants. The "Avial-1" multifoliate alfalfa bred by space mutation technology showed significant improvement in leafy rate, biomass yield and nutritional quality.

Molecular breeding includes transgenic breeding, molecular-assisted breeding and molecular designing breeding. In recent years, with the rapid development of biotechnology, molecular breeding technology has been widely used in forage breeding program. Especially, transgenic technology plays an important role in forage genetic improvement because a large number of functional genes have been discovered, such as the drought-resistant genes *ZxNHX/ZxVP1-1* and *MsLEA1*, acid-resistant genes *MsMYB741* and *MsPG1*, cold-resistant gene *MfERF1*, salt-resistant gene *PvNaH*(K^+)*, the branching and plant height regulated gene NAB1, the secondary metabolism regulated gene MsASMT1* etc. These functional genes were successfully introduced into alfalfa and other forage species by genetic transformation method. And the positive transgenetic plants with excellent agronomic characteristics show greater potential for genetic improvement compared with the control plants. At present, transgenic alfalfa and switchgrass lines with drought- or salt-tolerance are carried out the intermediate tests. In addition, the genome-wide association and genome-wide selection techniques are rapidly applied to evaluate the important agronomic traits of alfalfa, orchardgrass and other species. Gene editing techniques have been applied in *Medicago truncatula* and alfalfa. The haploid induction gene *ZmPLA1* was found by correlation analysis, and validated by CRISPR/Cas9 site-directed mutation technique. Recently, the genome sequencing of alfalfa and orchardgrass (*Dactylis glomerata*) has been completed. This indicates that the molecular breeding of forage is taking on a new development opportunity.

3.3 Production of Forage Seeds

3.3.1 Research Progress on the Theory of Forage Seed Aging

Most of forage seeds are relatively small and greatly affected by the external environment (such as temperature and humidity) which means forage seeds are extremely sensitive to face aging that reduce their storage life. In recent years, Chinese researchers have already made some progresses in studying seed aging mechanism.

Firstly, due to aging, the germination percentage and index, seedling length and weight, root length and root weight all decreased significantly in forage seeds like alfalfa (*Medicago sativa*), oat (*Avena sativ*), lyme grass (*Elymus dahuricus*), sainfoin (*Onobrychis viciaefolia*), smooth brome (*Bromus inermis*), siberian wildrye (*Elymus sibiricus*) and reygrass (*Lolium perenne*), etc. Meanwhile, seed aging also resulted

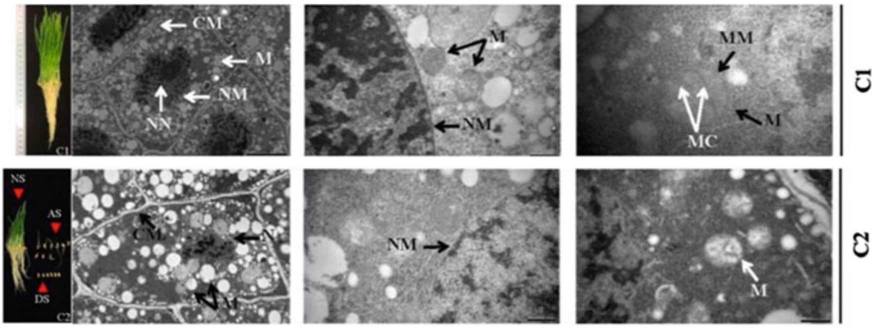

Fig. 3.1 Germination phenotype and mitochondrial microscopy observation of aged oat seeds. Germination of normal seeds (C1) and aged seed (C2) Normal seedlings (NS); abnormal seedlings (AS); dead seeds (DS); CM, cell membrane; N, nuclear; NN, nuclear nucleolus; NM, nuclear membrane; M, mitochondria; MC, mitochondrial cristae; and MM, mitochondrial membrane

into the damages in terms of cell structure, including loss of mitochondrial ultra-structural integrity, unclear boundary between nucleus and cytoplasm, mitochondria swelling, rupture of inner and outer membranes, and destruction of mitochondrial cristae (Fig. 3.1).

Secondly, on the physiological and biochemical level, accumulation of ROS and free radicals are considered to be the most important factors leading to seed aging, which are directly related to the damage of mitochondria. The contents of MDA and reactive oxygen (O2·-, H_2O_2, OH·) are increased and the APX-invovled AsA-GSH cycle was employed to scavenge ROS in embryo of aging oat seed. Over-expression of the oat *AsDHAR* gene could slow down the aging process of seeds by improving the function of AsA-GSH cycle to scavenge ROS and reducing lipid peroxidation after seed aging process.

Thirdly, aging resulted into seed deterioration accompanied by degradation of genomic DNA in *Elymus nutans* seeds. 4C/2C, as results from flow cytometry is an indicator of DNA replication rate, which decreased rapidly when these aged seeds were absorbing water for germination. A comparative study of the transcriptome between aged and normal oat seeds identified 11,335 differentially expressed genes which are mainly related to monomer process, monomer metabolism process, redox process, catalytic and oxidoreductase activity, etc. Some of them are involved in multiple pathways, e.g. starch and sugar metabolism, arginine and proline metabolism, ascorbic acid and aldoate metabolism, and so on (Fig. 3.2). The molecular effects of aging on seed germination are not only on the transcripts level but also on the translation level, especially mitochondrial antioxidant reaction and electron transport chain. For example, after oat seed aging, mitochondrial biogenesis is inhibited, and the enzyme activities involved in mitochondrial electron transport chain and ATP production are weakened; while protein is reduced due to lowering in mitochondrial protein transport, processing, and protein homeostasis.

In addition, seed priming is useful for repairing cell membranes and organelles, activating enzymes, promoting metabolism and synthesis, and finally improving the

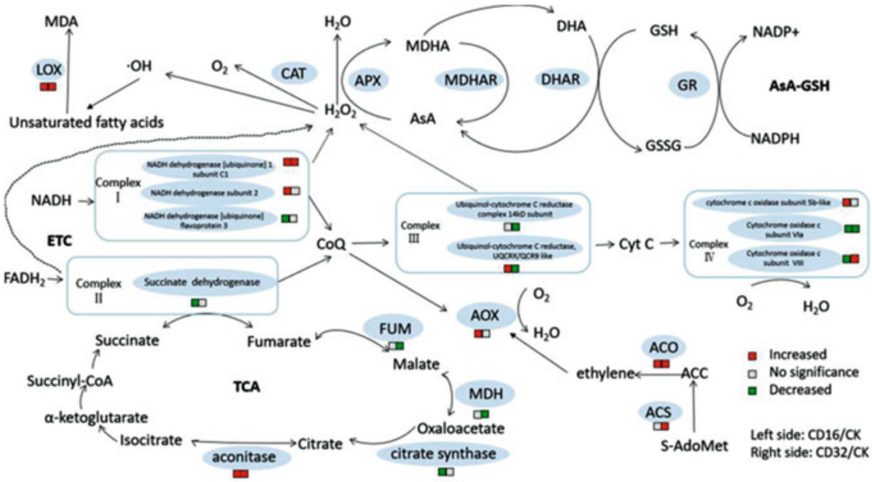

Fig. 3.2 Electron transport chain and antioxidant pathways in aged seeds

vigor of aged seeds. Some progresses have also been made in the studies in seed priming technology and mechanism. For example, aged oat seeds were primed with 200 μM melatonin for 24 h or 10 μM melatonin for 36 h, the germination rate of aged seeds significantly improved, with or without salt stress. During germination, content of free proline, soluble protein and oxidase activities in seedlings increased, while the MDA reduced. Under treatment of NO, mitochondrial TCA cycle and alternate respiratory pathway were upregulated, as the related enzymes in the TCA cycle were increased significantly, such as succinate-CoA ligase and fumarate hydratase. As the result, vigor, germination ability and seedling growth of aged oat seed were improved. When the aged oat seeds were treated by high concentration of PEG, the activities of SOD, CAT and POD were increased, while MDA was decreased. Thereby, germination percentage, germination index and seedling vigor index in aged oat seeds were higher. The priming experiment on aged smooth brome seeds by ascorbic acid (AsA) and glutathione (GSH) showed that the germination percentage, germination potential, germination index, vigor index, leaf length, root length and seedling weight all increased significantly ($P < 0.05$); mean germination time was reduced obviously ($P < 0.05$); and the priming effects of GSH on the germination of aging seeds and the growth of seedlings were more significant.

3.3.2 *Progress in Field Production, Harvest and Storage of Forage Seeds*

A series of national policies, such as the national grassland ecological protection, the development plan of alfalfa production for the dairy industry revitalization, the conversion of grain to forage, the conversion of farmland to forest and grassland, the construction of ecological civilization, and the rural revitalization, have increased the demand of grass seeds dramatically in China. From 2010 to 2015, there have been 100 newly built bases for forage seed production, including 48 for alfalfa seed production in China. After that, the total forage seed production increased from 25,000 tons in 1989 to 78,000 tons in 2016. Currently, there are nearly 2 million mu fields for forage seed production in China, and the annual forage seed yield is about 90,000 tons, among which the seed yields of alfalfa, oat, ryegrass, etc. are over 95% (Fig. 3.3). The main areas of forage seed production are distributed in Gansu, Qinghai, Inner Mongolia and Sichuan, and their yield in these provinces accounts for 76.8% of the total yield in China. Most of these provinces locate in north China, and some provinces in the south (such as Hainan) mainly produce ryegrass and some tropical grass seeds.

The main areas for producing forage seeds in China consist of 11 provinces in the north, including Inner Mongolia, Qinghai, Xinjiang, and Gansu, and 10 provinces in the south area, including Sichuan, Hainan, Guizhou, etc. Gansu Province is suitable to produce forage seeds due to sufficient sunshine, large diurnal temperature fluctuation, and little rainfall, for example, about 70% of the areas with annual rainfall of less than 500 mm (Fig. 3.4). Most forage seeds are produced from alfalfa, oat, triticale, and foxtail millet in Gansu Province where is the biggest area for producing alfalfa seeds in China, then followed by Inner Mongolia, Heilongjiang, Xinjiang, Shaanxi and Ningxia (Fig. 3.5). The highest alfalfa yield per unit is in Xinjiang Production and Construction Corps reaching 1280 kg/hm^2 (data not shown), and the one in Ningxia is also very high, i.e., 780 kg/hm^2 (see red line in Fig. 3.5), which is comparable to the national average in the United States. In Inner Mongolia, seeds of *Artemisia*

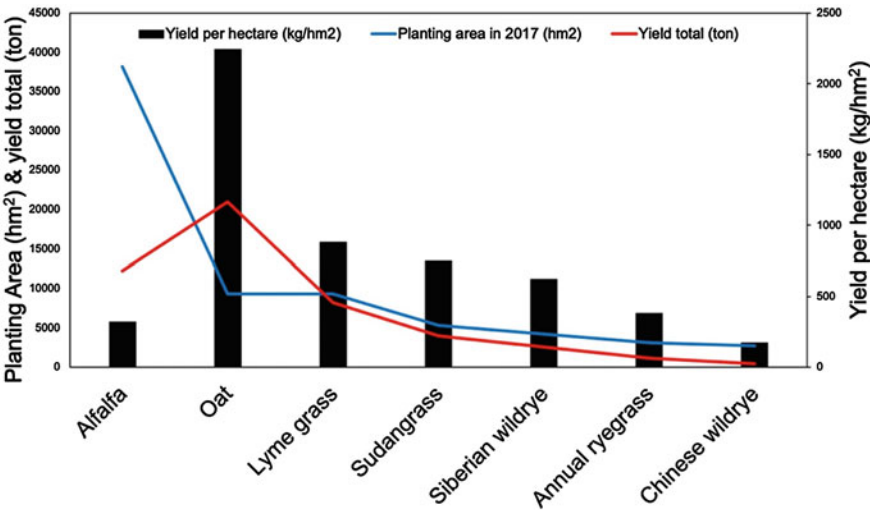

Fig. 3.3 The main forage seeds production in China in 2017

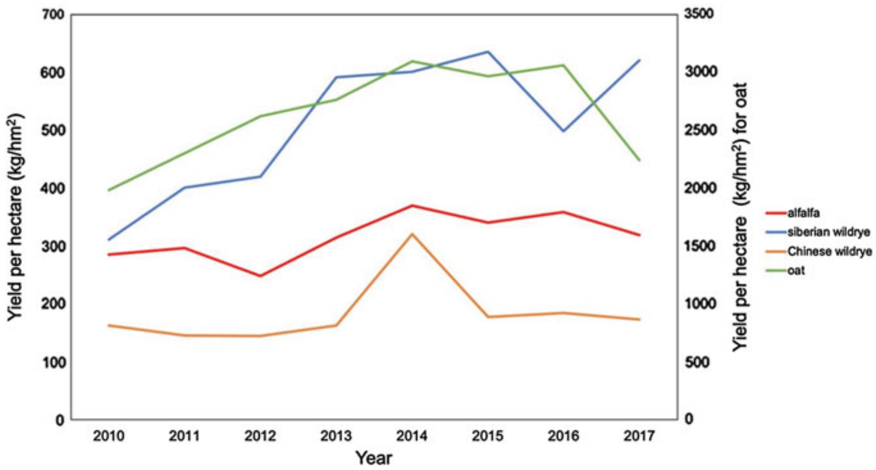

Fig. 3.4 Seed yield per unit area of four forage species from 2010 to 2017

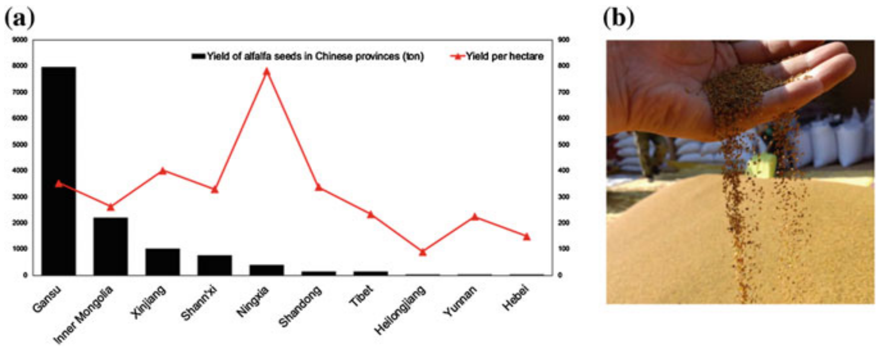

Fig. 3.5 Producing alfalfa seeds in China. A, Major provinces for alfalfa seed production in 2017. B, alfalfa seeds harvested in Gansu Jiuquan Daye Company

desertorum, *Caragana korshinskii*, alfalfa, *Hedysarum laeve*, oat, etc. constitute the majority. In contrast, the seed production in Sichuan Province in the southwest of China is from *Vicia villosa* roth, *Vicia sativa* and *Astragalus sinicus*.

Hainan, the southernmost in China, forage seed production has begun to take shape, mainly distributed in southern and western regions with suitable temperature, rainfall and light. In Hainan, seed production of tropical forage grasses is mainly in Sanya, while in the southwest, the seed production base is more than 1,000 mu in Ledong County, which is the largest forage seed production area in Hainan Province. In total, it consists of 92.6% legume and 7.4% gramineous forage seed yields. *Stylosanthes guianensis* CIAT 184 accounted for 80% of legume forage seed yield. *Paspalum plicatulm*, *Melinis minutifora*, *Setaria ancops* cv. Kazungula accounted for 46.2%, 39.3% and 8.9% of gramineous forage seed yield, respectively.

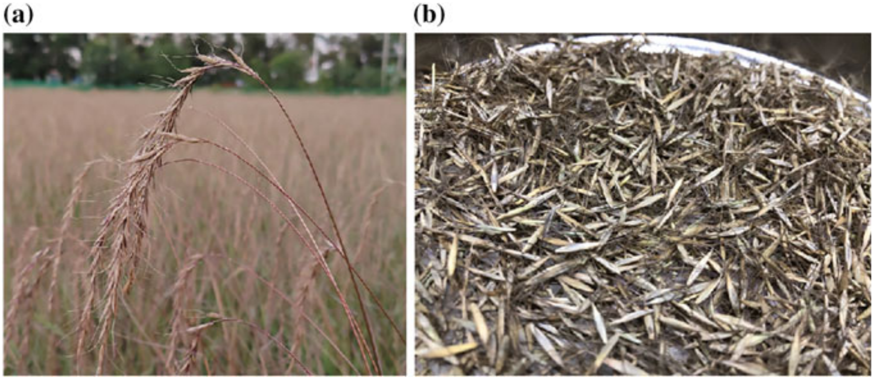

Fig. 3.6 *Elymus sibiricus* seeds before (**a**) and after (**b**) being harvested in Yuershan farm in Hebei Province, China (41° 44′ N, 116° 8′ E; 1455 m elevation)

There are four seed production bases for siberian wildrye (*Elymus sibiricus*) in China, i.e. Mengji seed production zone (see an example of harvested seeds in Yuershan farm in Hebei Province, China, in Fig. 3.6), Gansu Hexi Corridor seed production zone, Qinghai seed production zone and Northwest Sichuan Plateau seed production zone from the north to the south.

At present, Chinese wildrye (*Leymus chinensis*) seed production is mainly carried out in the three zones covering four provinces, i.e., Heilongjiang, Inner Mongolia, Hebei Province and Hexi Corridor of Gansu Province. The main seed production areas of *Dactylis glomerata* are located in Xinjiang and Sichuan. Lyme grass (*Elymus dahuricus*) seeds are produced in the border of Hebei and Mongolia, the Hexi Corridor of Gansu, Tianshan of Xinjiang, Qinghai and the plateau areas in northwest of Sichuan. The seed producing of legume forage white clover (*Trifolium repens*) is distributed in Southwest China (including Yunnan, Guizhou and parts of Sichuan) and central China (including Hubei and parts of Hunan).

At the same time, important progresses have been made in the studies on producing forage seeds in the field in China. For application of nitrogen, studies directed by CAU and Northeast Normal University indicated that the number of reproductive branches per unit area, seed production, grass yield and the efficient nitrogen in *Leymus chinensis* seed production were significantly increased, with application of nitrogen in autumn. Further studies showed that seed production could be improved by increasing photosynthetic efficiency and transferring assimilates from stem to ear tissues in *Elymus sibiricus.*

In terms of planting density and seeding rate, the study of Gansu Grassland Technology Extension Station showed that the seed yield of *Phleum pratense* increased 4.5% compared with the control under the conditions of sowing rate of 7.5 kg/hm^2 and row spacing of 40 cm in Minshan, Gansu province. The study in Qinghai Tiebujia Grassland Improvement Experimental Station indicated that seed yield of *Festuca arundinacea* was increased 1.52 times comparing to the control, with row spacing of 30 cm and sowing rate of 10 kg/hm^2 in high and cold areas of Qinghai province.

For field irrigation time and water quantity, the results showed that actual seed yield of tall fescue was increased 69.77% (to 3460 kg/hm^2) compared with the control when the irrigation amount was 900 m^3/hm^2 at the turning green stage, jointing stage, heading stage and filling stage, while the actual seed yield of *Psathyrostachys juncea* was increased 18.54% (to 505.9 kg/hm^2) when the irrigation amount was 600 m^3/m^2 at the above four stages. For the application of growth regulators, the studies in Nanjing Agricultural University showed that applying exogenous of triadimefon, paclobutrazol or zeaxanthin positively affected tillers number, reduced the lodging of plants, and significantly increased the number of effective panicles, spikelets, grains per spike and seed yield of *Lolium perenne* during tillering stage.

Regarding to the use of leaf-cutting bees (*Megachile rotundata*) to assist pollination in alfalfa farms, the researches by CAU and Inner Mongolia Agricultural University showed that the seed setting rate of alfalfa was 1.26–4.78 folds increased compared with the control, and the highest seed yield was 161.5 kg/hm^2. Through the comprehensive application of field management technology, the forage seed yield has been greatly improved, which provides a strong guarantee for the sustainable development of ecological civilization construction in China. For the harvest time of field seed production, a large number of studies have shown that seed yield and quality are positively correlated with seed moisture content that can be used as a seed harvest index. For example, studies by Northwest Agricultural and Forestry University and Tibet Institute of Agriculture and Animal Husbandry showed that the optimal harvest time of wild *Elymus nutans* was from 28 to 31 days after full flowering stage, and the seed moisture content decreased from 42.00% to 36.59%, while the seed yield increased by 56.62% (to 1856 kg/hm^2) compared with the control in Tibet. In addition, using desiccant reduced the drying time of herbage in the field and the loss of seed production.

The study by Northwest Agricultural and Forestry University and CAU showed that seed yield and thousand grain weight could increase 16.26% (536.45 kg/hm^2) and 5.97% (1.79 g), respectively, compared with the control by exogenous application of 5% K_2CO_3 at the tenth day before seed harvest. The research from Gansu Agricultural University showed that the seed yield of Gannong NO.3 alfalfa could increase by 72.85% (799.63 kg/hm^2) compared with the control by spraying 1.2% $MgClO_4$ on the leaves at the mature stage.

Seed coating is a critical element for seed quality, enhancing seed stress tolerance and extending seed longevity. The main coating grass species are: legumes such as alfalfa, astragalus and white clover, and gramineae species such as bluegrass, fescue and *Elymus*. The main types include growth-promoting, pest-resistant, drought-resistant and salt-tolerant coatings. For example, the study from CAU showed that the germination rate and germination potential of aged seeds of oats, *Elymus sibiricus*, alfalfa and *Bromus inermis* could be significantly improved by adding AsA or GSH to the seed coating agents. The research from Lanzhou University showed that the germination rate, plant height and biological weight of coated seeds can be significantly improved by adding different concentrations of fungicides and adhesives in alfalfa seed coating agents.

For the research progress of forage seed storage technology, the standard of "Rules for Forage and Turf Grass Seed Storage" (GB/T 24866-2010) has been drafted in China. Warehouse construction, seed warehousing treatment, mid-term inspection, seed moisture, germination rate and pest inspection, and warehouse management measures were required to perform based on this standardization.

3.4 Status and Development of Forage Seed Quality Testing in China

3.4.1 Standards of Forage Seed Quality Testing in China

Forage seed quality testing started late in China. The "Rules for grass testing of the People's Republic of China (GB/T2930-1982)", was the first standard which issued in 1982. Quality grading of forage seeds was firstly established and promulgated in 1985, including "Qualities grading of main cultivated grasses seeds (GB6142-1985)", "Qualities grading of main cultivated legume seeds (GB6141-1985)" and "Qualities grading of main cultivated Artemisia sphaerocaphala and Kochia prastrata seeds (GB6143-1985)".

In the twenty-first century, with the strengthening of seed trade activities and the standardized management of market operation, the demand for testing seed quality has also increased rapidly. Current national rules of seed testing for forage, turfgrass and other herbaceous plant mainly include quality testing rules and quality grading rules. Among them, current quality testing rules for grass seeds are mainly "Rules of seed testing for forage, turfgrass and other herbaceous plant-Sampling (GB/T2930.1~10-2017)" (Fig. 3.7), "Rules of seed testing for forage, turfgrass and other herbaceous plant in China—Testing report (GB/T2930.11-2008)" (Fig. 3.8) and "Determination of moisture content of forage seed—Moisture meters method (GB/T24867-2010)". "Rules of seed testing for forage, turfgrass and other herbaceous plant (GB/T2930.1~10-2017)" is the second revision of the rules since it was promulgated in 1982. It covers seed germination methods for totally 169 species of forage, turfgrass, feed crops and ecological grass, as well as 60 species of ornamental grass and medicinal plants. The current quality grading standards for forage seeds mainly include "Quality grading of legume seeds (GB6141-2008)", "Quality grading of the grass seeds (GB6142-2008)", "Quality grading and testing for main sandy forage seed (GB/T24869-2010)", "Quality grading of the Chinese ephedra (Ephedra L.) seeds (GB/T26614-2011)", "Quality grading of princes-feather (*Amaranthus hypochondriacus* L.) seeds (GB/T26615-2011)", etc. In addition to national standards, industry standards have also been formulated as supplements in recent years. For example, the enactment of "Specification of seed testing for forage and turfgrass—Accelerated aging for vigour test (NY/T 3187-2018)" has filled in the blank of forage and turfgrass seed vigour test in national standards in China. Rules of seed


中华人民共和国国家标准

GB/T 2930.1—2017

草种子检验规程
扦样

Rules of seed testing for forage, turfgrass and other herbaceous plant—Sampling

(The International Seed Testing Association, International rules for seed testing, edition 2012, Chapter 2, Sampling, MOD)

2017-11-01 发布 2018-05-01 实施

中华人民共和国国家质量监督检验检疫总局
中国国家标准化管理委员会 发布

Fig. 3.7 Rules of seed testing for forage, turfgrass and other herbaceous plant (GB/T2930.1~10-2017)


中华人民共和国国家标准

GB/T 2930.11—2008

草种子检验规程 检验报告

Rules of seed testing for forage, turfgrass and other herbaceous plant in China—Testing report

2008-07-31 发布 2008-11-01 实施

中华人民共和国国家质量监督检验检疫总局
中国国家标准化管理委员会 发布

Fig. 3.8 Rules of seed testing for forage, turfgrass and other herbaceous plant in China—Testing report (GB/T2930.11-2008)

testing and quality grading for forage and turfgrass are the important basis of seed testing and make it more standardized in China.

3.4.2 Forage Seed Quality Testing Technology in China

A great deal of research work has been carried out in China for years, especially in the field of seed germination and seed vigor test methods.

Research for forage seed testing has been focused on methods for removing seed dormancy, hard seeds and standardization of seed germination. For example, for grass seeds with physiological dormancy such as *Buchloe dactyloides*, *Zoysia japonica* and *Leymus chinensis*, as well as leguminous seeds with high hard seed percentage such as *Trifolium repens*, *Trifolium pratense* and *Trifolium lupinaster*, effective methods were carried out to break dormancy and hard seeds, so as to improve the accuracy of seed germination test. In addition, for some wild grass seeds that have not been included in the rules, such as *Glycyrrhiza pallidiflora*, *Sophora alopecuroides*, *Indigofera pseudotinctoria*, *Tephrosia candida*, etc., the standard germination methods are developing. All of these continuously promote and improve the standardization of seed germination percentage test for forage and turfgrass in China.

With the development of seed testing technology, the research on testing seed vigor method has become important. According to different forage species, artificial accelerated aging, electrical conductivity, near-infrared technology and average germination time were used to evaluate the seed vigor levels. For example, artificial accelerated aging reflects the seed deterioration in a short time. The conditions of artificial accelerated aging of *Avena sativa*, *Poa pratensis*, *Leymus chinensis*, *Agropyron cristatum* and other forage seeds were screened and determined, and "Specification of seed testing for forage and turfgrass—Accelerated aging for vigor test (NY/T 3187-2018)" was formulated. The electric conductivity measurement was used as an important reference index for the rapid determination of seed vigor, based on *Elymus Canadensis*, *Elymus sibiricus*, *Medicago sativa* and other forage seeds. It was proposed that the near-infrared technology could accurately distinguish *Avena sativa* seeds with different vigor levels. The mean germination time was used as the evaluation index for seed vigor test of *Avena sativa*, *Elymus nutans* and *Lolium multiflorum.* However, the seed quality testing standards and the forage seed quality testing methods still need to be improved and enriched urgently at the present stage in China.

3.4.3 Related Laws, Regulations and Quality Testing Institutions for Forage Seeds in China

The "Seed Law of the People's Republic of China" and the "Grassland Law of the People's Republic of China" are the main laws relating to forage seeds. It is stipulated that the grassland administrative departments of the people's government agencies at or above the county level should strengthen supervision and administration over the forage seed production, processing, quarantine and testing in accordance with the laws, so as to provide seed quality assurance. The "Measures for the Administration of Grass Seeds" implemented in 2006 and the "Assessment Method for Grass Seed Analysts " implemented in 2009 are the main regulations in force, which require that the quality of imported and exported grass seeds must meet the national standard, and an examination system for seed analysts should be established. All of these laws and regulations make grass seed testing in China standardized and marketized.

Since 1984, the Ministry of Agriculture has invested and established a number of forage and turfgrass seed quality supervision and testing centers (stations) in 20 provinces (districts or cities). At present, there are 47 forage and turfgrass seed quality supervision and testing institutions in China, among which 5 ministerial quality testing centers have passed the national metrology certification and the approval of the Ministry of Agriculture. The national grass product quality supervision and testing system has been preliminarily established, playing an important role in strengthening the quality supervision of grass seed and product production and circulation, standardizing the grass product market according to laws, promoting the preservation and utilization of grass germplasm resources, and ensuring the quality of grass seeds used in grassland ecological protection projects. In 1989, the Forage Seed Laboratory of China Agricultural University, on behalf of forage seed testing institution of China, officially joined the International Seed Testing Association (ISTA). In 2013, the Forage Seed Laboratory of China Agricultural University passed the on-site review and became the ISTA accredited laboratory, which can issue the blue and orange certificates for seed testing. At the same time, it is the only ISTA accredited laboratory with the ability of seed testing for forage and turfgrass in China mainland, which has become an important bridge for quality testing, international exchange and foreign trade of grass seeds between China and the world.

Chapter 4
Research Progress of Forage Grass Cultivation

Zhongkuan Liu, Zhenyu Liu, Nan Xie, and Liping Ban

4.1 Modern Seeding Methods

4.1.1 Mixed Seeding

In the mixed-seeding system, one species will change its living environment locally through its physiological activities, and the changed environment will affect the growth and development of other species in the system (Chen et al. 2011); When two species grow in the same environment, interspecific competition and promotion always exist at the same time (Chen 2011), when the competition effect is lower than the promotion effect, mixed seeding shows an advantage, but when the competition effect is greater than the promotion effect, mixed seeding shows no advantage or disadvantage.

Selecting suitable combination of grass species can transform competition into complementary effect to a certain extent, so as to make full use of environmental resources and improve grassland productivity. In the commonly used gramineous legume mixed seeding system, legume forages were mostly pea, *Vicia sativa*, red clover, white clover, etc., while gramineous forages are mostly oats, barley and rye, etc. (Zhang et al. 2001). Two to four kinds of mixed seeding were common. The results showed that the yield of mixed seeding was usually higher than that of single seeding, and the yield of different mixed seeding species varies greatly (Dong et al. 2003). Therefore, in practice, it is very important to choose the suitable combination of forage species.

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Under the condition of constant population density, the proportion of gramineous and leguminous forage seeds directly affects the population growth, forage yield and quality, but it also varies with different populations. In Shihezi, Xinjiang, Chinese scholars studied the yield and quality changes of alfalfa and *Bromus inermis* mixed grassland, and found that the mixed proportion affected the yield, quality and community stability of alfalfa and *Bromus inermis*, and with the increase of *Bromus inermis* proportion, the higher the yield of mixed grassland, the better the community stability (Zhang et al. 2009). In alpine pastoral areas, the optimum ratio of mixed seeding of *Vicia sativa* and oat was 3:7, under this ratio, the yield of mixed seeding was 27.9% higher than that of single seeding of oat, and 25.4% higher than that of single seeding of *Vicia sativa*, when the soil fertility was high, a higher aboveground biomass could be obtained by appropriately increasing the proportion of oat (Zhou 2002). However, in Hualong County, the experiment of selecting the suitable mixing proportion of oat and *Vicia sativa* showed that the mixing proportion of oat and *Vicia sativa* was 1:1 or 3.5:6.5 (Han 2000).

In the system of mixed seeding of grass and soybean, the productivity of grassland could be improved to the maximum by choosing the suitable mixed seeding mode and seeding density. Studies conducted in alpine pastoral areas show that the mixed seeding mode and density of Gramineae and legumes had significant effects on grass yield (Zhang et al. 2001). In addition, legume forage contained higher protein, calcium and other nutrients, while Gramineae contained higher carbohydrate. The forage with better quality should have higher nutrient content and lower fiber content. The results showed that the quality of forage grass was improved by mixed seeding of grass and soybean, and the crude protein content of forage grass was also increased with the increase of legume planting amount (Han et al. 1999).

4.1.2 Companion Seeding

Protected seeding refers to the way of seeding perennial forage under the protection of annual crops. Due to the slow growth of alfalfa, red clover, *Dactylis glomerata* and other perennial grasses in the year of seeding, weeds damage in the field was extremely serious, which had a great impact on the normal growth of seedlings (Lei et al. 2007). The fast-growing annual crops could quickly cover the ground, reduce weed competition, reduce wind erosion and water erosion. The protection crops should have the following characteristics: first, less tillers to prevent excessive shading of herbage; second, early growth to reduce the competition of weeds; third, early maturity to shorten the symbiotic period with herbage.

The techniques of protection seeding with winter wheat on Trifolium pratense cv. Minshan were studied with 3 different treatments (including protection seeding, herbicide and weeds control by hand) through measuring the plant height, grass yield and economic profit (Wang et al. 2009). The results indicated that the protection seeding was the effective way to protect Trifolium pratense cv. Minshan from other weeds and the economic profit could be increased as well. The results showed that naked oats were more effective in controlling weeds growth in seedling stage than naked oats; Alfalfa (15 kg/hm^2) + naked oats (120 kg/hm^2) with 40 cm row spacing were suitable for spring seeding alfalfa in Chongqing; the suitable cutting time of oats was from May 11 to May 21.

In order to solve the weed problems during the seedling stage of alfalfa (*Madicago sativa* L.) in hilly area of South Jiangsu Province, three companion crops (annual ryegrass, triticale and tall fescue) were evaluated for their fitness and seeding rate by alfalfa yield and plant height as well as weeds emergence (Qi et al. 2008). Triticale and annual ryegrass had better performance as companion crops during alfalfa establishment, and the combinations were broadcast seeding of alfalfa at 16.7 kg/hm^2 + annual ryegrass at 25.0 kg/hm^2 and strip seeding alfalfa at 16.7 kg/hm^2 with 40 cm row spacing + interrow seeding triticale at 266.7 kg/ hm^2. The sequence of better weed control of the studied companion crops was as follows: annual ryegrass > triticale > tall fescue. Protective seeding can effectively reduce the proportion of weeds in alfalfa fields. Considering the yield and nutritional quality of alfalfa, the best performance of the first crop of alfalfa can be obtained when the seeding amount of spring wheat is 120–180 kg/hm^2.

4.1.3 Low Temperature Seeding

Low temperature seeding technology mainly includes Close-winter seeding and Frost seeding, which is an effective seeding method to improve the germination rate of forage in northern China.

Close-winter seeding, that was to say, the seeds were sown before the soil was frozen, so that the seeds could spend the whole winter in the soil without germination, and start their growth activities when the water and heat conditions were met in the next spring. The research in the area around Qinghai Lake showed that, compared with spring seeding within a single growing season, several forages sown in close-winter have better emergence and growth, and the development degree was further than that in spring seeding, most forages could reach the beginning of heading, and some forages could reach the heading stage or even enter the flowering stage, the height of grass layer was 17–56 cm, the fresh grass yield was more than 1500 kg/hm^2, which was much higher than the growth height and fresh grass yield of the same forage in the first year of spring seeding. The study on the best seeding time of Alfalfa in Northern Xinjiang (Li et al. 2010) showed that, the alfalfa sown in close-winter was harvested three times in the first year, the hay yield reached 721.70 kg/667 m^2, which was higher by 26.9% than spring seeding, and the growth period was earlier by 15–18 days. The study on the suitable seeding date of wheatgras in Baiyinxile area (Zhang 2021) showed that the seeding effect was better at the end of October, in the second year, the growth rate was 1.86 cm/d, the seed yield was 1798.2 kg/hm^2, and 1000 seed weight was 2.137 g, which were significantly higher than that of spring seeding wheatgrass.

Frost seeding is an method that distribute seed directly onto the frozen soil surface in very early spring or late winter, expansion and contraction associated with freeze/thaw cycles incorporates the seed into the surface soil layer. The research (Liu et al. 2014) on the seeding date of highland barley in different ecological regions of Lhasa and Xigaze showed that, the yield of highland barley by frost seeding increased by 83.7% and 143.2% respectively compared with the traditional spring seeding, and the number of weeds in jointing stage of highland barley by frost seeding was far less than that by traditional spring seeding, and the height of weeds was also significantly lower. Zhang et al. reported that, it is better to carry out autumn plowing for the plot planning to seed in very early spring, and the autumn plowing should be early and deep, raking should be done in time after plowing, and seeding should be organized in time when the soil surface thaws 2–3 cm in early spring; In the case of no autumn plowing, when the soil surface thawed 2–3 cm in early spring, seeding should be organized in time after the soil was harrowed, and then it should be pressed to conserve soil moisture.

4.1.4 Furrow Seeding

Furrow seeding changed the surface morphology and enhanced its water storage capacity, furrow seeding in northern China could effectively improve the soil water use efficiency of winter wheat, even when the irrigation water was reduced by 30%, the effect of improving water use efficiency was still significant; The field evapotranspiration and humidity of winter wheat adopting furrow seeding were 0.1–0.35 mm/h lower and 1.26%–2.75% higher respectively than that of winter wheat adopting flat seeding. Some studies have shown that, compared with ordinary flat seeding, furrow seeding delayed the senescence of flag leaves at the later growth stage of winter wheat, and made crops have more time for photosynthesis and dry matter accumulation, moreover, furrow seeding had higher flag leaf area, and chlorophyll degradation was relatively slow, which played a good coordination role in photosynthesis. Furrow seeding significantly increased the dry matter accumulation of winter wheat in pre winter tillering and growth stages in southeastern Shanxi Province, and the dry matter yield at heading stage was 28.43% higher than that of traditional flat seeding. After the multi-site experiment and demonstration, it was found that the simplified foxtail millet cultivation technique adopting furrow seeding had the effects of rainwater harvesting and soil moisture conservation and could improve the yield, the demonstration field for the cultivation adopting furrow seeding showed a yield increased by more than 750 kg/hm^2 in comparison with the ordinary flat seeding at a yield increase rate over 15%. Huang reported (1996) that the furrow depth was 15–20 cm and the covering soil thickness was 2–3 cm, and the returning green of alfalfa adopting furrow seeding was about 10 days earlier than that of alfalfa adopting flat seeding in the spring of the second year, and the overwintering rate and hay yield were increased by 45.5% and 40.6% respectively. Compared with flat seeding, furrow seeding with film mulching for water storage and heat preservation could promote alfalfa planting obviously, which can better solved the problem of dislocation between precipitation and forage growth and development in semi-arid mountainous area, and had good forage production performance in the current year, the treatment of 40 cm ridge width with film mulching had the best forage yield and root neck development, followed by 30 cm ridge width, 50 cm ridge width and 20 cm ridge width, to consider the effect of the yearly rainfall and the increasing plants in row on the development of plants, the ridge width of 30 cm and 40 cm was suited for soil and water conservation or seed field, 20 cm and 30 cm for grass.

4.1.5 No-till Seeding

No-till seeding technology is a kind of sowing method that does not carry out soil ploughing, harrowing and other operations before planting crops to prevent the structural damage of surface soil layer, increase the surface straw coverage, and reduce soil wind erosion, mainly including the technology of breaking skin and opening ditch, anti blocking technology, seed fertilizer application technology, covering and pressing technology. No-till seeding can create less soil disturbance than moldboard plowing method, these methods are recommended on sloping soils where erosion is a concern.

The yield of Italian Ryegrass was different between direct sowing with tillage free and traditional sowing with whole tillage, but it did not reach a significant level, and there was no significant difference between plant height and tiller number; Direct seeding with tillage free had no obvious effect on the production performance of Italian Ryegrass compared with traditional sowing with whole tillage, if direct seeding technology with tillage free was used to plant Italian Ryegrass, as long as water and fertilizer management were strengthened, the production level of traditional sowing with whole tillage could be achieved [5]; Direct seeding of forage with tillage free could save a lot of labor, reduce planting costs, and also sow in advance to extend the grass supply period, therefore, direct seeding with tillage free was a planting technology worthy of promotion in winter fallow fields.

The most suitable forage-grass sowing method in wasteland was “heavy harrow scarification + broadcast sowing + heavy harrow covering seed”, that is to say, heavy harrow scarification was adopted first, then grass seeds were broadcast sown, and finally heavy harrow covering seed was adopted, compared with the traditional sowing method with tillage free (sowing + heavy harrow covering), the emergence rate was increased by 14.6%. According to the local conditions, perennial forage could be sown either in spring or in autumn in alpine pastoral areas under no tillage, spring sowing was suitable in the middle and late April, and autumn sowing was best arranged in the middle of October, among them autumn sowing was the best. The results showed that reseeding with tillage free and soil loosening was better than sowing with seed broadcast and suppresssing, and “reseeding with tillage free and soil loosening + sprinkler irrigation” was better than reseeding with tillage free and soil loosening and sowing with seed broadcast and suppresssing, the grass yield per unit area was increased by 10% and 32% respectively.

4.2 Field Management Technique

4.2.1 Weed Control Technique

The results of field weed control test using soil sealing herbicides (33% Shitianbu EC, 48% Trifluralin EC and 90% acetochlor EC) two weeks before alfalfa sowing showed that, three types different doses of the medicament had a certain effect on the emergence rate of alfalfa, among them, 90% acetochlor EC had the greatest impact; while 33% Shitianbu EC and 48% Trifluralin EC had good control effects on weeds in alfalfa fields among them, the control rate of weeds were over 86%, the yield of alfalfa increased by 15.47–23.48%, and the weed content of alfalfa bales dropped below 5% (Zhang et al. 2016). The security tests of 10 kinds of herbicides were carried out for soil sealing after alfalfa sowing, the results showed that irrigation after 8 h of applying herbicide in soil, 5% imazethapyr AS and 48% butralin EC were safe to alfalfa and the control effect were above 92.34% after 30d of applying herbicide; 480 g/L fluorin EC and 960 g/L S-metolachlor EC were also safe to alfalfa and the control effect reached 92.34% and 89.9% respectively after 30d of applying herbicide (Ma et al. 2017).

The yield and weed control effects showed that, 2,4-DB and bentazon applied alone or mixture had a better control effect on broadleaf weeds, and control efficiency was 75.80–90.65%;Haloxyfop-R-Methyl,quizalofop-R-methyl and clethodim had effective control on monocotyledon weeds in alfalfa field, and control efficiency were more than 71.10%; however, 2,4-DB decreased the cumulative yield of alfalfa more than 64%; while bentazon + Haloxyfop-R-Methyl,bentazon + Quizalofop-R-methyl and Haloxyfop-R-Methyl improved the yield of alfalfa harvested secondly up to 46.50%, 45.28% and 43.06% receptively; with the comprehensive consideration of herbicide performance, bentazon + Haloxyfop-R-Methyl and bentazon + Quiza lofop-R-methyl showed better results and could be widely applied in alfalfa fields. The effects of herbicide application on alfalfa yield and weed control at alfalfa three leaf stages showed that, the control effect of plant and fresh weight on oat was higher when applied at the four-leaf stage than at the five-leaf stage, and much better than at the six-leaf stage; the mixture of imazethapyr and haloxyfopr-methyl significantly improved the control effect on oats and increased alfalfa yield by 100–1000 kg/hm^2; the combination of bromoxynil octanoate and haloxyfop-r-methyl could reduce the control effect on amaranthus retroflexus, but it increased the control effect on oats and significantly increased the yield of alfalfa by 1000 to 2000 kg/hm^2; with the comprehensive consideration of the safety of the herbicides,the increase in alfalfa yield, and the control effect of weeds, the herbicides of weed control seedling stage of alfalfa in the Horqin sandy land, should be the mixture of imazethapyr 1200 ml/

hm^2 + haloxyfop-r-methyl 660 ml/hm^2 or imazethapyr 1800 ml/hm^2 + haloxyfop-r-methyl 660 ml/hm^2 at the four-and the five-leaf stages;the combination of bromoxynil octanoate 1050 ml/hm^2 + haloxyfop-r-methyl 660 ml/hm^2 or bromoxynil octanoate 1500 ml/hm^2 + haloxyfop-r-methyl 660 ml/hm^2 was also recommended to achieve the similar increase in alfalfa yield at the four-and the five-leaf stage.

In order to control weeds in mature alfalfa field with suitable herbicide in Huanghuaihai area, the effect of four herbicides (imazethapyr, quizalofop-p-ethyl, haloxyfop-r-methyl and oxyfluorfen) with different concentration on afalfal yield and weed community characteristics were studied, the results showed that both imazethapyr and haloxyfop-r-methyl treatments could increase alfalfa yield, and the best herbicide application concentration was imazethapyr with 2000 ml/hm^2 and haloxyfop-r-methyl with 700 ml/hm^2, but oxyfluorfen treatment would limit alfalfa growth significantly; weed species numbers in the treatments of imazethapyr, quizalofop-p-ethyl and oxyfluorfen decreased significantly; digitariasanguinalis, Portulacaoleracea and Echinochloacrusgalli were more difficult to control from specie important value in all treatments; species diversity index decreased with higher herbicide concentration in all treatments, from this study, herbicide imazethapyr with 2000 ml/hm^2 application concentration was the best weed control method, and the second one was haloxyfop-r -methyl with 700 ml/hm^2 application concentration. Spraying herbicide at 3–5 leaf stage of alfalfa field weeds in Ningxia, 5% imazethapyr AS and 84% cloransulam-methyl WG would not effect the normal growth of alfalfa, although other herbicides had good control effect to weeds such as *Chenopodium serotinum* L., *Amaranthus retroflexus* L. and *Solanum nigrum* L., but they had injury on alfalfa (Ma et al. 2017).

To solve the weeds existed in seedling period of alfalfa in Chongqing, the naked oat and common oat were selected with the accompany sowing crops to better control weeds in the seedling period of alfalfa; compared with common oat, the tested naked oat as the companion crop of alfalfa seeding could prevent weeds more effectively; the proper companion-seeding disposal of alfalfa sowed in spring in Chongqing area was 15 kg/hm^2 alfalfa and 120 kg/hm^2 naked oat; the suitable mowing period of oat was during the time from May 11th to 21th, and the suitable alfalfa mowing period was 10 days after oats mowing.

4.2.2 Nutrient Management Technique

Studies have shown that alfalfa could fix nitrogen in soil for its own needs, so it did not need to apply nitrogen fertilizer; Nitrogen application had no effect on alfalfa hay yield, and excessive nitrogen application was likely to cause leaching of nitrate nitrogen in soil, which would inhibit alfalfa growth. However, other studies have shown that although alfalfa had the function of nitrogen fixation, a large number of rhizobia were not formed in the early growth stage, in order to make alfalfa grow normally, appropriate amount of nitrogen fertilizer should be added. Studies have shown that with the increase of nitrogen content and application rate, the fresh weight per plant and the number of branches of Alfalfa also increased. The results showed that the application of low nitrogen content was more beneficial to the formation of root nodules, and then increased the nitrogen fixation capacity of alfalfa. Studies showed that under partial drought conditions, nitrogen application could increase alfalfa yield by 8%-25%, and the optimal nitrogen application rate was 80 kg/hm^2.

The results of application of different levels phosphorus fertilizers on alfalfa yield and quality indicated that plants height and side branches of alfalfa were significantly higher than CK with application different levels of phosphorus if there was enough K and N; Plants height of alfalfa was increased by 8.2–10.1 cm and side branches increased by 0.9–1.8 per plant; alfalfa yield increased by P application from 30.8 to 70.2%;the optimum P application rates based on benefit and yield was 102.4 kg/hm^2 under this experimental condition; there was not significant increase in content of crude protein, crude fiber, crude ashes and P, K et al., however, obvious increase in yield of crude protein, crude fiber et al. contents of alfalfa at different levels of phosphorus application was observed; compared to the treatment without P application, application of phosphorus at rate of 30–120 kg/hm^2 not only increased the absorption of P but also stimulated K and Ca absorption of alfalfa. Xie et al. showed that the yield increase rate of phosphate fertilizer application in the arid area was between 122 and 172%, and the yield reduction of phosphate fertilizer deficiency treatment was 38.24%. Xiao showed that phosphate fertilizer could also increase the number of Alfalfa Rhizobia. At the same time, when the nitrogen and potassium fertilizer were the same, the phosphorus fertilizer showed the effect of increasing the content of Alfalfa crude protein and nitrogen free extract. In addition, the research of Li (2004) showed that topdressing with phosphorus fertilizer could improve the yield and photosynthetic rate of alfalfa.

Application of potassium fertilizer could improve the resistance of plants to drought, cold, disease, salt and lodging. The content of potassium in alfalfa was as high as 2.4%. Alfalfa needed a lot of potassium. Every 10 tons of alfalfa hay needed to absorb 226.5 kg of potassium from the soil. However, Geng believed that the potassium content of soil in northern China was rich, which could basically meet the demand of Alfalfa for potassium, so the application of potassium fertilizer was rarely considered in alfalfa fertilization in northern China. Yang et al. showed that with the increase of planting years, the potassium content in alfalfa plants decreased. Appropriate application of potassium fertilizer could increase the yield and crude protein content of Alfalfa. Wen showed that the appropriate amount of potassium fertilizer could improve the plant height, lateral branch number, yield, crude protein, crude fat and calcium content of alfalfa. Xing et al. showed that potassium application could improve the chlorophyll content, photosynthetic rate and transpiration rate of alfalfa leaves, and appropriate amount of potassium fertilizer could significantly increase the yield and improve the quality of alfalfa.

The results of a 3-year field experiment to study the effects of nitrogen, phosphorus and potassium fertilizers applied on the hay yield and quality of alfalfa showed that, fertilization increased alfalfa hay yield in different degrees; according to the actual total hay yield in three years, the highest hay yield was 39.76 t/hm^2 when N was 50 kg t/hm^2, P_2O_5 was 120 kg/hm^2 and K_2O was 60 kg/hm^2, 44% higher than the control; based on the functional relationship between the total hay yield and fertilization treatment in three years, the highest total hay yield was 41.18 t/hm^2 when N was 68.3 kg/hm^2, P_2O_5 was 130.7 kg/hm^2 and K_2O was 55.0 kg/hm^2; fertilization significantly increased the crude protein content and relative feeding value of Alfalfa ($P < 0.05$), significantly reduced the contents of neutral detergent fiber and acid detergent fiber ($P < 0.05$), and the crude ash content had no significant difference among different fertilization treatments ($P > 0.05$) (Chen et al. 2019). Luo et al. pointed out that the combined application of organic fertilizer and N, P, K fertilizer should be paid attention to in the early stage of alfalfa planting and growth. The research of Fan Fu et al. showed that the fertilization schemes with the highest yield of alfalfa were N 0 kg/hm^2, P_2O_5 63.56 kg/hm^2 and K_2O 110.00 kg/hm^2. Gao et al. studied the effect of combined application of fertilizer on alfalfa dry matter yield in Hebei Province, and pointed out that when the dosage of ammonium chloride, potassium sulfate, magnesium chloride and calcium superphosphate were 155.9–174.3, 163.3–181.7, 30.1–33.6 and 566.2–632.9 kg/hm^2 respectively, the probability of alfalfa yield reaching 19,224.6 kg/hm^2 was 95%. The results of Liu and Li showed that the yield of fresh alfalfa could reach 45,106.6 kg/hm^2 under the combined fertilization of N 90 kg/hm^2, P_2O_5 120 kg/hm^2 and K_2O 150 kg/hm^2.

The interaction of nitrogen and phosphorus, phosphorus and potassium could increase the yield of alfalfa, but the interaction of nitrogen and potassium could inhibit the yield of Alfalfa. Among different nitrogen and phosphorus treatments, the annual total hay yield under N1P2 (N:105 kg/hm^2, P_2O_5:100 kg/hm^2) treatment was the highest of alfalfa under drip irrigation; Under this treatment, the crude protein content of leaves and stems was the highest, the NDF content of leaves was the lowest, and the nitrogen absorption efficiency, nitrogen factor partial productivity and phosphorus use efficiency were the highest; The hay yield, crude protein content and relative feeding value were significantly increased by spraying boron and molybdenum fertilizer of alfalfa under drip irrigation; If a single element was considered, the effect of boron fertilizer on the production performance and nutritional quality was greater than molybdenum fertilizer of alfalfa under drip irrigation. The results of P and K fertilizer on the alfalfa yield showed that the greatest alfalfa yield was obtained with the fertilizer application treatment of 600 kg/hm^2 superphosphate and 100 kg/hm^2 potassium sulphate. Experiments of P and K fertilizer in Beijing area showed that combined fertilization could significantly elevate yield of alfalfa, the highest yield was gained when fertilizing 45.8 kg/hm^2 P_2O_5 and 12.5 kg/hm^2 K_2O.

The effects of selenium fertilizer and selenium and cobalt mixed fertilizer on the forage yield and quality of alfalfa were studied by leaf spraying during growing durations in the soil and climate conditions of Yellow River bottomland in Henan Province, the results show that the selenium fertilizer and selenium and cobalt mixed fertilizer increased significantly the ratio of stem to leaf, decreased the ratio of fresh weight to dry weight and increased the dry matter content in alfalfa forage from shooting stage to florescence stage; Selenium fertilizer promoted only the forage yield during vegetative periods, however, selenium and cobalt mixed fertilizer promoted the forage yield during the whole growing durations; moreover, selenium fertilizer and selenium and cobalt mixed fertilizer enhanced not only the contents of Se and Co of alfalfa hay significantly, but also the contents of 6 kinds of other trace elements (Fe, Mn, Cu, Zn, Mo, and B) obviously, especially that of Se and Mo; Selenium and cobalt mixed fertilizer increased the contents of crude protein and decreased the contents of crude fibre of alfalfa hay significantly. The results of onfoliar fertilizers application on alfalfa showed that the yield of alfalfa increased more than 20% under the treatments of KH_2PO_4 and Ausnutria, and the crude protein content increased significantly by 9.37–10.62%, and crude fiber content was reduced by 5.91–4.36%. As a result, KH_2PO_4 and Ausnutria were recommended as foliar fertilizers during the growth period of alfalfa with the concentration of 1000 times and 500 times.

4.2.3 Water Saving Irrigation Technique

In recent years, the research on alfalfa irrigation technology has been paid great attention, it was reported that proper irrigation was beneficial to alfalfa, and insufficient or excessive water would affect alfalfa growth. Through the study of water stress, Kou et al. have proved that although water shortage could improve the nutritional value of alfalfa, but the yield would decrease greatly, which was not conducive to the large-scale production of alfalfa. The best soil moisture content to ensure alfalfa yield, quality and water use efficiency should be 60% to 70% of saturated water content, when the water content was higher than 90% or less than 40% of saturated water content, alfalfa would be under water stress and the normal life activities would be affected. Wen and Li showed that under sufficient winter irrigation, the irrigation in the next year returned to green period had no obvious effect on the yield of the first alfalfa, the second and the third was proportional to the irrigation quantity, and the fourth one was in inverse proportion to the irrigation quantity. Scientific irrigation system was the key to forage production and management. Due to different climatic conditions, irrigation systems in different regions were different. Guo proposed the irrigation amount and times of Hetao irrigation area, the first and second crops were 1400 m^3/hm^2, 4 times and 2300 m^3/hm^2, 5 times respectively. Sun and Ren obtained the optimal irrigation scheme of Alfalfa through Jensen model, according to the water consumption law and water source condition of alfalfa, when water resources were limited, the water demand of the most sensitive period (branching stage-budding stage) was first considered to maximize the utilization of water resources. Cao obtained the local irrigation system in eastern Inner Mongolia, 420 mm was the best irrigation amount to achieve high yield and high efficiency of alfalfa; At this time, the soil moisture layer of alfalfa could reach 40 cm, and the relative water content of soil was higher than 60% of the saturated water content, which could meet the growth and development needs of alfalfa. Tong et al. used WIN ISAREG model to simulate irrigation of alfalfa, and considered that irrigation 10 times in the whole growth period and irrigation quota of 25 mm was the optimal scheme of Xilinguole grassland, which was convenient for management and did not reduce production efficiency in production practice. The result indicated that the proper soil moisture within 20–40 cm in the growth period was 30% and the yield increased along with the increasing of irrigation amount, however, while the total irrigation amount reached 5400 m^3/hm^2, the effect was not significant; The economic efficiency reached the highest while the total irrigation amount was around 5400 m^3/hm^2.

The results showed that the average soil water content of 10–20 cm soil layer was 18.84% and 12.41% under the above ground drip irrigation and underground drip irrigation, and the soil water content of 10–20 cm soil layer under the above ground drip irrigation was higher than that under the underground drip irrigation; The growth and development of switchgrass under above ground drip irrigation was significantly higher than that under underground drip irrigation; During the growth period, the net photosynthetic rate, transpiration rate and water use efficiency of switch grass leaves under above ground drip irrigation were higher than those under underground drip irrigation. The results of sprinkler irrigation and ground drip irrigation on alfalfa showed that the effect of ground drip irrigation on the growth of alfalfa was greater than that of sprinkler irrigation; The treatment of the distance of the drip tube laying 50 cm was conducive to the growth of plant height and stem diameter, and the distance of 70 cm was conducive to the growth of alfalfa branch number; The height of alfalfa plant was significantly higher than other treatment levels at a depth of 20 cm; Compared with sprinkler irrigation, ground drip irrigation could significantly increase the yield of alfalfa, the highest alfalfa yield was 138,734.03 kg/hm^2 when the depth of burial was 20 cm and the distance was 70 cm. The results were showed as following, in the first year of alfalfa growth, the soil water content of separating furrow was the highest than any treatments, the soil water content of furrow irrigation was higher than that in border irrigation and that in traditional irrigation, the soil water content of border irrigation was the lowest in the seedling stage and the early period of vegetative growth of alfalfa, the variation of soil water content in different irrigation were becoming smaller with extension of alfalfa growth stage and decreased rainfall; The top dry biomass weight of traditional irrigation and of border irrigation were higher than that in furrow irrigation and that in separating furrow irrigation in every key growth stage of alfalfa; The water use efficiency (WUE) in border irrigation was highest among treatments, the WUE in traditional irrigation was lower than that in border irrigation, but higher than that in furrow irrigation and that in separating furrow irrigation in all alfalfa growth stage (Wang et al. 2006).The water use efficiency of drip irrigation and flood irrigation was 4.55–5.48 $kg/(mm \cdot hm^2)$, 3.21–3.81 $kg/(mm \cdot hm^2)$ respectively; Compared with the flood irrigation, the total water use efficiency of drip irrigation method was increased by 42–44%; When the irrigation volume of drip irrigation was 3000 m^3/hm^2 and that of flood irrigation was 5250 m^3/hm^2, the comprehensive economic benefits of alfalfa production were the best (Zhang et al. 2015).

4.2.4 Coupling Technique of Water and Fertilizer

The results showed that different water and fertilizer treatments had significant effects on N, P and K contents of alfalfa in Langfang of Hebei Province; The dry matter yield and nutritional quality of alfalfa could be significantly improved by increasing the amount of fertilizer and high irrigation, that was 250 kg/hm^2 of fertilizer and 80–85% of field capacity; in order to increase the yield, quality and water use efficiency of Alfalfa in semi-arid sandy soil, the amount of fertilizer and irrigation should be increased in the first and second cutting of grown stage of Alfalfa.

The results of water and nitrogen coupling supply on alfalfa production under subsurface drip irrigation showed that water and nitrogen supply had different effects on the plant height and stem diameter of alfalfa for each harvest; The plant heights of first and second cutting of alfalfa increased with increased nitrogen application rate and with increased irrigation supply, and the stem diameter at the first cutting was increased with increased irrigation rate; The yields of alfalfa hay at the first and second cutting increased with increased irrigation rate; Applied nitrogen significantly increased the alfalfa hay yield at the first and fourth cuttings and over the whole growth season; The irrigation effect, the nitrogen application effect, and the irrigation and nitrogen interaction for hay yield were all extremely significant ($P < 0.01$); The irrigation water use efficiency (IWUE) and water use efficiency (WUE) were decreased with increased irrigation rate and with increased nitrogen application; Considering the yield, resource utilization, environment and other comprehensive effects of drip irrigation of Alfalfa in Ningxia Yellow River irrigation area, the treatment of 620 mm drip irrigation and 120 kg/hm^2 nitrogen application was more suitable.

The research of coupling of water and fertilizer effects on productivity and quality of Aohan Alfalfa indicated, in the interaction treatment of N, P, W three factors, the highest treatment of hay yield was 300 kg/hm^2 (N) + 450 kg/hm^2 (P_2O_5) + 2300m^3/hm^2 (W); In the interaction treatment of N and W two factors, the highest treatment of hay yield was 300 kg/hm^2 (N) + 1150m^3/hm^2 (W); In the interaction treatment of P and W two factors, the highest treatment of hay yield was 450 kg/hm^2 (P_2O_5) + 2300 m^3/hm^2 (W); N, P, W interaction role was greater than N, W interaction and P, W interaction; The optimal water and fertilizer combination for crude protein, crude ash, crude fat, acid detergent fiber and neutral detergent fiber was 300 kg/hm^2 (N) + 450 kg/hm^2 (P_2O_5) + 2300 m^3/hm^2 (W).

The study on the effect of different water and fertilizer treatment on alfalfa growth and yield under underground drip irrigation showed that, the plant height increased with the increase of irrigation water and fertilizer amount, and gradually became stable, in which the irrigation level was the main influencing factor; The leaf stem ratio decreased firstly, then increased with the amount of irrigation and fertilization amount, the irrigation level as the main factors, followed by the interaction of water and fertilizer factors, finally fertilization level factors; The hay yield increased firstly and then decreased with the increase of irrigation amount and fertilizer amount, and the yield which was 20,989.75 kg/hm^2 was the highest under the irrigation level of 2

850 m^3/hm^2 and fertilization level of 285 kg/hm^2; The effect of interaction of water and fertilizer on hay yield was significant.

Effects of irrigation frequency and fertilization methods on Alfalfa Yield and water and fertilizer use efficiency indicated, comprehensive analysis of index such as yield, water and fertilizer use efficiency, and stem-leaf ratio, in the production of alfalfa on sandy soil, irrigation twice a week with fulvic acid potassium treatment had the best yield and water and fertilizer use efficiency.

The results showed that the plant height, leaf number, branch number, above-ground biomass and water use efficiency of alfalfa were significantly improved by alternate irrigation; The ratio of stem to leaf and the number of branches were significantly affected by phosphorus addition, However, the effects of alternate irrigation and P interaction on plant height, leaf number, stem-leaf ratio, branch number, above-ground biomass and WUE of alfalfa were not significant; Considering the growth index of Alfalfa Yield and water use efficiency, the coupling of alternate irrigation and phosphorus fertilizer was suitable for alfalfa production and irrigation management of the harvest nutrients, and the effect of applying P fertilizer was the best under the alternative irrigation of 75%.

4.2.5 Safe Overwintering Technique of Alfalfa

Selection of cold resistant varieties was the most important technical measure for alfalfa to overwinter safely in cold and cool areas of China. By analyzing the relationship between fall dormancy level and cold resistance index and overwintering rate of 46 alfalfa varieties (materials), it was found that there was a significant positive correlation between fall dormancy level and cold resistance index, and a significant negative correlation between fall dormancy level and overwintering rate, that was, the stronger the fall dormancy, the stronger the overwintering ability of Alfalfa. The Overwintering Rate of different varieties of alfalfa was different, and the difference of overwintering ability of different varieties of alfalfa was related to their different genetic characteristics, which indicated that the overwintering ability of alfalfa was affected by its genetic basis.

The selection of suitable sowing time was an important technical link in the process of alfalfa cultivation, improper selection of sowing time in the northern cold region would affect the safe overwintering of alfalfa. The results of Zhu et al. in Horqin sandy land showed that the sowing limit of Alfalfa for safe overwintering was in late July, and early sowing was beneficial to alfalfa overwintering. Zhang et al. (2005) showed that the minimum sowing time to ensure the safety of Alfalfa overwintering should not exceed August 20 at the latest in Heilongjiang Province. Through the comprehensive analysis of four physiological and biochemical indexes of four different alfalfa varieties and mixed seeding with *Festuca arundinacea* (3:7) in the same line, the results showed that mixed seeding could improve the overwintering ability of alfalfa, and it was found that the order of cold resistance from large to small was: Gongnong1 + *Festuca pratensis* > Gongnong1 > Wega7F + *Festuca pratensis*

> wega7F > WL319HQ + *Festuca arundinacea* > WL319HQ > Aohan Alfalfa + *Festuca pratensis* > *Aohan alfalfa.*

Alfalfa field management was also an important link to improve the safety of Alfalfa overwintering in cold areas of China, mainly including fertilization, irrigation and mowing. Fertilization before winter was conducive to alfalfa overwintering safely, the main types of fertilization were phosphorus and potassium, and Phosphorus (P_2O_5) 45–60 kg/hm^2 and potassium (K_2O) 45–75 kg/hm^2 was suitable. Silicon fertilizer could increase the content of soluble sugar and free proline in the root neck of alfalfa, reduce the content of malondialdehyde, and improve the cold resistance of Alfalfa. During the overwintering period, soil drought would cause the root neck of alfalfa to lose water and shrink, resulting in plant growth restriction or even death, winter irrigation before soil freezing could increase soil moisture and protect alfalfa from overwintering. Winter irrigation could increase the field soil temperature during the overwintering period, which was conducive to alfalfa overwintering, and high winter irrigation could significantly improve the overwintering rate of Alfalfa. Under late winter irrigation, the content of cold resistant substances and the activity of antioxidant enzymes in root neck of *Medicago sativa* in sandy land were higher, and the damage of *Medicago sativa* was less, which was more conducive to its overwintering. Chi et al. found that there was a significant negative correlation between the Overwintering Rate of alfalfa and the cutting times, the more cutting times, the more prone alfalfa to freeze injury. The last cutting period had a great influence on the nutrient content of alfalfa root stock before winter, which was closely related to the overwintering rate of alfalfa and the first crop yield in the next long season, it was safe to carry out the last cutting before 40 days of the first frost.

4.3 Forage-Crop Rotation Technique

Forage-crop rotation had been proved to be able to maintain soil structure, improve soil fertility, inhibit weeds and control diseases and pests. Scientific research had proved that forage-crop rotation was an effective way to improve the quality of farmland soil and make the soil ecosystem develop healthily. The rotation of legume forage and gramineous crops could provide nitrogen nutrition for gramineous crops through biological nitrogen fixation, and the soil environment after harvest of gramineous crops could promote the biological nitrogen fixation of legume forage. Through continuous practice in the Loess Plateau, the forage-crop rotation mode of combining land use and cultivation had been developed, mainly including alfalfa–winter wheat–summer maize, alfalfa–maize, alfalfa–millet, winter wheat–rape–alfalfa, winter wheat–hairy vetch–maize, etc., all of which made full use of land, water and heat resources to achieve the benefits of both grain and grass, ecology and economy.

Forage-crop rotation could not only guarantee grain yield, but also provide forage for livestock, improve resource utilization efficiency, soil fertility and soil nutrient status. The effects of wheat continuous cropping, short rotation (wheat + millet–pea–wheat) and long rotation (wheat + ormosia–ormosia–wheat) on soil fertility and nutrient utilization in Dryland of Loess Plateau were studied, the results showed that the contents of soil organic matter, total nitrogen and fast potassium were significantly increased, and the availability and accumulation of soil phosphorus were significantly improved. Adding legume crops to crop rotation was an effective and common way to provide nitrogen fertilizer and improve soil properties, nitrogen fertilizer was the main way to improve soil fertility in forage-crop rotation, research showed that the nitrogen content of wheat field increased by 37–94 kg/hm^2 after forage-crop rotation. The introduction of annual alfalfa into winter wheat field instead of summer fallow system significantly improved soil fertility. Song et al. studied alfalfa–crop rotation in the semi-arid area of the Loess Plateau in Central Gansu Province, and found that rotation increased soil aggregate content, improved soil permeability and soil porosity, helped to form a good soil structure and improve soil nutrient status. The soil microbial biomass and decomposition ability of decomposed plant residues in alfalfa–crop rotation system were higher than those in conventional cultivation system, which helped to maintain good material circulation and promote nitrogen availability. Compared with continuous cropping potato, rotation with legumes (alfalfa and *Vicia sativa*) increased the contents of soil urease and alkaline phosphatase in varying degrees, and increased the contents of soil available nitrogen, phosphorus and potassium. In the semi-arid loess region, the availability and activation rate of soil nitrogen, phosphorus and organic matter increased after ten-year alfalfa-grassland rotated with potato, corn and winter wheat, especially with winter wheat.

It was found that adding forage to traditional crop cultivation could improve soil fertility, reduce the loss of soil water and nutrients caused by fallow, and increase crop yield steadily. The study of wheat rotated with forage (forage rape, sagittaria sativa) in Longdong dryland showed that, compared with wheat stubble fallow, wheat rotated with forage did not affect the yield of winter wheat, but increased the total yield of the system by 27%. In the arid area of Northwest China, the study of planting different forages with winter wheat in summer fallow period showed that soil available nutrients and total nutrients were improved in varying degrees, water consumption and soil water use efficiency improved, dry matter accumulation and yield of wheat increased. When soybean, alfalfa, clover, pea, hairy vetch and other legumes were added to the continuous cropping system of corn and winter wheat, the legumes left nitrogen rich residues in the root system of legumes, which improved the soil fertility and increased the yield of corn and winter wheat. In the arid area of the Loess Plateau, the continuous cropping system of winter wheat was changed into the forage-crop rotation of winter wheat–alfalfa–potato–winter wheat, alfalfa–potato–winter wheat, winter wheat–sainfoin–winter wheat, the grain yield of winter wheat increased by 1.47–29.66%, and the biomass increased by 2.17–29.77%.

4.4 Diseases and Pest Prevention and Control Technology

The widespread occurrence of forage diseases and pests has seriously affected the quality and yield of forage, especially in alfalfa, oats, silage corn, grain corn and ryegrass, which are planted in a wide area. Most pests can harm forage grass leaves, causing plant growth slowly, die leaves death, flowers and buds falling off, and even the transmission of plant viruses. The main pest species infest forage plant in China are listed in Table 4.1. In addition, forage grass may also be disturbed by diseases, as shown in Table 4.2.

In order to protect the forage grass from biotic attack, the main diseases and pests infested forage plants need to be managed. There are many ways to control diseases and pests, each of which has its advantages and limitations. In the framework of integrated pest management (IPM) programs, multiple complementary tactics are necessary, including monitoring, cultural, physical and mechanical measures, host plant resistance, biological control, ecological control, along with the judicious use of pesticides, with the aim that diseases and insect pests are under control economically, safely, and effectively (Guedes et al. 2016; Zhang et al. 2019).

4.4.1 The Technology of Agricultural Control

Agricultural control reduces the number of grassland pest populations or the possibility of its occurrence through appropriate forage cultivation and management measures. It is a kind of grassland protection measure of cultivating robust forage grass to enhance its vitality and resistance, tolerance and self-compensation ability, and to inhibit the survival, reproduction, and transmission of pests. Agricultural control is the primary measure, including the whole process from soil preparation, sowing, field management to harvest and utilization, storage, and processing.

4.4.1.1 Application of Resistance Forage Cultivars

The disease resistance response can range from immune, highly resistant to highly susceptible, which provides the possibility for selecting different forage cultivars (strains) to control disease with the utilization of resistant strains. Therefore, in selecting and utilizing, resistance should be regarded as an essential factor for varieties (species) selection. Alfalfa downy mildew (*Peronospora aestivalis*) is a worldwide disease, and has become one of the main limiting diseases of early decline and degradation of alfalfa grassland in China. However, there were significant differences in the response of different varieties of alfalfa to downy mildew. It is reported that Alguquis, Barrell, Abika, Angus, Iruz, Bryz, Thor, Bei Wei, Rumbler, Lange Rende, Wisconsin, Green Alfalfa, and other varieties belong to the immune group. Plowler, Banner, Xingping, American No. 1, Grassland No. 2, Jilin Alfalfa, Ningxia Alfalfa,

Table 4.1 List of main pests infest forage plant in China

Insect species	Host plants	Damaging insect life stage(s)	Plant parts attacked	References
Hemiptera: Aphididae				
Therioaphis trifolii Monell	*Medicago* spp.,	Adult and nymph	Foliar	Zhang et al. (2016)
Acyrthosiphon pisum Harris	*Medicago* spp., *Onobrychis viciifolia* Scop. *Trifolium* spp., also other leguminous plants	Adult and nymph	Foliar	
Acyrthosiphon kondoi Shinji	*Medicago* spp. and *Trifolium* spp.	Adults and nymph	Foliar	
Aphis craccivora Koch	*Medicago* spp., *Onobrychis viciifolia* Scop. *Trifolium* spp., also other leguminous plants	Adult and nymph	Foliar and stem	
Macrosiphum avenae Fabr	*Avena sativa* L., *Lolium perenne* L. also other gramineous plants	Adult and nymph	Foliar and stem	Ma et al. (2017)
Schizaphis graminum Rond		Adult and nymph	Foliar and stem	
Rhopalosiphum padi L		Adult and nymph	Foliar and stem	
Acyrthosiphon dirhodum Walker		Adult and nymph	Foliar and stem	
Hemiptera: Miridae				
Lygus pratensis L.	*M. sativa,* also other leguminous and gramineous plants	Adult and nymph	Foliar and stem	Liu (2009)
Adelphocoris lineolatus Goeze		Adult and nymph	Foliar and stem	Gu et al. (2011)
Thysanoptera: Thripidae				
Odentothrips loti Haliday	*Medicago* spp., *O. viciifolia, Melilotus officinalis* Pallas, *Trifolium* spp.	Adult and nymph	Foliar and flower	Zhang et al. (2005)
Frankliniella intonsa Trybom	*Medicago* spp., *Astragalus sinicus* L., also other leguminous plants	Adult and nymph	Foliar and flower	Wu et al. (2019)
Thrips tabaci Lindeman	*Medicago* spp.	Adult and nymph	Foliar and flower	
Haplothips tritici Kurdjumov	gramineous plants	Adult and nymph	Foliar and flower	Meng et al. (1993)

(continued)

Table 4.1 (continued)

Insect species	Host plants	Damaging insect life stage(s)	Plant parts attacked	References
Haplothips aculeatus Fabricius	silage corn, also other gramineous plants	Adult and nymph	Foliar and flower	
Coleoptera: Curculionidae				
Hypera postica Gyllenhal	*Medicago* spp. and *Trifolium* spp.	Adult	Foliar	Liu et al. (2010), Zhang et al. (2017)
Tychius rnedicaginis Brisout	*Medicago* spp. and *Trifolium* spp.	Adult, larva	Foliar and seed	Wu et al. (2012)
Tychius melilotus Steph	*Medicago* spp. and *Trifolium* spp.	Adult, larva	Foliar and seed	Liu et al. (2014)
Coleoptera: Meloidae				
Mylabris calida Palla	*Medicago* spp., *Trifolium* spp., *Caragana sinica* (Buchoz) Rehd., also other leguminous plants	Adult and nymph	Foliar	Luan et al. (2015)
Epicauta gorhami Marseul		Adult and nymph	Foliar	
Coleoptera: Scarabaeidae				
Holotrichia diomphalia Bates	*Medicago* spp., *Trifolium* spp., fodder beet, *L. chinesis, L. perenne, Arena sativa* L., also other leguminous and gramineous plants	Adult and larva	Root and stem	Yuan and Jiang (1995)
Holotrichia oblita Fald		Adult and larva	Root and stem	Yuan and Jiang (1995)
Anomala exoleta Fald		Adult and larva	Root and stem	Yuan and Jiang (1995)
Anomala corpulenta Motsch		Adult and larva	Root and stem	Yuan and Jiang (1995)
Maladera orientalis Motsch		Adult and larva	Root and stem	Yuan and Jiang (1995)
Melolontha hippocastani Fabricius		Adult and larva	Root and stem	Yuan and Jiang (1995)
Coleoptera: Elateridae				
Pleonomus canaliculatus Fald	*Medicago* spp., *Trifolium* spp., fodder beet, *L. chinesis, L. perenne, Arena sativa* L., also other leguminous and gramineous plants	Adult and larva	Root and stem	Zhao et al. (2011)
Agriotes fusicollis Miwa		Adult and larva	Root and stem	
Selatosomus latus Fabricius		Adult and larva	Root and stem	
Melanotus caudex Lewis		Adult and larva	Root and stem	
Coleoptera: Tenebrionidae				

(continued)

Table 4.1 (continued)

Insect species	Host plants	Damaging insect life stage(s)	Plant parts attacked	References
Opatru subaratum Fald	*L. chinesis,* also other leguminous plants	Adult and larva	Root and stem	Zhao et al. (2011)
Lepidoptera: Pyralidae				
Loxostege sticticalis L	Fodder beet, leguminous forage, and other plant	Larva	Foliar	Ma (2004)
Ostrinia furnacalis Guenee	Silage corn	Larva	Foliar and stem	Liang et al. (2017)
Lepidoptera: Noctuidae				
Heliothis viriplaca Hufnagel	*Medicago* spp., *Trifolium* spp., also other leguminous plants	Larva	Foliar	He (1997)
Helicoverpa armigera Hubner	Silage corn	Larva	Foliar and stem	Liang et al. (2017)
Agrotis ypsilon Rottemberg	Forage grass	Larva	Root and stem	Zhao et al. (2011)
Euxoa segetum Schiffermuller	Forage grass	Larva	Root and stem	
Agrotis exclamationis Linnaeus	forage grass	Larva	Root and stem	
Orthoptera: Acrididae				
Locusta migratoria L	Grasses, forage crops	Adult and nymph	Foliar	Chen (2007)
Angaracris barabensis Pallas	Gramineous forage grass	Adult and nymph	Foliar	Liu et al. (2007)
Oedaleus decorus asiaticus Bei-Bienko	Grasses (*Leymus chinensis* (Trin.) Tzvel, *Stipa krylovii*) Roshev	Adult and nymph	Foliar	Zhang et al. (2015)
Bryodemella tuberculatum diluta Stoll	Grasses, forage crops	Adult and nymph	Foliar	An et al. (2007)
Myrmeleotettix palpalis Zubovski	Gramineous forage grass	Adult and nymph	Foliar	Liu and Feng (1999)
Pararcyptera microptera meridionalis Ikonn	Grasses, forage crops	Adult and nymph	Foliar	Li et al. (2004)
Orthoptera:Gryllotalpidae				
Gryllotalpa orientalis Burmeister	Grasses, forage crops	Adult and larva	Root, stem and seed	Zhao et al. (2011)
Gryllotalpa unispina Saussure	Grasses, forage crops	Adult and larva	Root, stem and seed	
Hymenoptera: Orchidae				

(continued)

Table 4.1 (continued)

Insect species	Host plants	Damaging insect life stage(s)	Plant parts attacked	References
Bruchophagus gibbus Boheman	*Medicago* spp., *Trifolium* spp., also other leguminous plants	Larva	Seed	Liu et al. (2014)

and Xinmu No. 2 belong to the high resistance group. Zhaodong, Longzhong, and Longdong varieties belong to the high susceptibility group, while Apollo, Zhungeer, Shaanxi, Hexi, Hotan, Shawan, and other varieties belong to extremely susceptible groups (Li et al. 2000). Furthermore, Zhou et al. (1996) identified and evaluated the rust resistance of 112 alfalfa cultivars. They found remarkable differences in rust resistance among alfalfa cultivars, and *Yanggao alfalfa*, Grassland No. 2, and orchid alfalfa can be directly used in production. The Eqi alfalfa cultivar, with high resistance and poor yield performance, could be used as the source of disease resistance in alfalfa breeding. In addition to alfalfa. The similar work was also applied in corn silage breeding for disease resistance. Corn silage is usually with high stalks. Diseases such as northern corn leaf blight *Exserohilum turcicum*, rust disease, and corn southern leaf blight *Bipolaris maydis* are difficult to be controlled once occurred largely in the field. Therefore, the prevention and control of silage corn diseases ahead the occurrence is recommended basing on the application of disease-resistant strains. Analyzing the rust resistance of silage corn cultivars, the researchers found cultivar Yucao No. 1, 2, and 3 are resistant to rust and Yayu silage 26, Yucao No. 2, Yu silage No. 23, and Dayan No. 1 are resistant to spot disease, and Yayu No. 8, Yucao No. 1, 3, Zheng Silage No. 1, Yayu silage 04889, 26 are resistant to corn brown spots (Chen et al. 2019; Liu et al. 2019). At the same time, the researchers also found that within a specific range, increasing planting density can help increase the biological yield of silage corn and improve the quality of silage corn silage. However, the high planting density often results in diseases (Chen et al. 2019).

Usually, the plants are infested by more than one pests, which make it is necessary to take into account the multiple resistance. In addition, it should be noted that although genetic genes determine the differences in disease resistance of varieties (strains), their disease resistance performance is also affected by environmental conditions such as temperature, moisture, soil pH, and soil nutrients. Therefore, the regional ecological distribution of the main forage species and cultivars plays essential role for grassland pest control.

Table 4.2 List of main pathogens species found in forage in China

Pathogene	Host plants	Symptom	References
Fungi-leguminous			
Pseudopeziza medicaginis (Lib) Sacc	*Medicago* spp.,*Trifolium repens* L., also other leguminous plants	Brown blotch	Chen et al. (2017)
Polythrincium trifolii Kunze	*Trifolium* spp., *also other leguminous plants*	Spots	Nan (2015)
Rhizoctonia solani Kuhn	*Medicago* spp., *also other leguminous plants*	Rot	Nan (2015)
Colletotrichum sp.	*Medicago* spp., *Astragalus adsurgens* Pall., *T. repens,* also other leguminous plants	Anthracnose	Zhang et al. (2020)
Fusarium spp.	*Medicago* spp.,*T. repens,* also other leguminous plants	Root rot	Yuan et al. (2020)
*Ascochyta medicaginicola Malbr. & Roum.(*syn. *Phoma medicaginis)*	*Medicago* spp., also other leguminous plants	Stem black	Nan (2001)
Cercospora medicaginis Ellis & Everh	*Medicago* spp., also other leguminous plants	Stem black	Nan (2001)
Uromyces striatus Schroet	*Medicago* spp.,*T. repens,* also other leguminous plants	Rust	Liu and Hou (1999)
Peronospora aestivalis Syd	*Medicago* spp.,*T. repens,* also other leguminous plants	Downy mildew	Chen and Zhou (2016)
Leveillula leguminosarum Golov	*Medicago* spp.,*T. repens,* also other leguminous plants	Powdery mildew	Yuan et al. (2020)
Erysiphe pisi Syd	*Medicago* spp.,*T. repens,* also other leguminous plants	Powdery mildew	
Fungi—gramineous			

(continued)

Table 4.2 (continued)

Pathogene	Host plants	Symptom	References
Claviceps spp.	*Elymus nutans* Griseb, *Achnatherum splendenus* (Trin.) Nevski., *Leymus* spp., also other gramineous plants	Ergot	Chen et al. (2016)
Puccinia spp.	*Lolium perenne L.*, *Agropyron* spp., *Poa* spp., also other gramineous plants	Rust	Zhang et al. (2011)
Erysiphe graminis (DC.) Speer	*L. perenne, Agropyron* spp., *Poa* spp., also other gramineous plants	Powdery mildew	
Virus			
Alfalfa mosaic virus	*Medicago* spp., also other leguminous plants	Mosaic	Al-Saleh and Amer, (2013), Wen and Nan (2015), Zhou et al. (2016)
Alfalfa dwarf virus	*Medicago* spp., also other leguminous plants	Dwarf	Samarfard et al. (2018)
Clover yellow mosaic virus	*Medicago* spp., also other leguminous plants	Mosaic	Alshahwanet al. (2017)
Bean yellow mosaic virus	*Medicago* spp., also other leguminous plants	Mosaic	Al-Saleh and Amer, (2013), Wen and Nan (2015), Zhou and Liao et al. (2016)
Tobacco mosaic virus	*Medicago* spp., also other leguminous plants	Mosaic	Wen and Nan (2015)
Cucumber mosaic virus	*Medicago* spp., also other leguminous plants	Mosaic	Al-Saleh and Amer (2013)
Barley yellow dwarf virus	*Avena sativa* L., also other gramineous plants	Dwarf	Wang et al. (2020)
Parasitic plant			
Cuscuta approximata Bab	*Medicago sativa* L., *other forage*		Tian et al. (2015), Chen et al. (2017)
Cuscuta cdmpestris Yuncker	Forage		Tian et al. (2015)
Cuscuta chinensis Lam	Forage		

(continued)

Table 4.2 (continued)

Pathogene	Host plants	Symptom	References
Cuscuta dpprdxumdtd Babingt	Forage		
Parasitic nematodes			
Ditylenchus medicaginis Wasilewska	*Medicago* spp., also other forage plants		Cao et al. (2016)
Meloidogyne	*Medicago* spp., also other forage plants		

4.4.1.2 Selection of Healthy Seeds

In order to ensure the health of the grassland, choosing disease or pest-free seeds or seedling is particularly important. Seed treatment using physical or chemical methods should be carried out to inactivate pests.

Thermal treatments could warm water soaking method, cold-soaking method, and dry heat method et al. Generally, treat with 50–55 °C warm water for 10 min to kill the pathogen without harming seeds (Gao and Nan 2019). In addition, the gravity difference between healthy and infested seeds could also be used for seeds selection. Generally, seeds damaged are lighter than healthy seeds, and the seeds with less weight can be bleached with saltwater, muddy water, and clean water. The lower quality seeds could also be removed by soaking in lime water.

Chemical are also used for seeds coating, which is an effective and economical measure to prevent diseases in soil and seed, and pests underground, and improve seed germination and seedling emergence rates in field. As reported, the use of thiophanate-methyl, thiram could reduce seed mortality by 40% to 65%. In the field experiment of seedling emergence using fungicide dressing, it was found that the field seedling emergence rate was 30% higher than the control (Gao and Nan 2019).

4.4.1.3 Field Management

Reasonable planting methods include rational close planting, mixed sowing, intercropping, and rotation. Planting density mainly affects the occurrence and damage of diseases and insect pests by affecting the environmental microclimate, such as the grass layer and the growth and development of forage grass. Generally high planting density, poor ventilation and light transmission, shade in the field, and high humidity are beneficial to the occurrence and damage of most diseases and shady and humid pests. In forage fields, mixed sowing of leguminous and gramineous grasses can improve soil fertility, increase yield of forage and improve the stability of grassland community, with effective control measure of forage diseases and pests.

Irrigation, fertilization, and field sanitation have a significant influence on diseases and pests. Proper drainage and irrigation of grassland can effectively improve soil water and air conditions, meet the needs of forage growth and feeding, and effectively control diseases. The proper of fertilization can improve the resistance and tolerance of herbage, change the soil properties and soil microbial community structure, deteriorate the living conditions of underground pests and thus play the role of pest control. Good hygiene can remove diseases, pests, and breeding places in the grassland, improve the ecological environment of the grassland, and reduce the probability of disease occurrence (Nan 2001).

4.4.2 Physical Control

Physical control to prevent and control pests and diseases is an effective and safe technical means with electricity, magnetism, temperature, humidity, light, color, sound, smell, etc. At present, the methods of physical pest control in forage plants mainly include electronic pest control, yellow plate insect trap, insect net pest control. At present, the most common tool used by farmers in electronic pest control is a kind of solar-powered frequent-vibration automatic pest control lamp, which makes use of the phototaxis and waviness of insects to lure insects to fly and then kill them. Yellow viscose plates can trap and kill winged aphids, whitefly and other small pests, which tend to yellow. Some pests such as *Agrotis ypsilon* can be trapped by sweet and sour sauce. In addition, soaking seeds in warm water and burning stubble after harvest can also be effective in controlling pests and diseases. In order to kill or expell the pests in forage seeds, high temperature, sun exposure under the sunshine, or low temperature can be used effectively. Physical methods are effective, green, and easy to use in the early stages of pest or disease outbreaks, and it is usually in conjunction with other methods.

4.4.3 Chemical Control

Chemicals used to prevent and control plant pests and diseases are called insecticides and fungicides, which could kill pests and pathogens, inhibit their infection, growth, and reproduction, neutralize their toxic metabolites. To date, the pesticides used largely are the organic chemicals extracted from natural plants like fish rattan, pyrethrum, tobacco, etc., microbes; or synthetic organic pesticides.

Chemical control has a wide range of application, simple and efficient, and can be used for the prevention and control of pests, especially in the case of large-scale outbreak of pests. However, the sensitivity of different pests to chemical insecticides was different. For example, the order of sensitivity of *T. trifolii* to five insecticides was avermectin, aktai, imidacloprid, lvbaishi and omethoate. For alfalfa aphids, the order of virulence was avermectin, imidacloprid, lvbaishi, omethoate and aktai (Jin 2019). Being the food for animals, the forage grass are required to be safe enough, and pesticide toxic residue is also an important index to be evaluated. Basing on the control effects, three insecticides against alfalfa thrips and aphids were selected and their residue quantity in plant were analyzed. the results showed that the amount of both imidacloprid and chlorpyrifos were lower than the maximum residue limits (MRL) 7 days later, while it took 14 days for cypermethrin to reach the MRL (Luo et al. 2017; Ma et al. 2017).

4.4.4 Biological Control

A biological control refers to the use of beneficial organisms or metabolites of beneficial organisms to regulate the plant micro-ecological environment in agro-ecosystem to make it beneficial to the host but not to the pathogen or pests, or to make the interaction between the host and the pathogen (or pests) beneficial to the host but not to the pathogen or pests, to control plant diseases or pests.

4.4.4.1 Use Microorganisms to Control Pathogens

The main types of microorganisms used for plant disease control are bacteria, fungi, and actinomycetes. The most extensively used biocontrol bacteria include *Bacillus*, *Pseudanonas*, *Agrobacterium radiobacter*, and *Pasteurella*. The biocontrol fungi mainly include *Trichoderma*, *Chaetomium*, *Paecilomyces lilacinus*, *Gliocladium*, *Phoma capitum*, etc. The biocontrol actinomycetes are mainly *Stretonyces* and related groups.

Root rot is one of the primary diseases in alfalfa production. The application of biocontrol technology is of great significance to environmentally friendly sustainable agriculture. Two strains showing strong antagonistic effect were screened from 95 strains, which were isolated from alfalfa rhizosphere soil in different planting areas (Zeng et al. 2019). These two antagonistic fungi were identified as *Trichoderma harzianum* and *Trichoderma koningii*, and showed 54.9% to 75.3% inhibitory rate on four species of *Fusarium*. Fungi and rhizobia are two common types of symbiotic microbe in legumes. *T. harzianum* and *T. koningii* could also significantly reduced the incidence and disease index of alfalfa stem spot mildew disease. The disease index of alfalfa after inoculated with single one or both strains was 72.3% lower compared to the control. For gramineous forage silage corn, seven species of antibiotic bacterium have significant inhibitory effect on *Setosphaeria turcica*. After inoculating by strain Y6S-26, one of seven antibiotic bacteria, the incidence area of northern corn leaf blight disease was below 25% (Xiao 2019). A study in Gansu Province located in northwest of China, showed that microbicide mimicry showed better persistence. It can not only effectively control the powdery mildew of oat, but also increase the chlorophyll content of oat, promote photosynthesis, so as to improve the yield (Sun 2019).

Apart from the biocontrol microorganisms isolated from plant rhizosphere soil, plant endophytes are novel biocontrol factors, and could be systematically distributed in plant tissues. Changes in the external environment have little impact on them and have more advantages over other biocontrol factors. The screening and application of biocontrol bacteria have become a hot spot in researching biological control of plant diseases in recent years, though most of the research has focused on crops such as rice. Four percent of endophytic bacteria in rice seeds have an antagonistic effect on rice sheath blight and rice blast, and their presence enhances the disease resistance of rice. Nevertheless, there has been relatively little research on forage grass. The endophytes in alfalfa were screened, and twelve endophytes were identified, including three strains of bacteria, eight strains of fungi, and one strain of actinomycetes, and have antagonistic effects on four pathogens, *Rhizoctonia solani*, *Fusarium auenaceum, F. oxysporum*, and *Phytophthora capsica.* The endophytic bacteria identified as *Bacillus subtilis* had the best antibacterial effect on the four pathogens (Chen 2017). In addition, *L. perenne* with the endophytic fungi, *Neotyphodium lolii*, is more resistant to rust (Ma and Nan 2011). In the screening of corn endophytic bacteria, one strain of actinomycetes, six strains of bacteria, and five strains of fungi have sound biological control effects on corn stalk rot and corn leaf spot (Sheng 2019). The bacterium *B. subtilis Y21* has a biocontrol effect on stalk rot and leaf spot disease, and its inhibition rate can reach 73% and 88%, respectively. The fungus *T. harzianum YZ9* could also inhibit the outbreak of both corn stalk rot and leaf spot disease, by significantly reducing their occurrence 64% and 79% respectively (Sheng 2019).

4.4.4.2 Use Microorganisms to Control Insects

The pathogenic microorganisms of insect pests have been widely developed and utilized, and many species have been industrially produced into biological pesticides (Duan et al. 2014; Ge et al. 2019; Sun et al. 2021). For example, *Bacillus thuringiensis* has been extensively applied to control pest from Lepidoptera, Diptera, and Coleoptera. The Entomopathogenic fungi well developed are mainly from genus *Metarhizium*, *Beauveria*, and *Paecilomyces*to control pests efficiently in orders of Lepidoptera, Homoptera, Orthoptera, and Coleoptera. Insect viruses usually parasitize one species or narrowly related few species or sub-species. At present, *Nuclear polyhedrosis virus* (NPV), *Cytoplasmic polyhedrosis virus* (CPV), and *Granulo virus* (GV) have been studied extensively. Insect viruses can be used to control larvae of Coleoptera, Hymenoptera, and mites.

Microorganisms was widely used in corn. Field experiment results showed that the average control effect of 50,000 IU/mg *B. thuringiensis* WP was 61.4%, the stem preservation rate was 62.5%, the ear preservation rate was 64.0%, and the yield increase was 6.6%, when used in the early stage of egg hatching and larval prime stage. Different microbial strains have different effects on pests. Feng et al. isolated a new strain of *B. thuringiensis* HbF-1 from the soil of Hebei Province. The strain *B. thuringiensis* HbF-1 had a high insecticidal activity against the larvae of *Anomala corpulenta* and *A. exolete*. However, it had no insecticidal activity against Lepidoptera larvae, such as cotton bollworm and corn borer. In addition, *Metarhizium* spp. are widely used in underground pest control, especially in grubs, which could be managed by more than 20 species belonging to genus *Metarhizium*.

4.4.4.3 Use Animal Natural Enemies

Animals from mammals, arthropods, nematodes, and protozoa are also important natural enemies to control the population of pests through predation or parasitism. Many birds (such as swallows, woodpeckers, gray magpies, etc.), amphibians (frogs, toads), predatory insects (such as ladybirds, lacewings, mantises, hoverflies, insectivorous bugs, ants, wasps, predatory mites, etc.), and parasitic insects (such as mites, cocoons, etc.) have a significant control effect on pests. In forage grassland, on corn silage, *Trichogramma dendrolim* is the most widely used species for controlling the Asian corn borer *Ostrinia furnacalis*. *T. dendrobium* parasite the host specifically during the egg period, so they are released during the oviposition period of *O. furnacalis*. It has a very significant effect on larval control of Asian corn borer. *T. dendrolim* were released with the insect density of 30,000/667 m^2 resulted in the control efficiency of 85% averagely in Heilongjiang Province, China (Liu 2020). The similar work was performed in Liaoning Province, China, which could save 77.50% of the loss (Wang 2021).

Locusts are one of the pests feeding on crops and forage grasslands, and microsporidia *Nosema locustae* is a single-celled eukaryotic protozoa parasitic on more than 20 species of locusts. According to the results of grassland experiments in Xinjiang, Qinghai, Inner Mongolia, and other places on the grassland, a mixture of 7.5 mL of concentrated solution (1×10^{10} spores/mL) and 1.5 kg/ha of wheat bran was used to make poisonous baits. After four weeks, the adjusted population reduction rate was 55%, and 33% - 35% of the survival locusts carried the microsporidiosis. The locust density in the experimental area three years later was far lower than the control area, and 62.7% of the survival locust swarms were infected with locust microsporidiosis (Wang et al. 2006; Zhang et al. 2007).

4.4.5 Ecological Control Technology

The ecological control technology is mainly carried out through artificial adjustment of environment, food chain and circulation, coordination of the relationship among crops, pests, and environment. Chickens and ducks are used for locust control in grassland in China. For example, in the alpine grassland of Qilian Mountains, the density of locusts can be effectively reduced by more than 40% after 2 weeks, and by 60% after 2 months. This method can not only control locust effectively, but also produce economic benefits, which provided a new measurement for grassland green locust control (Pan et al. 2012; Du et al. 2019).

All creatures play important role in the ecosystem. In the process of forage grass growth, only the main pests need to be managed, instead perishing all creatures that infest the host forage grass. Moreover, various pest control technologies have certain advantages and disadvantages. For many pests with strong adaptability, it is difficult to achieve continuous and effective control using any of these technologies alone. Therefore, the integrated pest management coupled with multiple technologies are necessary for the sustainable management of pest population in grassland protection.

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Chapter 5
Advances in Grass and Forage Processing and Production in China

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5.1 Introduction

Grass and forage industry in China has experienced a blooming increase in the past two decades. It was recorded that there was only 10 thousand tons of alfalfa hay produced in China in year 2008. However, about 4 million tons of alfalfa hay was produced in year 2020, in addition to 2 million tons of alfalfa haylage, 1.2 million tons of oats hay, 0.4 million tons of oats silage. Moreover, totally 1.25 million tons alfalfa hay and 0.3 million tons of oats hay were exported from abroad in year 2020. There was about 100 million tons of corn silage was made in China in year 2020.

The fast-growing of grass and forage industry in China accelerates research on developing techniques, additives and machinery for hay and silage production. However, the quality of hay and silage is still a major challenge due to the various climates and geographical conditions across the country, and also influenced by the level of mechanization for hay and silage production. Even so, the quality of alfalfa hay got an obvious increase. For instance, the ratios of premium, good and fair grade alfalfa hay were 5%, 40% and 44% in 2018, respectively, but in 2020, the ratios of

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premium and good grade alfalfa hay increased to 15% and 50%. According to the silage quality report released by the National Animal Husbandry General Station, the silage quality of the whole plant corn in the demonstration and extension areas in year 2020 reached above 85%, with a year-on-year increase of 6.1%; the average value of 30 h neutral detergent fiber digestibility (30 h NDFD) and lactic acid concentration increased by 2.5% and 7.1% respectively compared with that in 2018, and the ammonia content decreased by 12.5%, indicating that there is a pronounced increase in the proportion of high-quality silage.

5.2 Research Progress on Silage in Southern China

Southern China is generally defined as the south regions of the Qinling-Huahe line, and its west is the Qinghai-Tibet Plateau. It covers the provinces (autonomous region or province-level municipality) of Chongqing, Hubei, Hunan, Zhejiang, Shanghai, Fujian, Jiangxi, Guangdong, Guangxi, Guizhou, Hainan, Hongkong, Macao, and Taiwan and parts of Gansu, Shanxi, Henan, Anhui, Jiansu, Sichua, and Yunna. The land coverage of this region is approximately 25% of that in China. The area belongs to the tropics and subtropics monsoon climate; the air temperature during winter is generally higher than 0 °C, and some even exceed 15 °C. There is a longer growing season for plants and abundant rainfall. Therefore, high temperature and high humidity in this region are serious factors that limit the production of high quality silage. Moreover, research and utilization of silage start late in temperate regions owing to availability of more fresh grasses during a whole year. However, with the intensification and precision of farming, silage consumption has become indispensable to some animals as it improves their production performance and health, even in the tropics and subtropics. Although there have been few studies on silage in the subtropics of China from the 1940s, systematic researches began about 20 years ago (Cao et al. 1998; Zhao et al. 2001).

5.2.1 Main Silage Materials in Southern China

In southern China, the main silage materials are tropical perennial grasses, annual forage crops and grasses, and some agricultural and food processing by-products. Of them, the silages made from napier grass, king grass, hybrid *Pennisetum*, whole-plant corn, and Italian ryegrass are the most common. Some temperate crops and grasses, such as oats, wheat, rape, and Italian ryegrass are often grown on winter fallow paddy fields for silage. Alfalfa, a temperate perennial grass, is also grown for silage in the northern or higher altitude areas, and is used as annual grass only in winter fallow lands in eastern China (Hu et al. 2010; Zhang et al. 2015b). With increased demand for high quality and low cost forage, agricultural and food processing by-products are paid more and more attention: from traditional crop straw or residues to processing by-products. There are also some forage shrubs, leaves, or whole-plant and trees that can be used as silage materials (Table. 5.1).

Table 5.1 Main silage materials studied in southern China

Types	Material
Tropical perennial grass	Npeir grass (*Pennisetum purpureum*), king grass (*P. purpureum* × *P. americanum*), hybrid *Pennisetum* (*P. americanum* × *P. purpureum*; (*P. americanum* × *P. purpureum*) × *P. purpureum*), guinea grass (*Panicum maximum*), bahiagrass (*Paspalum notatum*), palisade grass (*Brachiaria spp.*), African Setaria (*Setaria sphacelata*) Stylo (*Stylosanthes guianensis*), *Desmodium intortum*
Temperate perennial grass	Alfalfa (*Medicago sativa*), red clover (*Trifolium pratense*)
Annual forage crop	Corn (*Zea mays*), sorghum (*Sorghum bicolor*), oat (*Avena sativa*), wheat (*Triticum aestivum*), barley (*Hordeum vulgare*), rape (*Brassica napusand*), triticale (*Triticale wittmack*), Soybean (*Glycine max*)
Annual grass	Sudan grass (*Sorghum sudanense*), *S. bicolor* × *S. sudanense*, Italian ryegrass (*Lolium multiflorum*), hairy vetch (*Vicia villosa*)
Forage shrubs and trees	Paper Mulberry (*Broussonetia papyrifera*), *Lucaena* (*Leucaena leucocephala*), Moringa (*Moringa oleifera*), *Neolamarckia cadamba*, *Amorpha fruticosa*, *Sophora davidii*, *Indigofera pseudotinctoria*, Mulberry (*Monus alba*), Acacia (*Sophora japonica*)
Other plants	Ramie (*Boehmeria nivea*), water hyacinth (*Eichhornia crassipes*), kudzu (*Pueraria lobata*), Bidens pilosa, Ulva lactuca, Pueraria lobata
By-products (straw, stems, leaves, processing residues)	Corn, rice, rape, cassava (*Manihot esculenta*), pineapple (*Ananas comosus*), banana (*Musa nana*), litchi (*Litchi chinensis*), citrus (*Citrus reticulata*), pawpaw (*Chaenmeles sinensis*), peanut (*Arachis hypogaea*), sugarcane (*Succcharum sinense*), sweet potato (*Ipomoea batatas*), bamboo (*Dendrocalamus latiflorus*) shoots, Amomum villosum, fungus chaff

5.2.2 Microorganisms on Silage Materials

Microorganisms on silage materials have a great impact on silage fermentation quality. In general, more of lactic acid bacteria (LAB) and less of undesirable microorganisms will benefit lactic acid fermentation of silage. Chen (2013) investigated the microorganisms present on the surfaces of 13 plant species or varieties (napeir grass, king grass, corn, oat, wheat, barley, stylo, etc.) grown in Guangdong and found that plant species had greater effect on LAB than on aerobic bacteria, yeasts, and molds; homo-fermentative LAB accounted for 58.4% of LAB, and *Lactobacillus plantarum* (30.2%), *Lactococcus lactis* (23.9%), and *Weissella confuse* (22.6%) were the most frequently appeared LAB. *Lb. plantarum* and *W. confuse* mainly appeared on spring planting plants, while *Lc. lactis* and *Lc. lactis* subsp. *lactis* were isolated mainly from winter planting plants. The amounts and species of LAB from various cuts, heights, and growth periods were different. The amounts of LAB on the second and third cuts *of Pennisetum* spp. were higher than that on the first cut. Crops at the milk and dough stages had more LAB species and higher amounts than those at the flowering stage. The amounts of LAB on the stems and leaves of corns were not significant; however, the species that were present on stems were more than those present on leaves. Sucrose was the preferred carbon source for most LAB. Spraying sugars significantly increased the number of LAB by mainly increasing the proportion of *Lb. plantarum* and *Leuc. mesenteroides*. The numbers of LAB on plants grown at 10, 15, and 20 °C were significantly higher than those at 25 °C. *Lb. mesenteroides* dominated at 10 °C and 15 °C, while *Lb. Plantarum* and *W. paramesenteroides* dominated at 20 °C and 25 °C, respectively.

Yang et al. (2016) investigated the composition of LAB present on the residues of tropical fruits (Pineapple peels, papaya peels, and banana stems and leaves) and found that LAB numbers were 3.5–5.8 cfu g^{-1} FM, and they consisted of *Lb. plantarum* (54.9%), *Lb. casei* (11.0%), *Lb. fermentum* (9.8%), *Lb. nagelii* (8.5%), *Enterococcus gallinarum* (7.3%), *Lb. paraplantarum* (3.6%), and *Lb. perolens* (4.9%), respectively. Chen et al. (2017a, b) reported that there were less LAB on the stand of *Pennisetum* spp., which was indicated by the change from 4.1×10^1 to 2.56×10^3 cfu g^{-1} FM. However, the amount of LAB significantly increased from the harvest to chopped stages of king grass and sweet corn, mainly owing to the increase in *Lc. lactic*, *Leuconostoc citreum*, and *W. confuse* (Chen and Zhang 2017). Guan et al. (2018) collected 48 corn material samples at the milk-ripe stage from the five major ecological areas of Sichuan, Chongqing, and Guizhou; the numbers of LAB, yeasts, molds, and enterobacteria were 2.9–6.4 cfu g^{-1} FM, 2.8–5.3 cfu g^{-1} FM, 1.2–4.9 cfu g^{-1} FM, and 2.8–5.5 cfu g^{-1} FM, respectively. *Weissella* spp. were the dominant epiphytic LAB in these corns. In their study, significant positive correlations were found between the average precipitation and relative abundance of the genera: *Lactobacillus*, *Lactococcus*, *Leuconostoc,* and *Acetobacter* on fresh corn. In addition, the relative abundance of undesirable bacteria (*Methylo*, *Sphingomonas*, *Aureimonas*, and *Devosia*) had a negative correlation with average temperature but a high positive correlation with humidity. Generally, the numbers of LAB, yeasts, molds, and enterobacteria in these corns were lower than those in the corns present in northern China and in the barley, oat, and triticale present in Canada (Duniere et al. 2017). The epiphytic LAB of mixed materials harvested from corn and soybean intercropping outnumbered that of monocropping materials (Zeng et al. 2020). The findings of Chen (2013) and Guan et al. (2018) indicate that the numbers of LAB on plants at high temperatures are less than those at low temperatures.

5.2.3 Improving the Fermentation Quality of Silage

In general, tropical grasses contain low water-soluble carbohydrates (WSC), which usually results in poor fermentation of silage. In addition, grasses are difficult to wilt in this region owing to rainy weather and humid air, which negatively affect the silage quality (Liu et al. 2011; Zhang et al. 2014). Yuan et al. (2020) reported that the natural ensiling of napier grass increased butyric acid and ammonia nitrogen concentrations after ensiling for 7 days, and reduced lactic acid concentration and increased pH after ensiling for 14 days, which was attributed to the growth of *Clostridia* owing to high moisture. Therefore, some silage additives are necessary to ensure the successful production of silage. Similar to the temperate regions, the addition of LAB, sugars, acids, materials rich in WSC, enzymes capable of degrading cell walls, or dry materials has also proved to be an effective method of improving the fermentation quality of silages made from various materials, even in southern China (Shen et al. 2004; Chen et al. 2011, 2020; Li et al. 2014). However, where there is a dry weather condition (in the dry season), wilting is still an effective method of improving the fermentation quality of most silages (Liu et al. 2011; Zhang et al. 2014). In addition, some methods of planting and harvesting also affect the fermentation quality of silage. The stover of maize grown in Hunan was separated into leaf blade, leaf sheath, whole stem, and whole maize stover; their WSC contents were 5.3%, 6.4%, 9.1%, and 8.5% DM, respectively, and the silage quality was in this order: whole stem > whole maize stover > leaf sheath > leaf blade. The addition of cellulase or LAB promoted lactate fermentation and reduced the loss of nutrients during ensiling, especially for the whole stem and whole maize stover (Sun et al. 2009). As Chen (2013) reported that corn stems had more LAB species than leaves, the silage of maize stems with more WSC was better than that of leaves by natural fermentation. Sweet corn stalk is an important silage material in some areas of southern China, and the plants after picking their ears may continue to grow because of photosynthesis. Hence, the harvest time of stalks has a great effect on their nutrient components and silage fermentation quality; the fermentation quality was best when the stalk was harvested after picking ears for 3 days in winter and during 3–9 days in summer (Cui et al. 2011). The silage made from intercropped corn and soybean produced higher lactic acid content and lower ammonia-N content than soybean silage and higher CP content and lower ammonia-N content than corn silage (Zeng et al. 2020).

New additives were also studied in this region. The addition of cut pawpaw or serous collected from pawpaw significantly improved the fermentation quality of napeir grass silage, and their pH values reduced from 4.6 (control) to 3.7–3.8 (Cao et al. 1998). The addition of green fermented juice improved the fermentation quality of *Ganodorma* fungus chaff (Zhuang et al. 2006) and water hyacinth and maize straw mixed silage (Chen et al. 2011). Liu constructed a transgenically engineered *Lc. lactis* strain with high-efficiency secretory-expressing cellulase genes from *Trichoderma reesei* and confirmed that the engineered strain efficiently secreted endoglucanase, cellobiohydrolase, and β-glucosidase; its addition, compared to that of wild strain or cellulose, greatly enhanced lignocellulosic degradation and improved the silage fermentation quality of high-moisture alfalfa. He et al. (2020a, b) reported that vegetal gallic acid could be used as a green additive, since its addition at 1% decreased pH, butyric acid, and NH_3-N contents and increased lactic acid content of stylo silage; moreover, the addition decreased the relative abundance of *Clostridium* or *Enterobacter* and increased that of lactate-producing bacteria. Zhu et al. (2020) screened a strain of *Bacillus subtilis* BS-KC and added it to mulberry silage; ammonia nitrogen content was significantly decreased. Stylo was ensiled with 10% *Bauhinia variegate* flower and the contents of butyric acid, NH_3-N, and free amino acid were decreased; the relative abundance of *Enterobacter* or *Clostridium* decreased and that of lactic acid-producing bacteria such as *Lactobacillus*, *Weissella*, and *Enterococcus* increased (He et al. 2020a, b).

In southern China, high temperature also has a negative effect on the fermentation quality of silage. Successful ensiling under high temperature conditions requires materials with more WSC (Zhang et al. 2010) and thermophile LAB (Liu et al. 2012; Gulfam et al. 2017). Chen et al. (2013) screened a thermotolerant strain of *Lb. rhamnosus* HT1, and was the most effective at improving the fermentation quality of silage at 45 °C; however, a commercial inoculant had no or reduced benefits. Gulfam et al. (2017) screened *Pediococcus acidilactici* GG13 and *Lactobacillus rhamnosus* GG26 and found that they both significantly improved the fermentation quality of napier grass silage at 50 °C, and strain GG13 was better than strain GG26. At the same time, southern China has a long growing season, and silage materials can be supplied for several months. That is, some silages are made during the high temperature season, while some are made during the low temperature season. Therefore, it is also necessary to study how to make good silage at a lower temperature. Inoculating LAB capable of growing at low temperatures is a convenient method. Chen et al. (2016) screened 3 strains of *Lb. plantarum*, and their inoculation significantly improved the fermentation quality of Italian ryegrass silage at 15 °C. Alhaag et al. (2019) reported that *Lb. rhamnosus* GG6, *Lb. plantarum* GG7, and *Lb. plantarum* MTD-1 promoted the lactic acid fermentation of acacia leaf silage at 10 and 15 °C.), Liu and Shao (2016) reported that tert-butylhydroquinone was a valuable additive in the ensiling of napier grass at various temperatures (15, 30, and 45 °C), and reduced the loss of beta-carotene at 45 °C.

5.2.4 Improving the Aerobic Stability of Silage

When a silo is opened, its anaerobic environment is changed to an aerobic environment, and microorganisms, which are dormant in the absence of oxygen, multiply, resulting in aerobic deterioration of silage. Deteriorated silage is undesirable because of high nutrient losses and the possible production of harmful matter associated with it. Some silages show signs of deterioration in less than 24 h, whereas others remain unchanged and stable during weeks of aerobic exposure. Silage deteriorates faster in high temperature condition than in low temperature condition (McDonald et al. 1991). Therefore, the inhibition of aerobic deterioration of silage is also a very important task in this region. Various additives, such as propionic acid, caproic acid, sorbic acid, ammonia, and *Lb. buchneri* are confirmed to be effective in southern China. Heterofermentative *Lb. buchneri* inhibited aerobic deterioration by increasing acetic acid production (Mangwe et al. 2016). Liu et al. (2014) isolated *Lb parafarraginis* ZH1 and found that it improved the aerobic stability of silages at both 15 and 30 °C, and *Lb. buchneri* improved the aerobic stability of silage only ensiled at a high temperature of 30 °C. *Lb parafarraginis* ZH1 inoculated silage produced more acetic acid, benzoic acid, and hexadecanoic acid than *Lb. buchneri* inoculated one, and benzoic acid and hexadecanoic acid had lower minimal inhibitory concentrations to target yeasts than acetic acid (Liu et al. 2018). Mang et al. reported that the inoculation of *Lb. formosensis* improved the aerobic stability of sweet potato vine silage by producing more propionate. The addition of oil-extracted powder of *Chlorella vulgaris* at 2% and 3% prolonged the aerobic stability time of sweet sorghum silage from 69.7 h (for control) to 100.2 h and over 168 h, respectively (Chen et al. 2018). *Lb. hilgardii*, alone or in combination with *Lb. plantarum,* improved the aerobic stability of sugarcane top silage, owing to the suppression of undesirable microorganisms, such as *Acetobacter pasteurianus*, *Paenibacillus amylolyticus*, and yeasts such as *Kazachstania humilis* (Wang et al. 2020a, b). Li et al. (2019) reported that the addition of tannic acid at 1% improved the fermentation quality, aerobic stability, and nutrient value of cassava foliage silage.

5.2.5 Reducing the Harmful Matters in Silage

Some silage materials contain anti-nutrient compounds that affect the utilization of silage by animals. Zhang et al. (2012a, b, c) studied the changes in mimosine and tannin contents during ensiling of leucaena leaves. Both mimosine and tannin content gradually decreased as fermentation time increased. After ensiling for 30 days, the reduction rates decreased, and after ensiling for 90 days, mimosine degradation rates in silages containing sucrose and sucrose + LAB were 49.0% and 48.0%, respectively, while that in control and LAB inoculation alone were 25.5% and 30.7%, respectively. The degradation rates of tannin in silages containing sucrose and sucrose + lactic acid treatments were 52.4% and 54.7%, respectively, while that in control and LAB inoculation alone were 40.0% and 42.3%, respectively. The degradation rates of mimosine and tannin were negatively related to pH values ($r = -0.824$ and -0.844, respectively) and positively related to lactic acid content ($r = 0.961$ and 0.957, respectively). Ensiling enhanced the nutritional value of fresh citrus pulp and reduced its concentrations of limonin and naringin (Yao et al. 2012). Lb. formosensis and Lb. buchneri inoculation not only improved the aerobic stability of sweet potato vines silage but also effectively reduced its content of condensed tannins (Mangwe et al. 2016).

Although detailed researches on silage in southern China have been on for 2 decades, there has been significant scientific progress in new material exploitation, fermentation control, microbial function analysis, and so on. An extremely important achievement is the rapid increase in the number of silage researchers and the production and utilization of silage in southern China.

5.3 Research Progress in Silage Processing on the Tibetan Plateau

The Tibetan Plateau, one of the five most important livestock production zones in China, is characterized by wide specific features, such as the Earth's third pole, the highest unique territorial unit and uneven temporal and spatial distribution of rainfall (Wang et al. 2017a, b). Its climate and natural environment are inherently extreme and instable. The cold and arid continental climates and short growing seasons are the most important limiting factors for forage production in Tibet, which result in malnutrition and poor production performance of livestock. Moreover, there are 15.84 million sheep (*Ovis aries* L.) and 5.05 million yaks (*Bos grunniens* L.) on the Tibetan Plateau (Wang et al. 2018a, b). These animals mainly rely on the native grassland. However, the traditional grazing system extends the degradation of grasslands and the gap between forage production and the animals' feed demand in recent decades, which also accelerates the threat to the vulnerable livestock production system on the Tibetan Plateau (Zhang et al. 2012a, b, c). Dairy farmers have long been storing forage as hay for winter supplementary feed, whereas dry matter and nutritive value losses often occur during the process of haymaking (Arinze et al. 2003). Therefore, silage production is a preferable strategy for sustainable development of livestock production on the Tibetan Plateau. This part introduces the research progress in silage production on the Tibetan Plateau from the following three aspects.

5.3.1 Mixed Silages

In recent years, demand is increasing for the efficient use of agricultural by-products in an effort to achieve sustainable and economically viable livestock systems. Hence, the efficient exploitation and utilization of crop straws has received significant attention. In Tibet, due to the harsh environment and insufficient feed supply during the long cold season, most Tibetan herdsman feed their cattle with crop straws. Nevertheless, crop straw is normally deficient in moisture content for a desirable fermentation, and often lacks certain nutrients (including nitrogen and phosphorus) for optimum animal performance. Legume herbages could provide a good source of proteins with multiple positive effects on both animal nutrition and the environment, associated with their role in N_2-fixation and thus a reduction in inorganic nitrogen-fertilizer inputs (Copani et al. 2016). Meanwhile, as conventional cultivated crops in Tibet, corn and legume herbages were widely intercropped by farmers. Recently, Wang et al. (2017a, b) evaluated the nutritional value and digestibility of corn (*Zea mays* L.) stover silage mixed with legume herbages in Tibet, and corn stover was ensiled with four levels (0, 10, 20 and 30% of fresh weight) of common vetch (*Vicia sativa* L.) and alfalfa (*Medicago sativa* L.), respectively. The results showed that the inclusion of legumes could somewhat improve the corn stover silages, as indicated by the higher lactic acid and crude protein contents and ratios of lactic acid to acetic acid, and lower amylase-treated neutral detergent fiber, acid detergent fiber and hemicellulose contents. It was suggested that mixing legumes to crop straw before ensiling appears to be a feasible strategy to improve the nutritive value of mixed silage. Moreover, Chen et al. determine the effect of ensiling different ratios of whole crop oat to lucerne on fermentation quality, aerobic stability and in vitro digestibility of silage on the Tibetan plateau. The results suggested that replacing oat with lucerne had no unfavorable effects on fermentation quality of silage, but improved crude protein content, aerobic stability and in vitro digestibility. 70% oat + 30% lucerne (based on fresh weight) silage was the best among the three mixed silages.

In addition to the mentioned above binary pattern, the triple pattern of mixed silage is also investigated on the Tibetan Plateau. Hulless-barley (*Hordeum vulgare* L.), wheat (*Triticum aestivum* L.) and oat (*Avena sativa* L.) are common cereal crops, and their grains are used as human food in Tibet (Wang et al. 2018a, b). Rape (*Brassica campestris* L.) is one of the main oilseed crops with economic significance on the Tibetan Plateau (Lv et al. 2015). These four crops are widely distributed and abundantly available in Tibet, so large amounts of straws are produced every year. Most of Tibetan herdsman feed various types of straw to their cattle. However, the lower digestibility and protein content of straw limit its use as feed for ruminants. Fortunately, some researchers have found that some agricultural by-products could be incorporated into rations by ensiling (Nishino and Hattori 2007; Cao et al. 2011a, b). If straws could substitute a part of forage and are conserved well as mixed silage, it would enlarge the feed resource and alleviate the shortage of feedstuffs. Recently, Yuan et al. (2016a, b, 2012, 2013) ensiled hulless-barley and oat straws with different types of grass to improve the utilization efficiency of straws in Tibet. However, providing only mixed silages of straws with grass does not satisfy the nutritional requirements of high producing ruminants.

Tall fescue (*Festuca arundinacea* Schreb.) and alfalfa (*Medicago sativa* L.) are also cultivated forages in Tibet. Both have high nutritive value and strong resistance against the harsh environment. Tall fescue has relatively higher water-soluble carbohydrate content and lower crude protein content (Yuan et al. 2012). However, alfalfa could provide abundant protein with multiple positive effects (Copani et al. 2016). Hence, it was hypothesized that a combination of sugar-rich crop, such as tall fescue, and protein-rich crop, such as alfalfa, would ensile successfully and serve to produce quality silage adequate for maintenance and production of dairy cows (Kennelly and Weinberg 2003). Also, ruminants prefer a ration with mixed forages (Huhtanen et al. 2007). However, high proportions of legumes may enhance silage nutritive value (Salawu et al. 2001) but may also reduce silage quality (Pursiainen and Tuori 2008). Given this, Wang et al. (2018a, b) investigated the effect of alfalfa proportions on tall fescue-straw mixed silage on the Tibetan Plateau. Results suggested that inclusion of alfalfa to mixtures of straws and tall fescue had favorable effects on fermentation characteristics, and obviously improved the nutritive value and in vitro digestibility of mixed silages. This effect was most evident when the inclusion rate of alfalfa was 30% (based on fresh weight) in oat straw-tall fescue mixed silage.

Overall, on the Tibetan Plateau, three main patterns are concluded in which interactions in mixed silages may lead to associative effects: (i) when grass (whole crop oat) and legume (lucerne) are combined, (ii) when a poor ensilage material (crop straw) is supplemented by a high energy plant (corn stover), and (iii) when local crop straws with sugar-rich grass (tall fescue were ensiled with legumes (alfalfa).

5.3.2 Fermented Total Mixed Rations

Total mixed rations (TMR) have been widely used for dairy cattle because they combine forages, grains, protein feeds, minerals, vitamins and feed additives formulated into a single feed mix to satisfy the nutrient requirement of animal. TMR are highly deteriorative feedstuffs, needs to be prepared near to time of use. This rapid deterioration restricts its use on some farms due to labor shortage. Fermented total mixed ration (FTMR) avoid daily labor for TMR preparation, improve the feed preservation and facilitate long distance transportation. Ensiling industrial and agricultural by-products with concentrate as TMR silage could provide year-round nutrition balance feed, and also could improve the palatability by altering odors and flavors from by-products through silage fermentation (Nishino et al. 2003). During the past couple of years, the FTMR have been widely used by herders in Tibet, where the alpine rangeland ecosystem is fragile due to the harsh climate and long period of negligible or zero plant growth each year (7–8 months). Chen et al. (2015) assessed the effects of replacing whole-plant corn with oat and common vetch on the fermentation quality, chemical composition and aerobic stability of FTMR in Tibet. They found that the replacement of whole-plant corn with oat and common vetch had no unfavorable effects on the fermentation quality and improved crude protein content and aerobic stability of FTMR, and the ratio of 38% oat + 18% common vetch was the best among three treated FTMR.

In pursuit of sustainable and economically viable livestock systems, many farmers worldwide are under increasing pressure to maximize the use of available agro-industry by-product-based diets for their livestock (Nkosi and Meeske 2010). In recent years, TMR silage was introduced to Tibet, so as to provide year-round and nutritional balanced feed, and exploit unpalatable by-products as feed resources. Including local by-products in FTMR could provide year-round and nutritionally balanced feed; however, the combined ensilage of straw may affect the fermentation characteristics of the FTMR, using fermentative stimulants such as fermentation substrates or lactic acid bacteria before ensiling is thus very essential. The results of Yuan et al. (2018) showed that molasses and *L. plantarum* could be used in FTMR to ensure a consistent fermentation in the silo by decreasing pH and shifting fermentation towards lactic acid and away from acetic acid in Tibet.

It is common practice for farmers in pastoral areas of northern Tibet to purchase silage from agricultural areas of southern Tibet, due to the lack of rain during the rainy season or failures during the silage process in pastoral areas of northern Tibet. It is thus necessary to relocate TMR silages before feeding to ruminants in Tibet. FTMR are prepared in the south where surplus agricultural crop is available and later moved north to the dairy farm for utilization. The inconvenient transportation in Tibet decelerated the relocation of silage, which might take 3–5 d. FTMR are inevitably exposed to air, and opportunistic aerobic microbes proliferate further aggravating the spoilage in the FTMR mass. Moreover, bale damage or breakage is unavoidable during the long-distance transportation, FTMR are thus often exposed to air which enhance the aerobic microorganisms' proliferation. Recently, Yuan et al. (2016a, b, 2015) demonstrated that ethanol has potential to improve the aerobic stability of the FTMR prepared with grass and legume. They concluded that *L. plantarum* combined with ethanol not only ensures better fermentation but also could improve aerobic stability of FTMR in Tibet.

5.3.3 The Isolation and Application of Psychrotolerant Lactic Acid Bacteria

As the Earth's third pole, the Tibetan Plateau gets a lot less attention than the Arctic or Antarctic. Being an average of 4000 m above sea level makes it peculiarly cold (Qiu 2008). In this distinct ecological region, the unique geographical and climatic conditions have contributed to the formation of specific microorganisms (Pang et al. 2012). It is therefore worth exploiting the microorganism resource on the Tibetan Plateau. Nevertheless, the cold and arid continental climates limit the forage yield in most areas of Tibet (Zhang et al. 2015a). Due to the unstable climate and natural environment on the Tibetan Plateau, the growing seasons of grass are too short and seldom crops are suitable for growing, particularly facing frosts from November to early April (Wang et al. 2017a, b). The animal husbandry system on the Tibetan Plateau faces higher risk as compared with other regions in China (Long et al. 1999). As a result, the use of techniques to preserve grass is vital to the sustainable development of local stock farming on the Tibetan Plateau.

Lactic acid bacteria (LAB) play an important role in silage-making. In natural fermentation, epiphytic LAB lowers the pH by turning water soluble carbohydrates into lactic acid in an anaerobic environment, forages are thus conserved. However, ensiling is a fermentation process strongly influenced by temperature (Weinberg et al. 2001), and a moderate temperature from 20 to 30 °C is generally preferred for silage fermentation. In practice, low temperature (<20 °C) could hinder silage production. Such silages are often found to have high pH value and low rate of pH decline (Ali et al. 2015) and low acid production (Kung 2010). Zhou et al. (2016) reported that low temperature could reduce fermentation efficiency by lowering the growth rate and enzymatic activity of micro-organisms. Even, the commercial lactic acid bacteria (LAB) inoculants might be inhibited and are thus not effective at low temperatures (Kim and Uchida 1990; Weinberg and Muck 1996). The inefficient silage fermentation at low temperatures might be attributed to the thermodynamic implication that low temperature inhibits bacterial metabolism. Aguilar et al. (1998) reported that membranes of the microorganism were usually equipped with low proton permeability in adverse growing conditions. Song et al. (2014) stated that, for most bacteria, a temperature reducing causes a transient cell growth arrest, during which the general protein synthesis is severely inhibited, and low temperature affected the viability and acidification activity of bacteria. Hence, it is necessary to isolate and examine the potential LAB capable of playing a positive role under low temperature conditions.

Recently, Wang et al. (2017a, b) assessed the characteristics of LAB isolated from Tibetan Plateau and their effects on silage quality of Italian ryegrass (*Lolium multiflorum* Lam.) at different storage temperatures (10, 15 and 25 °C). They found that strain LM8 (*Lactobacillus coryniformis*) performed better than other isolates at 10 and 15 °C, indicated by the higher lactic acid content and ratio of lactic acid to acetic acid, and the lower pH value and ammonia nitrogen content. Moreover, Wang et al. (2018a, b) found that the effect of combined homofermentative LAB strains on improving silage quality did not always coincide at low temperatures. It might be closely related to their physiological and biochemical characteristics. In cold environment, it seems that cocci LAB strains played a more important role than rod LAB strains in a combined silage inoculant.

5.4 Microbial Community and Metabolome of Silage

Ensiling is a complex fermentation process and involves many types of microorganisms, resulting in a variety of metabolites (Xu et al. 2019). Classical microbial populations associated with fresh forage, and the contribution of the lactic acid bacteria (LAB) to drive of silage, while bacilli, yeast, molds and clostridia to the spoilage of silage. Many of classical studies focused on the number and characterization, which could uncover the associations of fermentation system. The molecular biological techniques like polymerase chain reaction-based techniques (including length heterogeneity PCR, terminal RFLP, denaturing gradient gel electrophoresis (DGGE)) used to study silage microbial communities. Next-generation sequencing (NGS) has been used for investigating microbial communities at genus level in silage (Mcallister et al. 2018). The PacBio single molecule in conjunction with real-time sequencing technology (SMRT), can almost cover the full read length of the DNA fragment multiple times, resulting in a depiction the bacterial profile to species level precision for microbial communities during ensiling. While, these technologies based primer of marker gene sequencing, metagenomics avoids primer biases as all microbes in the community including eukaryotes and viruses can be sequenced and identified, which will become more extensive for investigating microbial communities of silage.

Certain metabolites have conventionally been investigated to assess the fermentation quality of silage, until recently a few studies focused on metabolites potentially affecting animal health and welfare (Guo et al. 2018; Xu et al. 2020). There is current an opportunity to use new technology to accumulate much about what happens during ensiling and how a silage is fermented. Metabolic and metabonomic approaches are now being applied to silage research. Metabolomic research, based on mass spectrometry, involves systematic assessments of the metabolic products of silage fermentations.

By focusing on the silage microflora, new technologies of metabolomics and metabonomics may provide a better understanding. For example, how homolatic LAB change silage fermentation and later improve digestion and utilization of the diet in the rumen and may lead to inoculants that are more effective in improving animal productivity. The metabolomic and metabonomic tools that are becoming available put the research community at the cups of being able to unlock interaction that are in the silos and in the animal. We need to find out not only which microbial species are active and thriving at various times but also what they are producing and how those compounds are influencing the microbial community and the animal itself. Potentially these technologies will open up new opportunity to improve silages in the silos, inhibit detrimental microorganisms, enhance rumen microbial activity and improve animal health and welfare.

5.4.1 Microbial Community of Silage

The microbial population of standing or freshly harvested forage crops is considerably different from that found during the process of silage fermentation or in the final product. This includes both the numbers as well as the taxonomic composition of the microflora in the aerial parts of plants (Pahlow et al. 2003). According to the reports of Cai et al. (1999a, b), at genus level of microorganisms attached on the surface of alfalfa and sorghum, there were very few *Lactobacillus* (<10^1 cfu· g^{-1} FM), while there were more *Leuconostocs* (10^5 cfu·g^{-1} FM) attached to the surface of alfalfa; *Pediococcus* attached to the surface of sorghum was very few, and there were more *Lactobacillus* and *Enterococcus* (10^4–10^5 cfu·g^{-1}FM). Some studies indicated that there are more *Lactococcus* in the early stage of silage, while *Lactobacilli* become the dominant bacteria at the middle and late stage of fermentation process (Oude Elferink et al. 1999; Eikmeyer et al. 2013). Guo et al. (2018) reported that *Enterococcus* was the dominant bacteria on 14 d of ensiling in untreated alfalfa silage, while, *Lactobacillus* dominated later fermentation in untreated and whole fermentation process in inoculated alfalfa silages (Fig. 5.1).

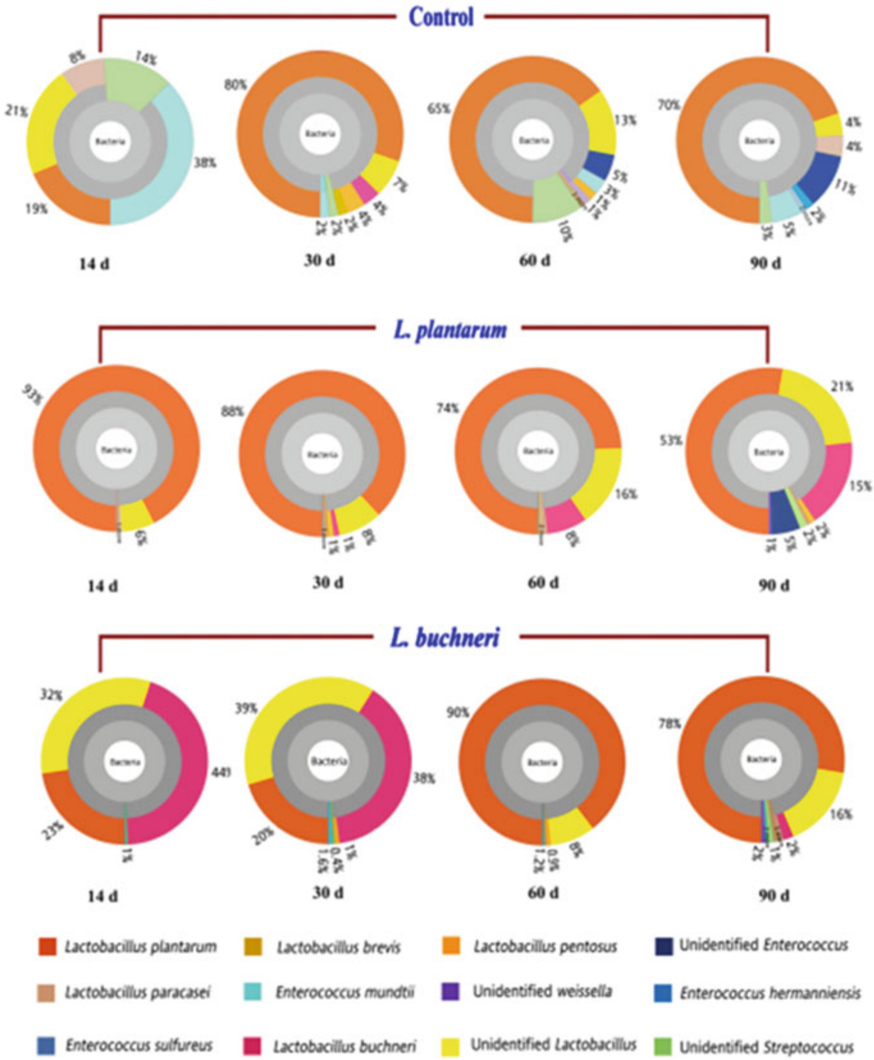

Fig. 5.1 Comparison of taxonomic profles of ensiling microbial communities of control, L. plantaruminoculated and *L. buchneri*-inoculated alfalfa silages after 14, 30, 60, and 90 days of fermentation. Metagenomic reads were taxonomically assigned based on the Ribosomal Database Project II database with a minimum bootstrap threshold of 80% and visualization by Krona (Guo et al. 2018)

Keshri et al. (2018) reported that *Weissella* (32.9%) and *Lactobacillus* (26.4%) dominated corn ensiling, in addition, the most abundant fungal genus was *Meyerozyma*, covering 53.5% of sequences followed by *Candida* (27.7%), *Cladosporium* (8.2%) in fresh corn and *Candida* was the most abundant fungal in ensiled corn (Figs. 5.2 and 5.3). *Lactobacillus* was the dominant bacterial genus at day.

After 60 of ensiling and day 2 of aerobically exposed barley silage with or without LAB inoculants and the abundance of *Acinetobacter* occurred and increased in non-inoculated barley silage upon aerobic exposure with prolonged exposed time (Liu et al. 2019a, b, c; Fig. 5.4).

Ni et al. (2017) reported that *Pedobacter* spp. and *Pseudomonas* spp were dominated in fresh Italy ryegrass, and *Leuconostoc* spp. and *Pediococcus* spp. were the dominate LAB after ensiling for 2 months; while *Lactobacillus* spp. in whole crop corn silage, and *Enterococcus* spp. in wilted alfalfa silage (Fig. 5.5). The differences of microbial colonization on forage surfaces influenced by many factors such as plant species, climate, geographical location, solar radiation intensity, period of duration

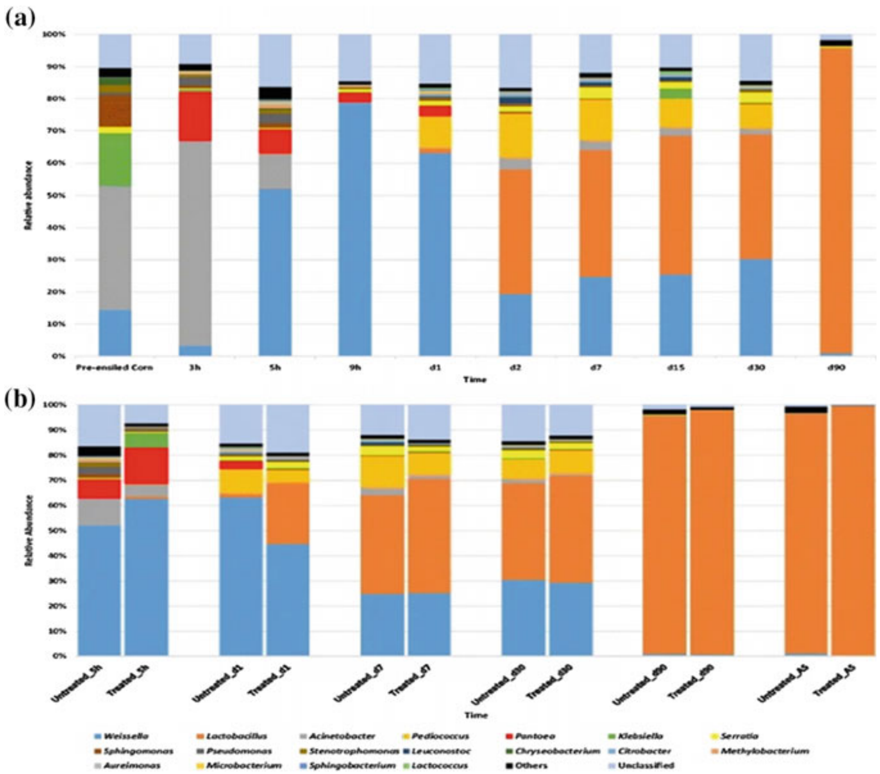

Fig. 5.2 Dynamics of abundant bacterial genera during the course of ensiling in **a** corn silage without inoculant **b** untreated versus *L. plantarum*-treated corn silage. Twenty most abundant genera are presented and remaining were summed up and presented as others (Keshri et al. 2018)

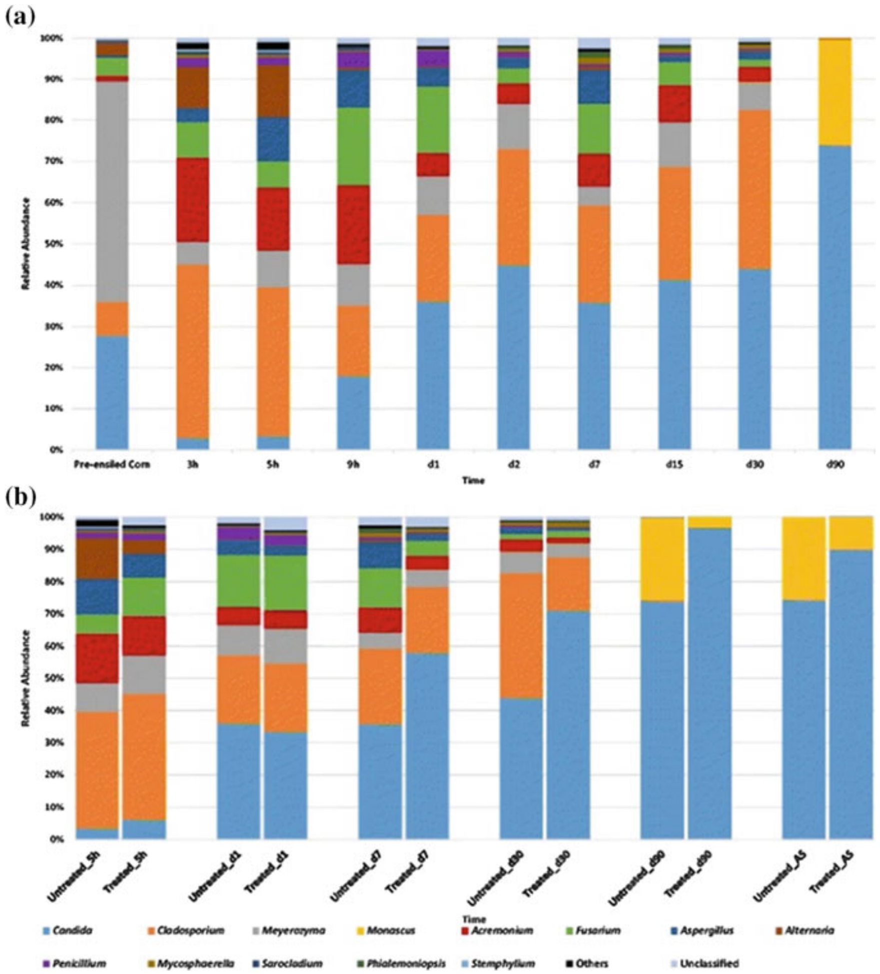

Fig. 5.3 Dynamics of abundant fungal genera in course of ensiling in **a** corn silage without inoculant **b** untreated versus *L. plantarum*-treated corn silage. Genera having less than 0.1% of overall relative abundance were summed up and presented as others (Keshri et al. 2018)

and the type of fertilizer used (Pang et al. 2011a; Mcgarvey et al. 2013). In addition, the epiphytic microbial population and characteristics of raw material largely influence the succession of microbial composition, as well as the inoculants modulate the succession of microflora and result in the final fermentation quality. Guan et al. (2018) were the first to use NGS to study microbial communities in farm bunker-silo of corn.

The results indicated that *Weissella* species were the dominant epiphytic bacteria in raw material, while *Lactobacillu* and *Acetobacter* spp. were dominant bacteria after ensiling (Fig. 5.6). Rainfall and humidity affected community of epiphytic

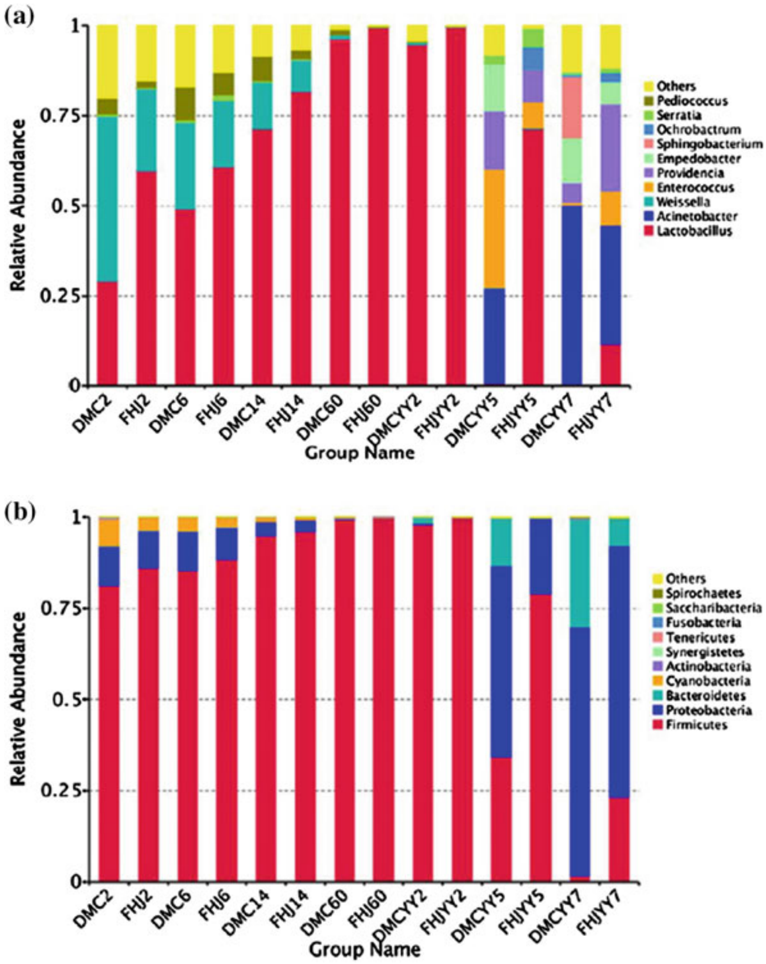

Fig. 5.4 The bacterial community during the ensiling process and aerobic exposure revealed by NGS of barley silage. The bacterial community of the phylum level (**a**) and the genus level (**b**) (Liu et al. 2019a, b, c)

bacteria on the corn material, and the temperature affected richness of bacterial species during ensiling.

As far as feed silage is concerned, a good microbial fermentation process modulates forage into high-quality silage. In the past 20 years, with the application of microbial molecular biology techniques, a large number of studies have been carried out on the silage microbial community structure. Some scholars have used DGGE molecular biology to evaluate the effects of application of different types of lactic acid bacteria (Parvin et al. 2010; Li and Nishino 2011a, b) and different silage time (Parvin and Nishino 2009) on the community structure of lactic acid bacteria and

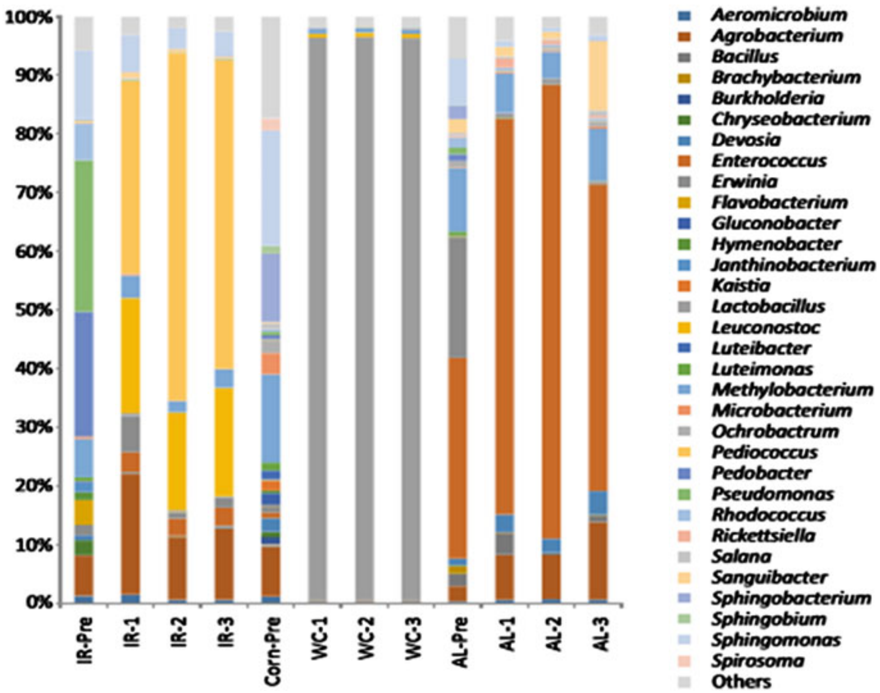

Fig. 5.5 Genus-level microbiota analysis by next-generation sequencing (NGS) for pre-ensiled crop and silage of wilted Italian ryegrass (IR), whole crop corn (WC), and wilted alfalfa (AL). Genera detected at less than 1.0% of total sequence reads are not included (Ni et al. 2017)

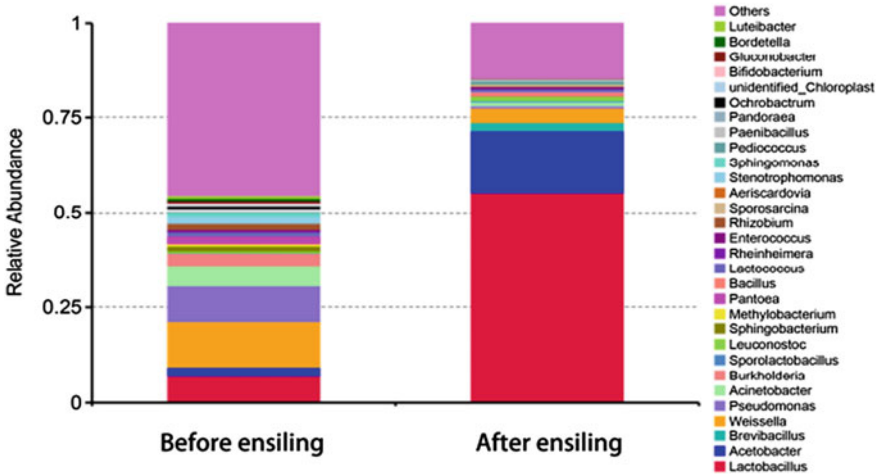

Fig. 5.6 Relative abundance of bacterial composition in corn bunker-silo silages before and after fermentation collected from five major area in Southwest China at genus level (Guan et al. 2018)

fungi in silage. In addition, some studies have used terminal-restriction fragment length polymorphism (T-RFLP) and reverse transcription-PCR (RT-PCR) molecular biology methods to analyze the community structure in silage. Next generation sequencing technology has been used to describe the evolution of bacterial population during ensiling, with a focus on comparing epiphytic populations on fresh forage to those associated with terminal silage. Studies have described the effects of silage inoculants (Eikmeyer et al. 2013; Bao et al. 2016; Romero et al. 2017; Ogunade et al. 2017), other have described differences among bacterial populations during ensiling of different forage types (Mogodiniyai et al. 2016; Dunière et al. 2017; Ni et al. 2017) or temporal and spatial variability of microbial communities in silages stored in buckers (Kraut-Cohen et al. 2016). Although the method of T-RFLP, RT-PCR and NGS can directly reflect the microbial community structure, it has less information and could not accurately reflect the number of microorganisms and their effects on the fermentation of silage. The SMRT can almost cover the full read length.

The DNA fragment multiple times, results in a reduced error rate and increased ability to depict the bacterial profile to species level precision (Schloss et al. 2016). In addition, some LAB species that have not been found by previous scholars can be found by SMRT approach (Xu et al. 2019, 2020; Fig. 5.7). Hence, the SMRT sequencing platform are considered suitable for precisely assessing the microbial community at the species level in ensiled forages with a low microbial biodiversity (Bao et al. 2016; Guo et al. 2018). Using this technology will be able to get a better understanding of the community structure and interactions of microorganisms in silage with different inoculants and provide technical support for the regulation of

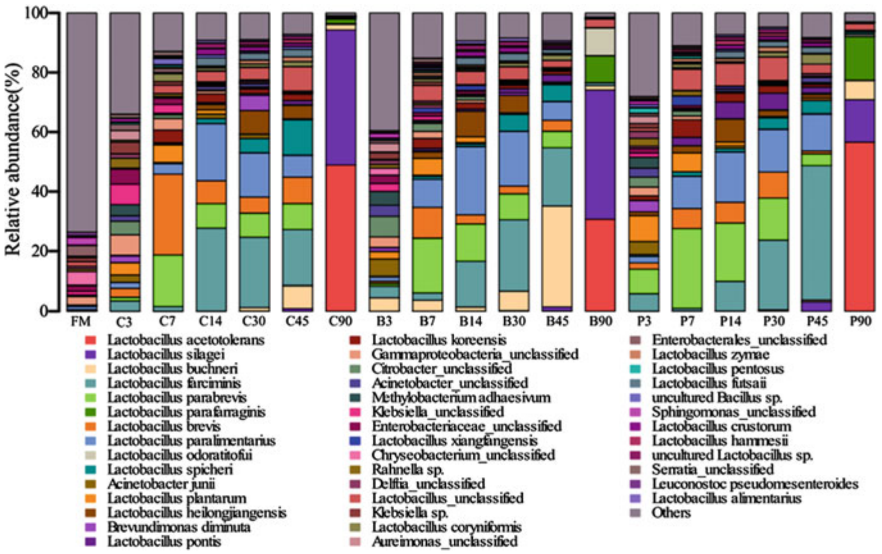

Fig. 5.7 Relative abundances of whole crop corn silage bacterial species across different treatments and fermentation time (Xu et al. 2020)

silage fermentation (Xu et al.. 2020; Fig. 5.8). Marker gene (16 16S rRNA, 18S rRNA, and ITS) sequencing methods have becoming antiquated and metagenomics become more extensive for investigating microbial communities of silage because that the approach avoids primer biases as all microbes in the community, it also helps generate information on the function of the community. Wu et al. (2020) firstly used metagenomics investigated chemical additive and inoculants on the distribution of microbial communities and found virus antibiotic resistance genes in high-moisture corn kernel silage. Thus, the gene and microbial function can be investigated through metagenomics, which will be extensive and scientific for investigating microbial communities of silage.

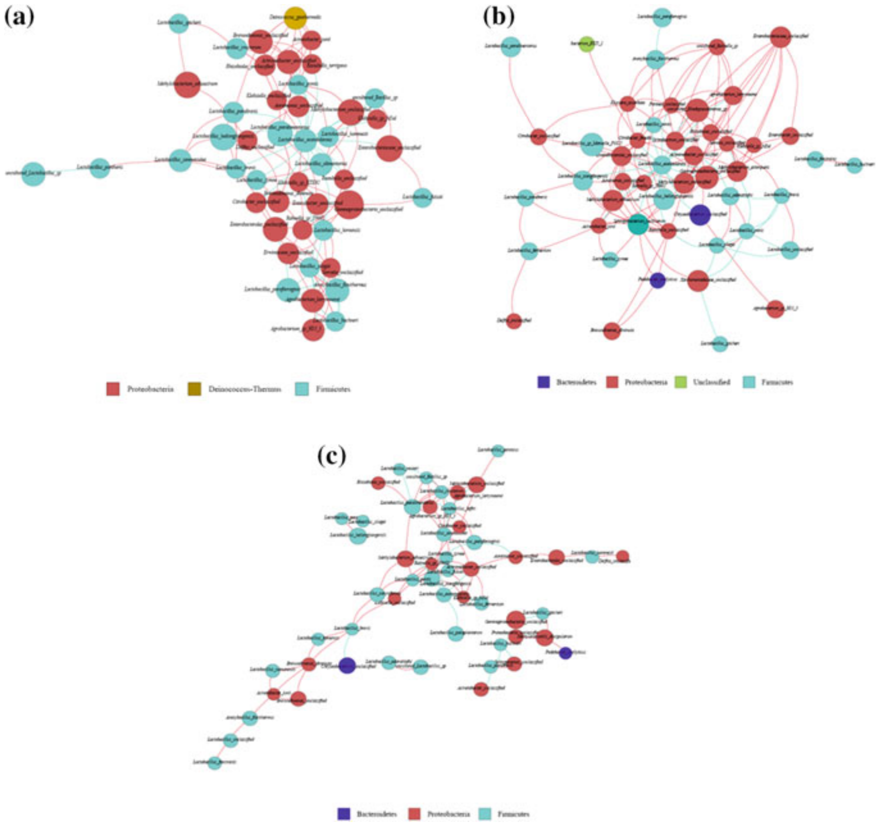

Fig. 5.8 Interaction networks of the whole crop corn silage microbiota (**a**–**c**). 16S rRNA gene-based correlation network of the whole crop corn silage microbiota, displaying statistically significant interactions with absolute value of correlation coefficients >0.6. Node size is scaled based on the overall abundance of each taxa in the microbiota. Edge width is proportional to the strength of association between each metabolite–phylotype pair (as measured by the correlation), red edge indicates the positive correlation, and green edge indicates the negatively correlation. **a** Samples without inoculants. **b** Samples inoculated with *L. buchneri.* **c** Samples inoculated with *L. plantarum* (Xu et al. 2020)

5.4.2 *Metabolome of Silage*

Metabolomics is the quantitative measurement of the dynamic multi-parametric metabolic response of living systems to pathophysiological stimuli or genetic modification. Metabolomics uses advanced analytical chemistry techniques for comprehensive measurements of a large number of small molecular metabolites in cells, tissues and biological fluids. The abilities to quickly detect and quantify hundreds or even thousands of metabolites in a single sample help scientists know the details of metabolism and biology of the whole system. Therefore, metabolomics has become an increasingly popular method to help achieve phenotypic characterization of humans, crops and model organisms.

The field of metabolomics has developed rapidly by advances in analytical technology of mass spectroscopy (MS) in recent years (Cabaton et al. 2013; Wagner et al. 2006). The widespread application of metabolomics has applied in the area of systems biology, drug discovery, drug research, early disease detection, toxicology, food and nutrition science, etc. (Fiehn et al. 2000; Waters et al. 2001). Nowadays, liquid chromatography coupled with single-stage mass spectrometry (LC–MS) and gas chromatography coupled to mass spectrometry (GC–MS) are widely used analytical method in metabolomics accounting for more than 80% published studies. However, each analytical platform has its own disadvantages. Even though GC–MS methods have been used to quantitative metabolites, there is a limit for only volatile compounds. The developments in LC–MS have significantly broadened the applicability of MS-based metabolomics. However, the high cost of the instrument has limited its use to date. As a result, it is better to employ multiple technology platforms.

For a long time, most studies on the metabolites of LAB during the fermentation process of silage mainly focused on some conventional metabolites such as organic acids, ethanol, 1,2-propanediol and biogenic amines. Generally, organic acids can not only effectively reduce the acidity of the silage and ensure the fermentation quality of the silage, but also can inhibit the reproduction of other harmful microorganisms in the silage and improve the aerobic stability of the silage. Many studies have shown that some metabolites of LAB can effectively inhibit the growth of fungi in silage and improve the aerobic stability of silage such as acetic acid and 1, 2-propylene glycol (Muck 1996; Reich and Kung 2010). However, some studies have shown that the main reason why the LAB improves the aerobic stability of silage is the hexadecanoic acid produced by its metabolism. The study of Valan Arasu et al. (2013) showed that the antifungal substance produced by *Lactobacillus plantarum* KCC-10 in silage was a biological phenolic substance and Broberg et al. (2007) found that *Lactobacillus plantarum* could also produce antifungal 3-phenyllactic acid and 3-hydroxydodecylic acid. It seems that the substances produced by the metabolism of LAB during the fermentation of silage to improve aerobic stability of silage are diverse and related to the types of LAB. In addition, the ethanol in silage is mainly produced by the fermentation of intestinal bacteria and yeast, which is a sign of poor fermentation quality of silage and dry matter loss and *Lactobacillus buchneri* can produce biogenic amines during the fermentation of silage and cause a decrease in livestock intake of silage

(Nishino et al. 2007). The metabolites of LAB on grass silage have been investigated (Broberg et al. 2007), the results showed that the inoculants LAB strains increased the concentrations of 3-hydroxydecanoic acid, 2-hydroxy-4-methylpentanoic acid, benzoic acid, catechol, hydrocinnamic acid, salicylic acid, 3-phenyllactic acid, 4-hydroxybenzoic acid, (trans, trans)-3,4-dihydroxycyclohexane-1-carboxylic acid, p-hydrocoumaric acid, vanillic acid, azelaic acid, hydroferulic acid, p-coumaric acid, hydrocaffeic acid, ferulic acid, and caffeic acid. And p-hydrocoumaric acid, hydroferulic acid, and p-coumaric acid were released from the grass during ensiling. Wang et al. (2020a, b) analyzed sugars in modulating metabolomics profiles of alfalfa silage with ultrahigh-performance liquid chromatography tandem time-of-flight mass spectrometry (UHPLC/TOF–MS), the results indicated that fructose and pectin increased the relative concentration of peptides while decreased triterpene glycosides medicagenic acid, betavulgaroside IV, and prosapogenin; and the addition of pectin increased phenyllactic acid. Storm et al. (2014) found some mycotoxins and other secondary metabolites in corn silages.

It seems that there are many unknown LAB metabolites in silage need to be further discussed other than the conventionally studied lactic acid bacteria metabolites. Lactic acid bacteria could produce a large number of metabolites during fermentation, including various organic acids, bacteriocins, amino acids, fatty acids, oligosaccharides, vitamins, small peptides, flavor enhancers and aromatic substances. With the advancement of scientific and technological analysis methods, metabonomics analysis technology has been widely used in the fields of biology, medicine, environment, food and nutrition. This technology provides a powerful tool for analyzing complex metabolic systems and systematically discovering and quantifying metabolites. However, unlike in other areas where metabolomics is widely used, there is little report about metabolomics research in silage fermentation system. Xu et al. (2020) investigated metabolome in corn silage inoculated with or without *Lactobacillus plantarum* and *Lactobacillus buchneri* using the time-of-flight mass spectrometry (GC-TOF/MS) after the fermentation of 3, 7, 14, 30, 45 and 90 days. The results indicated that the metabolites were dynamics with fermentation time prolonged and inoculants *Lactobacillus plantarum* or *Lactobacillus buchneri* modulated the fermentation with different way on metabolome (Fig. 5.9).

Some metabolites with antimicrobial activity were detected in whole crop corn silage, such as catechol, 3-phenyllactic acid, 4-hydroxybenzoic acid, azelaic acid, 3,4-dihydroxybenzoic acid and 4-hydroxycinnamic acid. Catechol, pyrogallol and ferulic acid with antioxidant property, 4-hydroxybutyrate with nervine activity, and linoleic acid with cholesterol lowering effects were detected. In addition, a flavoring agent of myristic acid and a depression mitigation substance of phenylethylamine were also found in this study. Samples treated with inoculants presented more biofunctional metabolites of organic acids, amino acids and phenolic acids than untreated samples (Xu et al. 2019; Table 5.2). Thus, much of metabolites exist in ensiling system, some released from materials, some produced by microorganisms and some are transformed from other metabolites.

The metabonomics study of the metabolites of lactic acid bacteria in silage will enable us to comprehensively and systematically understand the metabolites of lactic

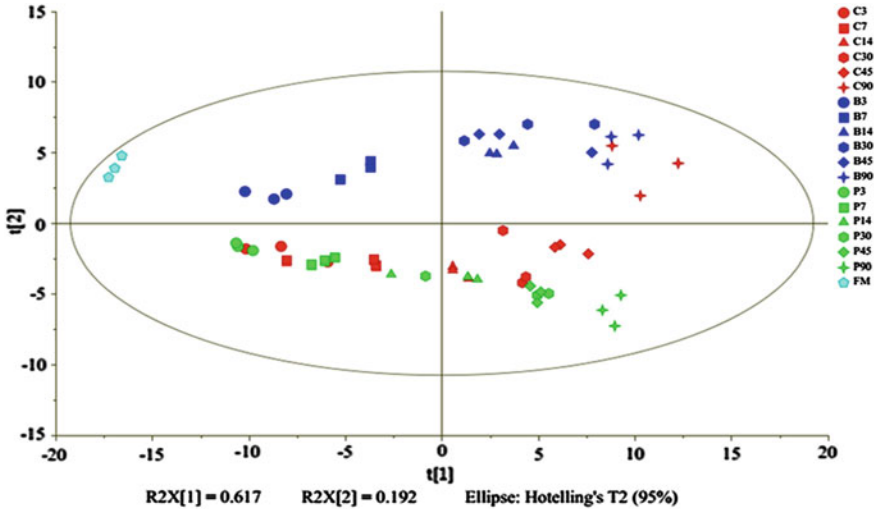

Fig. 5.9 Principal component analysis (PCA) of metabolic profiles in whole crop corn silage inoculated without inoculation (control; C) or inoculated with *L. plantarum* (P) or *L. buchneri* (B) (n = 3) for different fermentation time. Input data were the total mass of the signal integration area of each sample, and the signal integration area was normalized with a method of internal standard normalization for each sample (Xu et al. 2020)

acid bacteria in the fermentation process of silage. This will provide important biological information for more scientific evaluation of the nutritional value of silage and non-nutritive functions for livestock, as well as the discovery of functional metabolites, the screening of beneficial lactic acid bacteria and the regulation of fermentation of silage. The study of silage metabolomics will also become an emerging field of silage research.

5.5 Research, Development and Application of Lactic Acid Bacteria in Silage

Ensiling is the most commonly preservation method for forage crop and is fermented by a complex consortium of microorganisms, predominantly lactic acid bacteria (LAB), which convert WSC into enough organic acids, mainly lactic acid, under anaerobic condition, as a result, pH decreases and undesirable microorganisms are inhibited (Pang et al. 2012). The LAB associated with silage fermentation are diverse, mainly include genera *Lactobacillus* (*L.*), *Leuconostoc*, *Lactococcus*, *Enterococcus* (*E.*) and *Weissella*. Generally, LAB live on the surface of pasture and fodder crops, but due to the insufficient number of LAB, mostly undesirable bacteria, and LAB multiply very slowly in the early stages of silage, leading to the proliferation of harmful microorganisms, and affect the speed and quality of fermentation, so if want

Table 5.2 Relative concentration and fold-changes in metabolites with biological functions in whole crop corn silage with inoculation of *L. buchneri* or *L. plantarum* after 90 days of ensiling (Xu et al. 2019)

	Relative concentration[a]			Fold-changes[b]		
Metabolite name	Control	*L. buchneri*	*L. plantarum*	Log_2 (B/C)	Log_2 (P/C)	Log_2 (P/B)
Phenylethylamine	0.179	0.153	0.101	0.227*	−0.831**	−0.604**
Catechol	0.037	0.020	0.024	5.336	−5.086	0.250
Linoleic acid	0.216	0.077	0.098	3.850*	−3.510*	0.340
Ferulic acid	0.465	0.196	0.242	2.369	−2.065	0.304
Myristic acid	0.042	0.024	0.028	0.801	−0.575	0.226
Azelaic acid	0.019	0.020	0.023	3.875	−3.709	0.167
Arachidonic acid	0.009	0.009	0.008	3.428	−3.628	−0.201*
3-Phenyllactic acid	0.412	0.706	0.875	−0.779*	1.089*	0.309*
3,4-Dihydroxybenzoic acid	0.409	0.247	0.085	0.728	−2.268*	−1.539**
4-Hydroxybenzoic acid	0.132	0.135	0.145	3.046	−2.943	0.103
4-Hydroxybutyrate	0.182	0.139	0.173	0.390	−0.072	0.318*
4-Aminobutyric acid	1.446	1.194	0.576	0.276	−1.327**	−1.051*
Glycolic acid	0.002	0.001	0.001	0.646	−2.417	−1.770

[a]The relative concentration of each metabolite is an average of data from three biological replicates using GC-TOF–MS

[b]The Fold-changes were calculated using the formula $\log_2(X/Y)$. X and Y refer different treatments: C, control; P, *Lactobacillus plantarum* treatment; B, *Lactobacillus buchneri* treatment; $*0.01 < P < 0.05$; $**P < 0.01$. The major metabolites were selected based on at least one of Fold-changes ($\log_2$(B/C), $\log_2$(P/C), $\log_2$(P/B)) contrast was statistically significant

to preserve the silage intact, LAB concentration should be at least 10^5 CFU/g of fresh silage.

LAB silage additive is a kind of microbial additives used specifically for silage production, the main role is to purposefully regulate the microbial flora in the silage fermentation process, in order to control the effect of silage fermentation, promote the conversion of polysaccharides and crude fiber, thereby improving the quality of silage. Ni et al. (2015a) investigated the whole-crop wheat silages inoculated with LAB strains were better preserved than the control, with lower pH values ($P < 0.05$) and higher contents of lactic acid ($P < 0.05$) than the control; Pholsen et al. (2016) reported that fresh or wilted purple Guinea and sorghum before ensiling were 10^3 to 10^5 LAB in CFU/g FM, the DM in fresh purple Guinea grass was lower ($P < 0.05$), at 30 days of ensiling, in silage inoculated, the OM and CP were significantly ($P < 0.05$) higher and the NDF, ADF and ADL were significantly ($P < 0.05$) lower than the control. Cai et al. (2020) studied fermentation quality and microbial population of corn stover and sugarcane tops silage prepared with LAB inoculant and cellulase enzyme. Aerobic bacteria were the dominant population with 10^7 colony-forming unit/g of fresh matter in both crops prior to ensiling, while 10^4 to 10^7 LAB became the dominant bacteria during ensiling.

The reason for this, in the addition of LAB preparation can ensure that the number of LAB required for the initial fermentation of silage, so that as soon as possible into the malolactic fermentation stage, pH value rapidly decreases, protein decomposition inhibited, resulting in silage ammonia concentration of nitrogen decrease, ammonia nitrogen/total nitrogen value decreases, butyric acid concentration decreases, and lactic acid concentration increases, thus improving the fermentation quality, nutritional value and palatability and reducing the dry matter loss of the silage. Therefore, many LAB inoculants and chemical additives have been developed, and because of safe and easy to apply, non-corrosive to machine, do not pollute the environment and be regarded as natural products, many LAB-containing additives, which include *L. plantarum*, *L. rhamnosus*, *L. acidophilus*, *Pediococcus acidilactici* and *E. faecium* have been developed and are available (Cai et al. 1998). These inoculants may involve accelerating the process of silage fermentation, dominating lactic acid fermentation, accelerating the fermentation of silage, inhibiting secondary fermentation (Ni 2016), reducing the loss of protein and dry matter in silage (Pang et al. 2011a; Ni et al. 2015a, b).

5.5.1 Classification of LAB

Morphologically, there are two main groups of LAB, rod and cocci. The study on the effect of LAB on the silage fermentation quality concluded that cocci multiply vigorously at the early stage of storage, and during the whole fermentation process, rod plays a dominant role in promoting lactic acid fermentation, adding LAB can effectively inhibit the growth and reproduction of other bacteria. Moreover, the antibacterial effect of rod is better than that of cocci, and the addition of LAB makes the pH value, volatile nitrogen and total nitrogen ratio decrease, lactic acid content and the generation ratio of L (+) lactic acid increase and improve the fermentation quality of silage.

Figure 5.10 shows the LAB commonly used in silage. According to the fermentation type, LAB can be divided into homofermentation and heterofermentation. LAB additives can be divided into two types according to the type of fermentation as homofermentation LAB and heterofermentation LAB.

Homofermentation LAB, including L. *plantarum*, *Pediococcus* and *Lactococcus*, can produce lactic acid rapidly, lower the pH to below 4.0, and inhibit the degradation of sugars and proteins. Advantages of homofermention LAB include fermentation of 1 molecule of glucose produces 2 molecules of lactic acid, fermentation acetic acid and ammonia nitrogen content is low, so that the product has more soluble carbohydrates, and can improve the quality of silage fermentation. Disadvantages is the aerobic stability of silage is reduced and cannot effectively inhibit secondary fermentation. It is well known that homofermentation LAB reduce the energy loss of

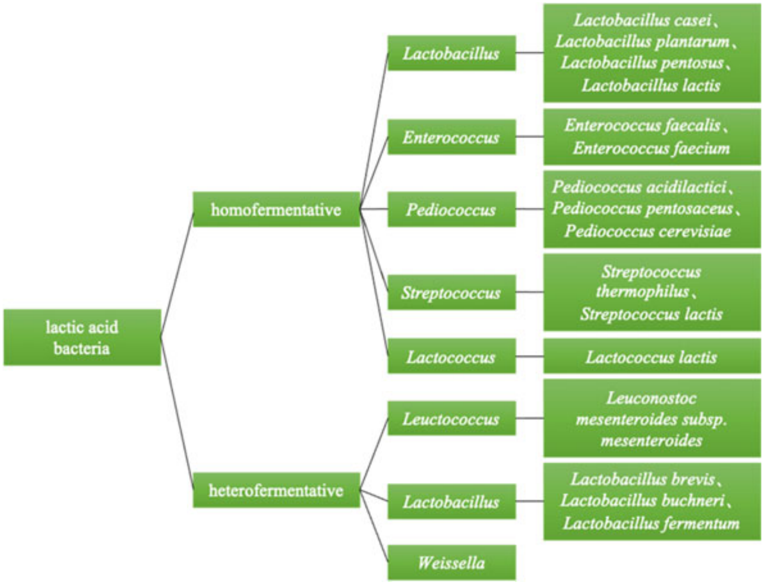

Fig. 5.10 Lactic acid bacteria commonly used in silage

silage compared to heterofermentation, but also reduce the production of antifungal substances. Therefore, it was found that about one third of the literature showed that inoculation with homofermentation LAB accelerated the aerobic spoilage of silage (Ni 2016). According to research of Pahlow et al. (2003), homofermentation LAB reduced pH, increased the ratio of lactic acid to acetic acid, and decreased ammonia nitrogen content in 60% of the studies, while dry matter recovery was improved in 35% of the studies; besides homofermentation LAB had a more significant effect on forage grasses, alfalfa, legumes and other vegetation with fewer LAB attached and a high buffering capacity, as well as low moisture corn subjected to severe freezing or drought damage. These additives resulted in higher milk production according to the meta-analysis by mechanisms that are still unclear (Muck et al. 2018).

Heterofermentation LAB such as *L. buchneri* and *L. brevis* can produce lactic acid and acetic acid at the same time, which can inhibit the growth of harmful bacteria such as yeast and mold in the aerobic stage and improve the aerobic stability of silage, although the acid production rate is slower than that of homofermentation LAB. For heterofermentation LAB, advantages are can improve the aerobic stability and prevent the aerobic spoilage of silage, reduce the anaerobic storage stage and open cellar after the growth of yeast and mold, because heterofermentation LAB use lactic acid to produce acetic acid, and acetic acid is a kind of fermentation products that can improve the aerobic stability of silage, followed by butyric acid and lactic acid. While disadvantages are that fermenting glucose can produce a variety of fermentation products, such as lactic acid, acetic acid, ethanol and CO_2, etc., and it is very easy to produce D-type lactic acid, which is not easily metabolized by livestock. Ni (2016) found that the addition of *L. buchneri*, a heterofermentative LAB, significantly increased the content of acetic acid in whole rice silage and maintained aerobic stability in a laboratory-scale test. While *L. buchneri* having no effect on animal productivity, current research is focused on finding other species in the *L. buchneri* group capable of producing more rapid improvements in aerobic stability. Therefore, in order to enhance the aerobic stability of silage and improve the animal productivity in the actual production process, can take homofermentation and heterofermentation LAB add at the same time.

Microbiological additives are usually in the form of a bacterial package consisting of one or more LAB species. LAB complexes have potential synergistic effects, such as combining *Lactobacillus* and *Pediococcus* in a single, highly concentrated, and potentially synergistic combination. Combination inoculants aim to provide the aerobic stability benefits of heterofermentation LAB with the silage fermentation efficiency and animal productivity benefits of homofermentative LAB (Muck et al. 2018).

5.5.2 Factors Affecting the Fermentation of LAB Additives for Silage

Screening conditions of LAB additive are vigorous growth, can overcome the various flora attached to the crop itself and produce large amounts of lactic acid in the shortest possible time, rapidly reduce the pH value and acid-tolerant, widely use all kinds of soluble sugars, such as glucose, fructose, sucrose, fructose, especially pentose, which does not make sucrose produce glucan, fructose produce mannitol and does not degrade organic acid, adapt to a wide range of temperature and a variety of growth conditions, no ability to hydrolyze proteins, and must be made into powder or particle form and can be stored stably.

Previous investigations showed that individual strains differ in their crop preference ability to ferment various substrates, growth potential in various moisture and temperatures, and ability to enhance fiber digestibility (Cai et al. 1998).

The main factors influencing the effectiveness of LAB additives include the type of feedstock, sugar content, type and activity of the bacteria, dosage and method of application.

LAB additive itself. For example, *Pediococcus pentosaceus* in the pre-fermentation can quickly produce acid, reduce the pH of silage, and inhibit the growth of spoilage bacteria, while the *L. plantarum* grows slowly at an ambient pH of 5.0 or higher, but grows well at a pH of 4.0 or lower. Thus, *Pediococcus pentosaceus* is often used as starter bacteria for silage fermentation, while *L. plantarum* is used as a dominant strain for later fermentation. Good LAB as silage additives must have a strong growth capacity, LAB activity has a direct impact on whether LAB will work in time for the silage process; on the other hand, LAB reproduction ability can make the number of LAB in silage rapidly increase, fermentation enhance, otherwise, it does not achieve the expected results. LAB acid-producing efficiency directly affects the process of silage pH rate change, and the acid tolerance ability of LAB directly affects the later fermentation of silage. LAB use the sugar source as fermentation substrate producing lactic acid to reduce the pH of silage, as well as the production of many beneficial substances to improve the nutritional quality of feed.

Environmental factors. The optimum growth temperature for LAB is 35 °C, however, considering the loss of dry matter in the silage process, the silage temperature should be controlled at 20–30 °C, when the temperature rises to 40–50 °C, LAB number will be reduced, and easy to cause excessive dry matter loss. Whether the silage system is an anaerobic environment is an important factor in determining the dominant flora in the silage fermentation process.

Characteristics of forage crops. General silage on raw material moisture requirements for 68–75%, but the most suitable silage moisture content should be 65–70%. Pang et al. (2012) found that corn (*Zea mays* L.) contained the most species (*Weissella*, *Leuconostoc*, *Lactococcus*, and *Enterococcus* spp.), but few epiphytic LAB were detected on the other forage crops and grasses, including alfalfa (*Medicago sativ*a L.), clover (*Trifolium scabrum* L.), sainfoin (*Onobrychis viciifolia* L.) and Indian goosegrass (*Eleusine indica* L.) examined in Tibetan Plateau.

LAB ferment water soluble carbohydrate (WSC) producing lactic acid to lower the pH of silage in order to preserve more nutrients. In general, the content of WSC in crop straw should be more than 6% (DM) to make good quality silage. Common corn, its buffering ability is weak, pH can drop sharply, easy to make high quality silage, while alfalfa buffer energy is strong, pH is not easy to reduce, so alfalfa is one of the forage grasses that most difficult to make silage. Currently, the conclusions regarding the effects of microbiological additives on animal performance are inconsistent, with results often influenced by a wide range of factors including strain, environment and material. Moreover, few extensive studies have been conducted using the same strain, and the publication of many negative results has been hindered, making it impossible to effectively assess their impact.

5.5.3 Research and Application of LAB Additives for Silage

Current research on LAB is mainly focused on the effects on aerobic stability, fermentation quality and LAB species and microbial diversity during silage of different materials. Through a lot of studies, it was found that *L. plantarum* is one of the best strains of homofermentation LAB that can meet the requirements of rapid acid production and acid tolerance, with a wide range of growth temperatures, using a variety of WSC and non-hydrolysis of proteins, but because of some *L. plantaru*m has the best activity only when the pH value is 5.0–6.5, so at present, it is usually used in conjunction with fermentation starters such as *Pediococcus pentosaceus* or *Enterococcus faecalis* (Bolsen and Heidker 1985; McDonald et al. 1991). Ninety percent of the LAB additives used in commerce today produce substances that inhibit the growth of *Micrococcus aureu*s, and the additive to silage can improve the digestibility of dry matter, protein digestibility and free feed intake, and reduce the amount of gas produced during in vitro fermentation. Inoculation of silage with high-temperature and acid-tolerant silage LAB additives, such as *Pediococcus acidilactici* and *Lactococcus lactis*, capable of rapid lactic acid production. these silage inoculants shorten the first stage as well as accelerate the rate of pH decline, allowing acid-tolerant lactic acid bacteria to predominate. Pang et al. (2011b) found that the homofermentation type LAB was adapted to the particular ecosystem of corn stover fermentation and could therefore be suitable as inoculants for silage-making from corn stover. Han et al. (2014) both detected LAB in silage and cow manure, and found that *L. acetotolerans*, *L. pontis*, *L. casei*, *L. suebicus* and *L. plantarum* could be inoculated into silage as animal probiotics. However, Filya et al. (2007) also showed that the addition of complex LAB to corn stover had no effect on pH or volatile fatty acids. The addition of LAB to whole corn resulting in a significant decrease on neutral and acid detergent fibers (NDF and ADF), but had no effect on the number of LAB, pH or fermentation acid (Pang et al. 2011b).

Reports on the improvement of silage quality by different types of LAB are inconsistent. Kung et al. (2007) showed that heterofermentation LAB was less effective than homofermentation LAB, both in terms of lactic acid production and improvement of silage quality, while Danner et al. (2003) reported that the use of heterofermentation LAB was more effective than homofermentation LAB. Of course, the effectiveness of LAB preparations is also influenced by the process of making silage such as the particle size of the crushed material, the degree of compaction and the sealing. The use of LAB additives only improves the quality of silage, and it is only effective if it does not violate silage technology. As research on LAB further deepens, the application of LAB in silage also changes from single to complex, all kinds of LAB in silage will play a synergistic role, so as to be able to better improve the quality of silage. For example, the study of Ni et al. (2015a) showed that the effect of adding only LAB was not as pronounced as the effect of adding both LAB and cellulase at the same time.

Problems encountered by LAB silage additives is the process of silage LAB produce antibacterial substances, such as bacteriocins, so far has not been studied in detail, while the development trend of LAB silage additives is with the development of screening methods and genetic engineering, according to the different roles of LAB in silage can be selected to add. And research out LAB in the silage process produced by the specific role of antibacterial substances, laying the foundation for getting quality silage.

It is not necessary to use additives in the preparation of silage in order to obtain good quality, but strict control of the preparation process can still achieve the desired results. Where costs allow, additives can be used to improve silage quality in a wide range of environmental conditions. Amongst the various additives, microbiological additives, especially LAB, are gaining popularity because of their relative safety and affordability. When it comes to silage preparation, different species of LAB have different strengths and therefore the key to efficient use of silage is to exploit their individual strengths and create synergies. In this process, it is important to discover LAB that have strong acid-producing ability, wide range of adaptability and the ability to significantly improve aerobic stability and other excellent qualities, as well as further revealing the mechanism of silage fermentation and aerobic stability remains the core element. Based on this, multiple strains of good LAB bacteria can be optimally combined for different applications, and the effectiveness of each can be maximized to improve the overall quality of silage and livestock production performance.

5.6 Application of Food Byproducts in Total Mixed Ration Silage

5.6.1 Utilization of Food Byproducts as Feedstuff

China is rich in various natural resources. With the rapid development of food industry, a large amount of food byproducts have been released every year, which are estimated to be more than hundreds of millions of tons (Xie et al. 2015). These materials are usually rich in nutrients and high in moisture content, thereby, deteriorated easily after being released by factories, especially in summer. Only small amounts of byproducts are disposed of as compost, mostly are incinerated as waste, resulting in both environmental pollution and enormous resources waste (Wang et al. 2011). There is an increasing demand for efficient use of these byproducts due to economic and environmental concerns (Xu et al. 2007).

5.6.2 Introduction of Food Byproducts

Tea is one of the most popular beverages in the world (Graham 1992; Khokhar and Magnusdottir 2002). The catechins are presented in higher quantities in green tea than in black or oolong tea, because of different processing of tea leaves (Graham 1992). Unlike the well-known (poly)phenol-rich beverages (e.g., coffee and tea), 100% fruit juice exists in the context of current dietary guidance as a key source of fruit servings and plays roles in disease prevention and in delivering biologically active (poly)phenols (Ho et al. 2019). It is reported that the potential health benefits of dark-colored fruits are not solely due to their anthocyanin content because they contain other (poly)phenols (e.g., flavonols, flavan-3-ols), which are normally derived from whole fruit and 100% fruit juice (e.g., grapes, berries, pomegranate, and cranberry) (Ho et al. 2019). With the increasing awareness on health and nutrition issues, consumption of green tea, as well as 100% fruit juice, especially dark-colored fruits, will occupy an important position in the food and beverage market.

Food byproducts are normally the solid waste presscake left behind after food processing, which usually reserve a large amount of nutrients from food, therefore, can be used as feedstuff to reduce the feed cost. The high moisture content and abundant nutrients determined that they must be used up in a short time if fed directly. However, the poor palatability caused by high fiber content, tannin or other components existing in byproducts might affect the feed intake and utilization rate. Besides, used as dry feed would consume additional energy and cause nutrients loss during heating. In view of the above opinions, ensiling could be one of the suitable ways to preserve the high-moisture food byproducts. Furthermore, adjusting moisture with dry feeds as a total mixed ration (TMR) silage is also effective to incorporate such high-moisture materials as feedstuff.

5.6.3 Chemical Composition and Feed Characteristics of Food Byproducts

Tea traditionally refers to beverages produced by hot water infusion of dried leaves from the *C. sinensis* plant (Ferruzzi 2010). Researches have indicated that green tea grounds (GTG) still contain a lot of protein, tannin, caffeine, beta-carotene and vitamin E, which might help to prevent disease if fed to ruminants (Cai et al. 2001). GTG usually contain 22–35% of crude protein (CP), 2.3–7.1% ether extract (EE), 24–37% acid detergent fiber (ADF) and 31–45% neutral detergent fiber (NDF) on dry matter (DM) basis (Wang and Xu 2013; Xu et al. 2003a). Barley tea grounds (BTG) contain 12–19% of CP, 2.2–3.4% EE, 15–25% ADF and 27–35% NDF on DM basis (Cai et al. 2002; Enishi et al. 2000; Xu et al. 2008a). Fruit pomace is the press cake resulting from pressing different fruits for juice, the composition of the final pomace is linked to the morphology of the original feed stock and the extraction technique used (Kennedy et al. 1999). Brewers' grains are by-products of the brewing industry, which are derived mainly from barley fermented to produce beer. They contain 23–29% CP of DM basis and are high in digestible fiber. Due to their fibrous nature and low energy content, brewers' grains are suitable for ruminants, particularly in dairy cows, to balance intake of large amounts of high starch diets (Xu et al. 2007).

According to the previous studies, ensiling is suitable to preserve the high-moisture food byproducts. Besides, adjusting moisture with dry feeds as TMR silage is also effective to incorporate such materials as feedstuff.

5.6.4 Application of Food Byproducts in Silage

5.6.4.1 Silage Preparation

Preservation by ensiling is highly dependent on lactic acid fermentation. Nutrient losses and proteolysis are inevitable during the ensiling process. They are always reduced or inhibited by a rapid decline in pH during the initial period to create a low pH environment that is unsuitable for the action of plant and microbial proteases (McDonald et al. 1991; Rooke and Hatfield 2003). However, the lack of lactic acid bacteria (LAB) and water-soluble carbohydrates (WSC) in food byproducts restricted the lactic acid fermentation when they are ensiled alone (Cai et al. 2001; Xu et al. 2003a). In order to solve such problems, many researches have been carried out by adding additives or mixed ensiled with other feed resources.

5.6.4.2 Application of Byproducts in Silage

Researches indicated that addition of *Lactobacillus plantarum* and commercial acremonium cellulase (AUS) in both GTG and BTG could improve the fermentation quality as indicated by lower pH and NH_3-N content and higher lactic acid content (Cai et al. 2001; Xu et al. 2003a, 2008c). It is probably that the inoculation ensures sufficient LAB at the initial period, while AUS increased WSC content, which could be used by LAB to produce lactic acid. BTG silage could also be well preserved when treated by formic acid or sodium hydroxide (NaOH) which could inhibit even the fermentation of LAB, and therefore, exhibited low NH_3-N content, no lactic acid, acetic acid, propionic acid and butyric acid (Xu et al. 2008c). Research also indicated that LAB treatment had the best effect on improving fermentation quality and inhibiting protein degradation of GTG (Wang et al. 2011).

In addition, it has been found that the inclusion of high-quality materials in GTG silage may be effective to improve fermentation quality. GTG could be ensiled successfully without bacterial inoculants when mixed with materials containing sufficient sugars (Cai et al. 2003; Nishino et al. 2007). Apart from forage silage, GTG could also enhance the lactic acid fermentation of byproducts-mixed silage when there are insufficient materials for lactic acid production (Kondo et al. 2006). Research reveals that neither GTG-associated LAB nor green tea polyphenols account for the enhancement of lactic acid fermentation. It is probably that GTG supply some nutrients other than polyphenols, which are heat-stable and effective for LAB growth during ensiling (Kondo et al. 2004d).

5.6.4.3 Application of Byproducts in TMR Silage

Ensiling is suitable for preserving high-moisture byproducts. However, there are also problems with simple ensiling, such as nutritional imbalance, poor palatability and poor preservation (Xu et al. 2004a, b). If ensiled with dry feeds as a TMR, the risk of effluent production would be minimized and the time for mixing prior to feeding could be omitted. In addition, unpalatable by-products could be incorporated into TMR as their odors and flavors could be altered by silage fermentation (Xu et al. 2007).

Noor et al. (2008) reported that GTG could be used as an ingredient in TMR silage production for animal feeding. Xu et al. (2004a, b) reported that the addition of GTG or BTG at 10%, 20% and 30% DM ratio of TMR could be well preserved and exhibited low pH and NH_3-N content, and high lactic acid content. Suto et al. (2007) recommended that the moisture content of TMR should be held at about 55%, when the TMR contains 10–30% of GTG on DM basis, as lactic acid content tended to increase with the increased proportion of GTG and the decreased moisture content of TMR. Researches on nutrient digestibility and feed intake also indicate that tea waste can be included in the diet of ruminants, but the level is limited due to presence of anti-nutritional factors (Xu et al. 2007; Zahedifar et al. 2019).

Besides, many researches have shown that the substitution of GTG for wet brewers' grains (BG) at ratios of up to 15% on DM basis of TMR could be well preserved with high lactic acid content, low pH and NH_3-N content (Xu et al. 2007, 2008b). While, the replacement of BTG and soybean meal mixture (7:3 on DM basis) for BG at ratios of up to 15% DM of TMR could result in increased lactic acid concentration and decrease pH, acetic acid and NH_3-N of the TMR silage (Xu et al. 2008a).

5.6.5 Nutritive Value of Byproduct Silage and TMR Silage

In view of the high nutritive value and multiple functional components, the byproducts could be used as feed resources or nutrient supplementary. Researches of tea grounds on the production of broilers and pigs have been reported, which indicate that the addition of tea grounds at proper amount could enhance or maintain the quality and output of the resultant meat and eggs. However, high fiber content restricts the proportion of these products in diet. While for ruminant, this is not the problem but how to make efficient utilization and obtain better animal performance. In addition to fermentation characteristics, the potential nutritive value for ruminants was also evaluated to determine the proper inclusion ratio of byproducts in TMR silage or diet, including feed intake, digestibility, rumen fermentation, nitrogen (N) balance, blood component and milk production.

5.6.5.1 Nutritive Value of Byproduct Silage

The nutritive value of GTG is thought to be equivalent to that of BG. For GTG silage, digestibility of CP and EE are 74.6% and 50.7% on DM basis, respectively. The estimated total digestible nutrients (TDN), digestible CP and digestible energy are 71.1%, 23.9% and 13.4 MJ/kg on DM basis, respectively (Xu et al. 2003a). For BTG silage; however, digestibility of CP and organic cell wall are 53.3% and 47.5%, and the TDN, digestible CP, digestible energy are 63.1%, 6.4% and 12.0 MJ/kg on DM basis, respectively. It is suggested that the nutritive value of BTG silage is about 80% of that of barley (Enishi et al. 2000; Xu et al. 2003b).

Many researches have indicated that well-fermented GTG silage contributes to preserve more tea catechins and antioxidative activity (Nishino et al. 2007; Xu et al.

2003a). However, research on tea catechins and antioxidative activity of GTG indicated that ensiling significantly lowered antioxidative activity and decreased the contents of partial tea catechins in GTG silage, whereas, reductions of tea catechins were ameliorated and no marked changes were found in total phenols and antioxidative activity during ensiling when ensiled as a mixture with dried beet pulp (Nishino et al. 2007). Inhibited degradation of tea catechins were also found in wet GTG silage treated with LAB and cell wall degrading enzymes (Xu et al. 2003a).

Besides, it has been indicated that condensed tannin (CT) could reduce rumen forage protein degradation due to reversible binding to these proteins (Min et al. 2003), suppress the breakdown of protein by rumen microorganisms (Salawu et al. 1999) and decrease ruminal gas production (Makkar et al. 1995). It is consistent with the study of Nishino et al. (2007) that addition of dried beet pulp increased gas production of GTG silage, which in other words suppressed gas production with the increase of GTG. It is consistent with the finding of Salawu et al. (1999) that tannin protected proteolysis of proteins during silage fermentation but was digestible in the lower gut, and it also agreed with finding of Kondo et al. (2004b) that proteins in GTG seem to be stable during ensiling, but digestible post-ruminally. Evidence also indicates that CT at levels of 2.0–4.5% DM can reduce rumen forage protein degradation and protect amino acids to increase the absorption in the small intestine of ruminants, while deteriorating intake and digestibility at >5.5% DM (Min et al. 2003; Nishino et al. 2007). This may illustrate the no detrimental effect on gas production with the increase of GTG, which probably due to the less amount of tannins than that is critical to suppress the activity of rumen bacteria. Furthermore, researches also indicated that the addition of GTG to forage silage or byproducts-mixture could increase gas production (Kondo et al. 2004a, 2006).

5.6.5.2 Nutritive Value of TMR Silage

Beverage by-products such as coffee, oolong tea, and green tea residues are a good potential source of energy and protein. Moreover, the methane output of TMR incorporated with byproducts was numerically lower than the other TMR treatments. By fermenting with a mixed microbial culture, these beverage residues have the potential to help eliminate some of environmental pollution problems, as well as provide an affordable feed for livestock. However, the current use of beverage by-products is limited due to their high phenolic acid content. Researches on GTG indicated that tannins exhibit contrasting effects on feed intake and digestibility when GTG applied in different ratio (Min et al. 2003). Therefore, further research is needed to determine the DM intake, the health implications of feeding beverage residues, the appropriate method of offering the feedstuffs and the optimum levels of incorporation into diets (Senevirathne et al. 2012).

Considering the digestibilities of DM, CP and TDN, the ideal mixing proportion of BTG for TMR silage is 10% to 20% on DM basis, as they were significantly higher than that with 30% of BTG (Xu et al. 2004). The possible proportion of replacing wet BG with BTG for TMR silage was suggested to be 10% or less of diet DM (Xu et al. 2008a). In the study, feed intake, digestibilities of EE and NDF were lower for the 15% treatment than that of the control. Furthermore, a high GTG level of 15% of diet DM can be recommended for silage based TMR (Xu et al. 2007). Progressive increase of GTG (0, 5, 10 and 15% on DM of TMR) substituted for wet BG had no effect on voluntary feed intake of TMR silage, while digestibility was slightly lower than the control. No differences among treatments were observed in retention N, pH and total volatile fatty acids concentration (Xu et al. 2007, 2008b), while for some TMR silage with 15% GTG, decreased digestibility were found. Therefore, the possible mixing proportion of GTG for TMR silages can be 10% of the diet DM.

Kondo et al. (2004c) found that the DM intake of cows fed TMR with GTG silage was slightly but not significantly increased with the increment of GTG, while ensiled GTG contained high amounts of lactic acid, acetic acid and CT. It is inconsistent with the negative correlation between DM intake of silage and the acetic acid and lactic acid concentrations (Jones et al. 1980), or the decreased feed intake in ruminants owning to high tannin (Silanikove et al. 1994). It is supposed that the inclusion of GTG silage at 5% DM in TMR was relatively low to show the negative impact of tannin on feed intake, and has no detrimental effect on the performance of lactating cows. Furthermore, researches also indicated that the addition of GTG silage could be added up to 20% of diet DM. Compared with the control, addition of GTG at 10% diet DM had no significant effect on ruminal fermentation, plasma metabolites, as well as milk yield and components (Eruden et al. 2003, 2004). No significant effects were found on feed intake and digestibility in both 10% and 20% tea group, except that the CP intake was increased and digestibilities of ADF and NDF were decreased in the 20% group. Nishida et al. (2006) also suggested that feeding diets containing 20% of GTG silage had no negative impact on ruminal fermentation, but increased the plasma antioxidative activity and vitamin E concentration.

In addition, methane output from beverage residues mixed total ration on in vitro fermentation represents a loss of energy to the host animal, and contributes to global greenhouse gas emissions (Holter and Young 1992; Johnson and Johnson 1995; Moss et al. 2000). Research has shown that fermented coffee, oolong tea and green tea residues are a potentially good source of protein and energy, and fermented residues of coffee caused a numerical decrease methane output (Senevirathne et al. 2012), as the methane output from the TMR containing fermented residues of coffee, oolong tea and hay (control) did not differ, but was lower for all compared to the TMR containing fermented green tea residue.

5.6.6 Conclusions

Ensiling is suitable for preserving the high-moisture food byproducts. Both ensiled with additives and mixed ensiled could be well preserved. Besides, adjusting moisture with dry feeds as a TMR is also effective to incorporate them as feedstuff. According to the previous researches, the addition of tea grounds in mixed silage could be up to 20% on fresh matter and the possible mixing proportion of tea grounds for TMR silage is suggested to be less than 10% or 10% to 20% on DM basis. Whereas, the inclusion of tea grounds silage for TMR differs by the variety of main roughage, ranging from 5 to 15% or more on DM basis.

Apart from the possible addition ratios in silage and TMR, researches also provide feasibilities of using tea grounds as protein resources or substitution of other feed materials. The characteristics of high protein content and low cost will certainly relieve the dependence to some extent on imported protein products. However, there are also problems that byproducts are always mass-produced and beverage companies are always scattered at suburbs. Therefore, it is necessary to work out a reasonable plan to reduce the unnecessary cost.

Furthermore, in view of the controversies on tea catechins and CT, it is necessary to have a further understanding of the functional ingredients in byproducts and their association with animal performance, so as to make efficient use and obtain better performance. Besides, efforts should be made to reduce the high fiber content so as to reduce the limitation on other animals, as well as to assess the potential risk of byproducts, such as pesticide residues.

5.7 Hay Processing and Production in China

5.7.1 Concept of Hay

In general, hay includes all dried edible plant materials for animals, and almost covers the first type of feed in the Harris International Feed Classification System-roughage. Namely, hay includes air-dried feed or other edible raw materials which has a crude fiber content greater than or equal to 18%. Such as dried forage grass, forage crops and crop straws, as well as feeding shrub and leave. In the narrow sense, hay specifically refers to forage grass or forage crops which are cut in the period of high quality and yield and made by a certain drying method, and still remain green state.

5.7.2 Role of Hay

(1) Hay making can alleviate imbalance in forage supply throughout the year. Hay is also a raw material for making grass powder, grass pellets and grass briquettes and other grass products.
(2) High-quality hay is an essential and important part of the diet composition of grass-feeding livestock animals because of its characteristics of green color, rich leaves, tender stem, aromatic odor, good palatability, and high digestibility.
(3) High-quality hay can not only fill the stomach and intestines of ruminants, supply effective fiber, and promote gastrointestinal motility and can also be

used as an energy source for ruminants to form carcass fat, milk fat, lactose and glycogen.

5.7.3 Types of Hay in China

(1) According to the botanical classification standard of forage grass, hay can be divided into *Gramineae*, *Leguminosae*, *Compositae*, *Cyperaceae*, *Cruciferae*, etc.. In each family, the hay can be named according to the species name of raw materials. For example, alfalfa hay is legume hay, and *Leymus chinensis* is *gramineous* hay.
(2) According to the cultivation method of forage grass, hay can be divided into natural grassland hay and artificial grassland hay. The artificial grassland hay can be divided into single species hay and mixture grassland hay depending on the cultivation mode. For example, alfalfa hay is a single-species hay, and the hay mixed with alfalfa and *Clinelymus dahuricus* is a mixture grassland hay. The natural hay harvested from natural grassland is almost mixed hay.
(3) According to the drying method of hay making, hay can be divided into sun-dried hay and oven-dried hay. In general, the quality of oven-dried hay is better than the sun-dried hay. Hay is the raw material for further processing grass powder, grass pellets and grass briquettes.
(4) According to the grass product type of making, hay can be divided into scattered hay and hay bales. Hay bales can be divided into square-shaped bales and round-shaped bales by the shape of the bales; hay also can be divided into high-density bales (200–350 kg/m^3), medium-density bales (120–200 kg/m^3) and low-density bales (<120 kg/m3) by the bales density.

5.7.4 Procedure of Hay Making

(1) Cutting and pressing: The cutting and pressing machine is used to fracture the stems, destroy the cuticle, vascular bundles and epidermis of forage crops exposed to the air in order to speed up the moisture loss rate of stems and shorten the drying time. Take the alfalfa for example, the drying time after fracturing the stem is shortened by 30%-50% compared with no fracturing.
(2) Scattering: After cutting, forage grass was scattered into grass windrows of 10–15 cm thick for sun drying 4 h-5 h in order to make the grass cells die quickly, stop breathing and reduce the nutrients losses. After this process, the moisture content of fresh grass dropped from more than 75% to about 40% by evaporating rapidly of moisture in grass.
(3) Tedding: Forage grass should be tedded after the dew is accumulated on soft plant tissues at night or early in the morning when the moisture content of the forage grass drops to about 40%, which can speed up the drying rate of the forage grass, reduce the losses of leaves and dry matter.

(4) Raking: Before preparing for baling, it is necessary to narrow the windrow from two rows to a row by the raking operation to ensure the baling speed. Out of which, the bottom forage corps can be turned to the top of the windrow, which can further improve the drying speed and drying uniformity of the whole windrow.

(5) Picking up and baling: Baling operation is performed when the moisture content of the forage grass is below 16% in order to ensure the quality of hay. The hay is commonly wrapped into low-density bales in the field by a pick-up baler. If commercial grass is produced, the low-density bales are compressed into high-density bales with a secondary compression baler in the factory. In recent years, there are some enterprises that use the large baling machine to make large medium density bales in the field for the direct sale.

5.7.5 Research and Hay Production in China

The grass industry which is an old and brand new industry is changing from small to large and from weak to strong in China. From wide view of the development history of the grass industry in China, it is also the development history of hay production technology that can be roughly divided into three stages. The first stage was the foundation stage of modern grass industry (1949–1978): In this stage, only reciprocating mower and dump rake were used as hay production machinery, and the raw material of hay making was basically natural grassland grass, and the product type was scattered hay, resulting in no commercial hay trade in this stage due to the economic system at that time. The second stage was the founding stage of modern grass industry (1979–1999): after the Third Plenary Session of the 11th Central Committee of the Party, forage production has formed a new pattern in which the state, collectives, and individuals coexist in multiple forms of management. Especially in the late 1970s, China began to import picking and baling machines from the United States, France and West Germany at the time, then adopting the picking and baling technology in forage harvesting. Low-density square bales and round bales gradually replaced scattered hay. From that time, the commercial hay trade began, not only did the domestic market become active, but *Leymus chinensis* hay from the northeast was even exported to Japan and South Korea. The third stage is the development stage of the grass industry in the new period (since 2000). At the beginning of the twenty-first century, the grass area by artificial cultivation expanded rapidly in China, which benefited from the ecological management and western development and the need for efficient development of herbivorous livestock industry. The number of enterprises with large-scale, modern, mechanized production of hay production has gradually increased. However, some enterprises pay more attention to output than quality. Since 2010, hay production enterprises have sprung up under the strong support of a number of national grass policy. By August 2018, there are 1477 registered and existing companies engaged in the grass and forage production in China, and about 75% of them were founded after 2012, which is closely related to the implementation of policies such as "Alfalfa Development Action to Revitalize the Milk Industry", "the Development of "Grassland and Animal Husbandry" and "the Reformation from Grain to Feed". The regional distribution characteristics of grass production enterprises are obvious. Northwest, North China, and Northeast are the main distribution areas for grass and forage production. However, the distribution among provinces is not balanced, and Gansu, Inner Mongolia, and Hebei province with the largest number. Large leading enterprises with an investment of more than 50 million RMB account for about 6%, which is relatively small. Most of the enterprises (over 75%) are medium-sized and small enterprises with an investment of less than 10 million RMB. However, the actual productivity of enterprises is generally lower than the design productivity. There are about 800 businesses that can operate normally. The annual turnover of commercial grass of our country is about 8–10 million tons, among which the hay quantity imported is about 1.7–1.8 million tons, the domestic natural hay yield is about 3.5–4 million tons, and the cultivated hay yield is about 2.4–2.6 million tons.

Although China has made some progress in the hay making industry and technology, there is still a certain gap compared with other developed countries. There is a large gap in commercial grass products, and the quality of domestic grass products is low, which induce insufficient competition in the international market. There are many reasons for this phenomenon, such as underdeveloped technology, low mechanization level, unreasonable spatial layout, etc. In the face of various constraints, the development of hay processing field in China in the future will have the following characteristics: First, the development of domestic hay processing machinery should be strengthened. The research level and product development capability will be further improved on the basis of the existing research on processing machinery, and the international advanced technology will continue to be tracked. In the future, the research will focus on alfalfa mowing and flattening machinery and technology, the key technology of small square baler and knottier components, high-density baling technology and baler, etc. Second, the hay production standards and detection system should be further improved. In the future, the hay processing standards must be standardized and strictly implemented nationwide, so as to continuously develop and expand the domestic market and gradually catch the international market. Third, the commercialization and circulation speed of hay should be promoted. In the future, the grass demand for compound feed production and large-scale livestock farms in China will reach at least 10 million tons. Moreover, more than 75% of the livestock animals in China are facing shortage of grass in winter, and regional and seasonal imbalance will further promote the development and circulation of hay. Forth, it is provided that the connecting services for the upstream and downstream customers of hay production to promote the construction of financial futures service platform.

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Chapter 6
Assessment of Forage Safety and Quality

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6.1 Quality and Safety Problems of Forage

Forage is an important livestock feed used to produce green animal products. The quality and safety of forage is the basis to ensure the safety of livestock and poultry products, which is important for the development of high-yield and high-quality animal husbandry. In recent years, the forage product processing industry in China has developed rapidly, and the quality of forage products has greatly improved. However, for quite a long time, attention has been given to quantity while ignoring the quality and safety of forage. Safety management in forage production, harvest, processing, and storage is insufficient, and the detection and detection are inadequate. There are hidden hazards in the quality of forage products (Chen et al. 2015).

6.1.1 Toxic and Harmful Ingredients in Raw Materials

Raw forage material guarantees the safety and health of animal products. Some poisonous and harmful substances are present in raw materials or produced during

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processing, such as excessive nitrate, nitrite, glucoside, alkaloid, tannin and other compounds, which cannot be completely removed due to the limitations of processing technology, and these will bring toxicity to livestock and poultry. Long-term consumption of these low-quality forages may not only cause a variety of diseases but also seriously affect the quality and safety of animal products. Accordingly, use of raw material should involve strict check, reasonable use, or proper handling of poisonous and harmful substances.

Excessive application of nitrogen, or in the case of diseases, insect pests and adverse conditions, can lead to the accumulation of nitrate in forage. Nitrate is low in toxicity, but it can be converted to nitrite by reducing bacteria. Nitrite is highly toxic to animals. Nitrite is a strong oxidant that can oxidize haemoglobin to methemoglobin. The large increase of methemoglobin causes red blood cells to lose their oxygen-carrying function and leads to histohypoxia. In addition, nitrites can form N-nitroso compounds when combined with amines or amides under certain conditions (Luo and Jiang 2003; Wang 2000).

Sorghum seedlings and cassava contain cyanogenous compounds. Cyanogen itself is nontoxic, but hydrocyanic acid can be produced by enzymatic hydrolysis of plant enzymes or rumen microorganisms. Hydrocyanic acid is highly toxic to animals. When hydrocyanic acid is absorbed by animals, it rapidly blocks electron transfer during oxidation, making tissues and cells unable to use oxygen and leading to intracellular asphyxia and dysfunction of the brain and cardiovascular systems.

6.1.2 Toxic and Harmful Substances Produced by Environmental Pollution

Due to geological and chemical conditions of forage growing areas, waste pollution caused by human activities, and the extensive use of pesticides and fertilizers, harmful substances in soil, irrigation water, and air exceed their limits. With the growth of forage, harmful substances will be absorbed by the forage. Such harmful substances, including cyanide, fluoride, 3,4-benzopyrene, POLY chlorinated biphenyls, and dioxins, which mainly come from waste incineration, can infiltrate into forage via multiple channels (Jia 2011; Wu 2003). With the development of food quality and safety in China and the establishment of an effective food quality and safety monitoring system, forcing the transformation of planting structures from food crops to feed crops in some contaminated areas, large quantities of toxic substances accumulate in herbage. At the same time, with the rapid development of industry and mining industry in China, especially in some remote areas, there are more herbage plantations but the environmental management is not strict enough, so the potential of pollution is greater. In addition, in some seriously polluted lands, forage grass is used for ecological restoration in some seriously polluted lands, and harvested forage grass may also be used as raw materials for forage products.

6.1.3 Toxic and Harmful Substances Produced by Improper Processing and Storage

During the transportation, storage, processing and sale of forage products and their raw materials, improper storage or long-term storage may lead to mouldy and deteriorated forage. Some moulds are pathogenic organisms that may cause animal allergies or produce highly toxic mycotoxins, such as aflatoxins. Aflatoxin can be quickly absorbed by the gastrointestinal tract after being taken in by animals, damage the liver tissues of animals, destroy liver function, and cause systemic bleeding, digestive dysfunction and neurological symptoms. The liver is an important immune organ and metabolic organ of the body. Once the liver is damaged, it will lead to damage to the immune system of the body, and as animals are easily infected with diseases, and disease incidence rate will rise. Aflatoxin is one of the most potent carcinogens. The carcinogenic effect of aflatoxin B1 is 75 times greater than that of dimethyl nitrosamine (Wang et al. 2003; Khlangwiset et al. 2011; Rodrigues and Naehrek 2012; Shuaib et al. 2010).

6.1.4 The Use of Additives in the Production of Forage Grass Products is Not Standard

In 1998, the Ministry of Agriculture issued the "Notice on the Prohibition of Illegal Use of Veterinary Drugs" and then issued more specific notices on prohibited drug varieties, emphasizing that it is strictly forbidden to use veterinary drugs without the approval of the Ministry of Agriculture. In 2001, the Ministry of Agriculture issued the No. 168 notice of "The Specification for the use of Feed Drug Additives", which clearly stipulated that there are only 57 kinds of feed drug additives in China, taking into account applicable animals, minimum dosage, maximum dosage, precautions, and incompatibility. During the processing of forage, excessive use of additives and uneven distribution of additives may exert toxic effects on animals, such as ammoniated forage. If the forage product contains too much ammonia, it will have toxic effects on animals. The addition of antibiotics and trace elements in feed can play a positive role in preventing animal diseases, promoting animal growth, increasing the quality of animal products, and improving the efficiency of the breeding industry (Wu 2003). However, the long-term overuse of antibiotics increases the cost of feed and causes bacterial resistance, drug resistance genes, environmental pollution, and food safety problems, which seriously affect the healthy development of the livestock industry and endanger human health. In 2019, the Ministry of Agriculture and Rural Affairs, PRC issued Notice No. 194, decided to stop the production, import, operation and use of some drug feed additives, withdrawing all kinds of growth-promoting pharmaceutical and feed additives except traditional Chinese medicine. The announcement banned the use of antibiotics in feed from July 1, 2020, opening a new era of nonresistant feed in China. Under the condition of no resistance production, the diet is required to meet the nutritional needs of livestock and poultry for maintenance, growth, immunity and reproduction (Zhu et al. 2020).

6.2 Quality Evaluation of Forage Resources in China

6.2.1 *Overview of the Forage Resources, Quality and Evaluation*

6.2.1.1 Defining Forage Quality

With the tremendous increase in the human population and the growing demand for milk and meat products, ruminant production continues to make significant contributions to the food supply in China (Bai et al. 2018; Du et al. 2018). As a result, forage sources have become an increasingly critical component of the integrated food chain since they account for a significant proportion of the dry matter (DM) fed. At present, the forages used in ruminant diets in China mainly consist of silage (mainly corn silage, alfalfa silage, oat silage and haylage), grasses (mainly guinea grass and sheep grass), hay (mainly alfalfa and oats) and straws. However, the quality of the home grown forages is highly variable within and between-farms leading to uncertainty in nutrient supply, which can affect diet formulation strategies, nutrient intake by animals and finally the production (St-Pierre and Weiss 2015). Thus, the ultimate goal of the ruminant producer in the management of ruminants is to maintain the quality of the forage at a level that will support the optimal state of gain or milk production.

The quality of forage can be defined as a function of the nutritive value, intake and efficiency of forage (Horrocks and Vallentine 1999). The nutritional value of the forage is determined by the concentration of nutrients, the digestibility of nutrients and the nature of the digestion end products. Animal responses, such as intake and digestibility of nutrients, may be assessed in short-term animal studies. However, where only small samples are available, laboratory analyzes must predict intake and digestibility. Proper conversion formulae, intake and digestibility measures and intake predictions can be used to provide adequate quantitative estimates of animal performance (gain or milk production) to predict forage quality (Ball et al. 2001).

6.2.1.2 Variations and Sources of Forage Quality Variations

Forages are excellent sources of fiber, energy (corn silage), and/or protein (alfalfa) and serve as primary ingredients in ruminant rations in China (Yan et al. 2011; Zhang et al. 2017). However, the composition of forages is not consistent among and within farms due to variability occurs at different stages starting from crop management (hybrid or variety, seed rate, plant density), harvesting and processing (harvest maturity, cutting height, particle length, grain processing for corn), preservation methods and storage conditions (ensiling and hay making), forage sampling for the laboratory analysis and laboratory analysis. Except for the variation caused by the observer (laboratory, sampling, analysis, and so on), true variations have economic value for the dairy farmer as uncertainty in nutrient supply might result in feed formulations that do not match with actual animal requirements (St-Pierre and Weiss 2015).

In a recent study, Tharangani et al. (2020) investigated the quality variations of whole plant corn silage (n = 250) collected from small scale (≤150 cows), medium-scale (151–1000 cows), large scale (1001–5000 cows) and very large scale (>5000 cows) and variability estimates (i.e., SD) for the nutritional composition of corn silage respective to scale of operation have been established. Based on the results, the variability of the contents of aNDFom, starch and DM were averaged 3.1, 6.3 and 5.4, respectively. Further, short term variations of corn silage within and between-farms were reported based on the analyses of the chemical composition of corn silage collected from 14 farms distributed in 7 provinces in China over 7 consecutive days (n = 196). Farm was the largest contributor to overall variability observed for all measured nutrients in corn silage (Fig. 6.1). Farm contributed between 37 and 92% of the overall variability. Figure 6.2 expressed analytical, sampling and daily variations of nutritional composition as a percentage of the total within farm variation. The variance in sampling ranged from approximately 30–70% of the total within farm variation and was the main source for ash, aNDFom and DM variability within farms.

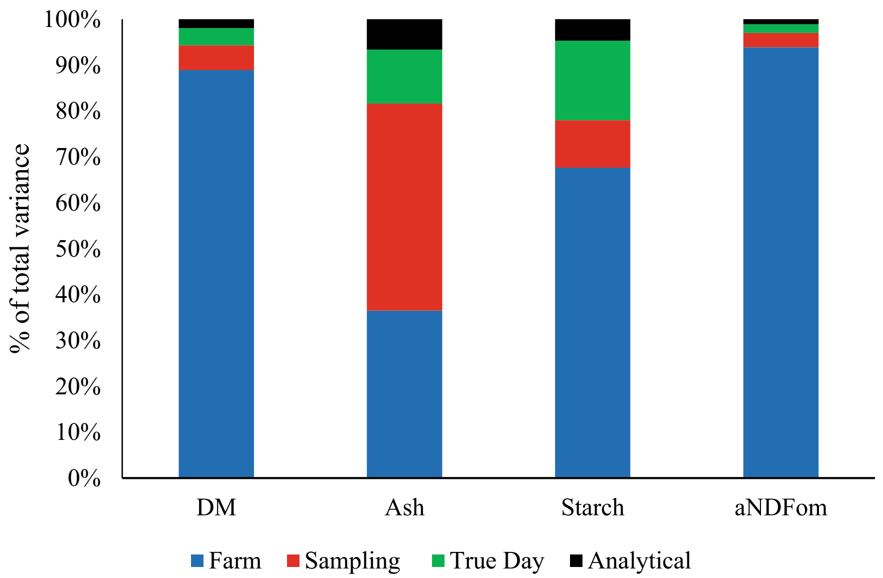

Fig. 6.1 Partitioning total variation from sampling corn silage (CS) at multiple farms (14 farms) with duplicate daily samples (over 7 days) and each assay duplicated (n = 196)

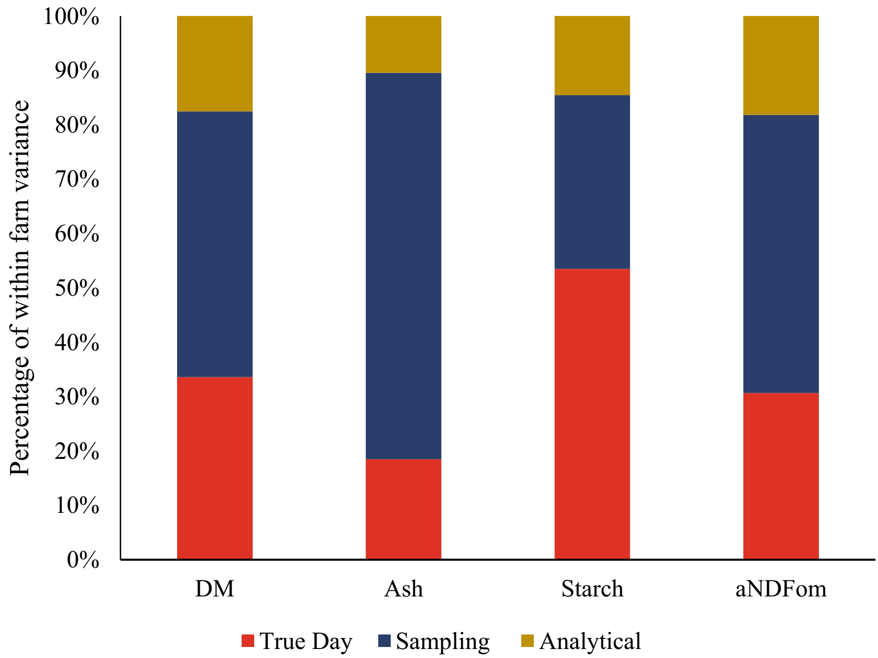

Fig. 6.2 Partitioning within farm variation for corn silage (CS) with duplicate daily samples (over 7 days) and each assay duplicated

True daily variation ranged from 18 to 52% of the total within farm variation and was substantial for all nutrients. Among all measured silage nutrients, aNDFom was the most variable nutrient over seven days and Fig. 6.3 shows the daily variations of aNDFom in four dairy farms in North China.

According to USDA GAIN report (2019), the locally produced alfalfa is highly variable in quality and can only supply about 60 percent of domestic needs. Wang and Zou (2020) also reported that data on the production of alfalfa in China is very limited and the data available is also highly inconsistent across sources. Thus, China is one of the top importers of US alfalfa at present and will continue to import US alfalfa to cater to the increasing demand due to its high quality and price competitiveness (USDA GAIN report 2019). However, high variability in quality is common to all forages irrespective of the country, the same theory applies to US alfalfa as well. In one study St-Pierrie and Weiss (2015) reported that for corn silage and hay crop silage, sampling variation comprised between 30 and 70% of the total within farm variation for DM, neutral detergent fiber (NDF), starch, and crude protein (CP). Further, day to day variations contributed more to the observed variability of DM and NDF contents of hay crop silages including alfalfa.

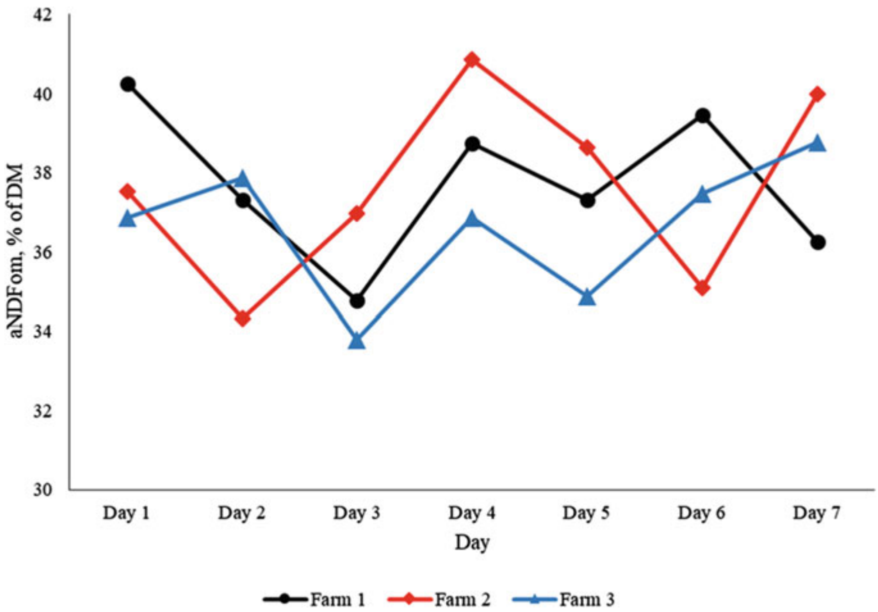

Fig. 6.3 Concentrations of aNDFom in corn silage from three different dairy farms over 7-day period. The coefficient of variation (CV) for farm 1, 2 and 3 were 5%, 6.4% and 4.7%, respectively

6.2.1.3 Need for the Routine and Accurate Forage Quality Assessment

Accurate forage quality assessment is essential when formulating diets because of extreme farm to farm variation, book or table values for nutrient composition are not adequate for home grown forages, such as corn silage, hay crop silage, and hay. These forages should be sampled, analyzed, and the individual farm data used to formulate diets, especially if they account for a significant proportion of the dry matter (DM) fed. Further, accurate forage quality estimations are vital for forage resources marketing. For example, due to the rising demand and the comparative advantages of imported alfalfa in quality and price, China is likely to remain a major importer of alfalfa (Wang and Zou 2020). Thus, an accurate estimation of forage quality is needed for forage pricing.

6.2.2 Identification and Current Quantitative Measurement of Forage Quality Components of Forage Resources in China

Basically, forage resources are evaluated visually for the sensory quality and forages that comply with visual assessment standards are further evaluated for chemical and biological quality. Currently different technical standards for specific forages have been established and well documented in China.

6.2.2.1 Forage Sampling and Sample Preparation

Representative samples are the cornerstone of forage analysis since the heterogeneity of the nutrient composition of the physical components of forage is one of the most important factors related to the ability to obtain a representative sample. Many common forages, such as corn silage, consist of physical components that are extremely heterogeneous in terms of nutritional composition and can often lead to biased samples (Weiss et al. 2012; St-Pierre and Weiss 2015). Unrepresentative sampling could lead to result in a change in silage composition very often even though actually did not occur. This may lead to diet reformulation based on an apparent change in the composition of the forage when the silage did not actually vary. As a result, reformulation based on this fault data may lead to a poorly balanced diet and a loss of milk yield, weight gain or even an increase in health issues, such as ruminal acidosis. Therefore, in order to reduce the sampling error, a correct sampling procedure that always results in perfectly representative samples should be followed. While this is possibly an unattainable task, it is always possible to develop sampling techniques that should reduce sampling error. Currently in China, forages are being sampled and sample preparation is being conducted in accordance with technical standards (NY/T 2129 and GB/T 20195 for sampling and sample preparation, respectively).

6.2.2.2 Visual Assessment

Forage visual assessment serves as an excellent and essential first-line forage assessment tool. While there is no sufficient nutritional information in the visual evaluation, it may detect problems in the forage that may not be detected by standard forage analysis. Thus, in combination with any other forage analysis, it could be used. In general, forages are evaluated for the color, odor, texture with or without some other physical quality parameters such as particle size for the preliminary forage analysis in China.

(1) *Fresh forages*

Fresh forages are currently visually assessed for the stage of maturity (maturity stage is determined by looking at the presence of seed heads of grass forages or flowers or legume seed pods) and leaf: stem ratio (Determined by looking at forage whether the stems or leaves are more evident as high-quality legume forages would have a high proportion of leaves, and stems would be less evident). However, technical standards for the visual assessment of each forage type is not available at present.

(2) *Conserved forages*

Technical standards for the common conserved forages in China are presented in Table 6.1 In Addition to these standards, locally established specific technical standards for some conserved forages also available at present. However, the standards

Table 6.1 Technical standards for the visual assessment of common conserved forage resources in China

Forage type	Color	Odor	Texture	Particle size	References
Alfalfa silage	Green, yellow-green, dark green or yellow–brown without brown or black	Sour smell or slightly alcohol, acetic acid smell, no musty, rancid or ammonia smell	The stems and leaves have clear structure or basically remain intact, loose, soft and moist, without fuzzy, rotten, slimy or hard dry stems and leaves		DB41/T 1906-2019
Alfalfa hay	Green or light green surface, and the surface of the hay can be yellow or chlorosis due to sun, rain or storage. The inside should be green or light green with no mildew	No peculiar smell or aroma of hay	The stems and leaves are kept relatively intact		T/CAAA 001-2018
Oat silage	Light green, yellow-green or yellow–brown, without brown or dark brown, and no obvious mildew spots	Sour or soft sour, without irritating sour, odor, ammonia and musty	Loose, soft, not agglomerate and no lumps		T/CAAA 004-2018
Oat hay	Green or light green, and the surface of the hay is yellow or lost due to sun, rain or storage. Inside should be green or light green, no mildew	No peculiar smell or aroma of hay			T/CAAA 002-2018

(continued)

Table 6.1 (continued)

Forage type	Color	Odor	Texture	Particle size	References
Mixed silage of alfalfa and grass	Yellow-green or yellow–brown	Sour or soft sour	Clean, the stem and leaf structure are complete, the soft material is not easy to fall off, it is not sticky or hard, and there is no mildew		DB15/T 1456-2018
Whole plant corn silage	Close to the natural color of the raw corn crop or yellow-green, without dark brown and mildew spots	Slightly mellow and sour, without peculiar smell such as rancidity	Stems and leaves have a clear structure, loose texture, no stickiness, no agglomeration, and no dryness	Corn seed crushing rate of ≥90% Penn sieve testing the upper sieve 10–15%, Middle screen 65–75%, Lower screen 15–30%	GB/T 25882-2010

shown in Table 6.1 are applicable for the visual assessment of conserved forages produced any part of the country.

6.2.2.3 Laboratory-Based Assessment of Forage Quality

(1) Wet chemistry methods and other laboratory-based methods used for the assessment of nutritional, fermentation and microbiological quality

Laboratory methods are widely used for the analysis of nutritional, fermentation and microbiological quality of forages and involve conventional methods using various chemicals, drying and burning procedures as well as newer electronic sophisticated equipment. The most common and practical method of evaluating the quality of forage is possibly to send fresh or conserved forage samples to an analytical laboratory. The contents of DM, CP, ash, starch, fiber fractions (NDF, aNDFom, uNFDom240, lignin, ADF), fats, water soluble carbohydrates (WSC: fructan + sugars) or non-structural carbohydrates (NSC: starch + WSC), some minerals and vitamins are generally determined by forage analytical laboratories. Table 6.2 shows the technical standards procedures widely used to determine the nutritional composition, fermentation profile and microbiological quality of forages.

Currently, the forage mineral content is determined by a process in which the feed sample is completely incinerated into ash and the selected macro-minerals (Ca, P, K, Mg, S, and Na) and micro-minerals (Mo, Zn, Fe, Cu and Mn) are subsequently

Table 6.2 Technical standards for the detection of forage nutritional, fermentation and microbiological quality

Forage quality parameter	Technical standard reference
Nutritional composition	
Moisture	GB/T 6438
Crude protein (CP)	GB/T 6432
Ash	GB/T 6438-2007
NDF	GB/T 20806
ADF	NY/T 1459
Fermentation profile	
pH	GB/T 10468 for the sample extraction execution and subsequent analysis using pH meter
Ammonia-N	Colorimetric determination
Organic acids (Acetic, propionic, butyric and lactic acid)	High performance liquid chromatography
Mycotoxin detection	
Zearalenone	GB/T 28716-2020
Deoxynivalenol	GB/T 30956-2014
Aflatoxin B_1	GB/T 36858-2018

analyzed using atomic absorption spectroscopy and calorimetric procedures in wet chemistry. For the ensiled forages, pH, ammonia nitrogen, organic acids including volatile fatty acids and lactic acids are being analyzed in accordance with the technical standards. As reported in the recent literature, prevalence and re-occurrence of mycotoxins in feed resources in China are high (Guan et al. 2011; Wu et al. 2016; Ma et al. 2018).

(2) Use of near infrared reflectance spectroscopy (NIRS) technology in forage quality assessment

Near infrared spectroscopy is a quick, non-destructive and reliable alternative technique, reflecting a radical change from traditional chemical methods in which the absorption properties of the entire matrix are defined. It provides results at the time of analysis, which makes it an interesting tool in the determination of forage quality parameters. Over the last two decades, NIRS has been extensively applied in China for evaluating chemical composition, digestibility, rumen degradability and fermentation characteristics of forage resources and NIRS have been calibrated for commonly used forage resources against large sample sizes (Liu and Han 2006). However, the use of NIRS for the accurate determination of mineral contents of forages has limited applicability (Li et al. 2006 and Lei et al. 2012).

(3) *In-vitro, in-situ and in-vivo methods of forage quality testing*

The nutritional value of a feed is determined by its chemical component content and its conversion by the animal to nutrients/digestibility. It is possible to describe digestibility as the fraction of a feedstuff or dietary constituent lost through the digestive tract while passing through it. Conventional digestibility measurements have substantially contributed to the development of systems to describe the nutritional value of feedstuffs (Van Soest 1982). The net energy framework is currently the most effective approach to describing the requirements for nutrients and the nutritional value of feedstuffs (NRC 2001). The single greatest energy loss during feedstuff use by ruminants consuming forage-based diets is voided by the animal as feces according to the classical energy partitioning scheme that provides the basis for the net energy system. Therefore, the measure of digestibility in vivo is a fundamental technique due to the magnitude of fecal energy loss and its role in determining nutritional value, which should be fully understood by those researching the nutrition of ruminants consuming diets dependent on forage-based diets (Danielsson et al. 2017). However, in vivo procedures are time consuming, need skilled personnel and costly. Thus, in situ and in vitro procedures are the best alternatives for in vivo methods. While in vivo and in vitro procedures are rarely used for farm forage analysis, they are widely used by scientists to evaluate the quality of forage. Most frequently, the disappearance of dry matter and NDF at a particular time are measured, and this value can demonstrate how digestible a forage can be. The term in situ refers the process in which small polyester bags containing forage samples are placed in the rumen cannulated animals consuming similar diets to the forage being evaluated.

6.2.3 Current Integrated Indexes and Grading Systems Used for Forage Quality Evaluation

6.2.3.1 Current Technical Standards for the Quality Evaluation and Grading of Common Forages in China

Forage specific evaluation and grading systems for commonly used forage resources in China have been established and well documented. In addition to the technical standard forage quality evaluation and grading systems, specific regional level forage quality evaluation systems also available and some of them are under the trial stage. However, continuing research on quality evaluation and quality improvement of forage resources is subjected to have more updates for the already established technical standards. Tables 6.3, 6.4, 6.5, 6.6, 6.7, 6.8 and 6.9 present forage evaluation and grading systems currently used in China for common forage resources.

Table 6.3 Technical standards for oat silage grading (T/CAAA 004-2018)

Quality parameter	Grade			
	1	2	3	4
pH	≤4.4	>4.4, ≤4.6	>4.6, ≤4.8	>4.8, ≤5.2
Ammonia-N, total N %	≤10	>10, ≤20	>20, ≤25	>25, ≤30
Acetic acid %	≤10	>10, ≤20	>20, ≤30	>30, ≤40
Butyric acid %	0	≤5	>5, ≤10	>10
CP %	≥9	>9, ≥8	<8, ≥7	<7, ≥6
NDF %	≤55	>55, ≤58	>58, ≤61	>61, ≤64
ADF %	≤34	>34, ≤37	>37, ≤40	>40, ≤42

Note Acetic acid and butyric acid are expressed in terms of mass ratio in total acid; crude protein, neutral detergent fiber, acid detergent fiber, and crude ash are in terms of dry matter

Table 6.4 Technical standards for Type A oat hay grading (T/CAAA 002-2018)

Quality parameter	Grade			
	1	2	3	4
NDF %	<55	≥55, <59	≥58, <62	≥62, <65
ADF %	<33	≥33, <36	≥36, <38	≥ 8, <40
Moisture %	≤14			

Note Type A oat hay is characterized by >8% CP content. The content of neutral detergent fiber, acid detergent fiber and crude protein are all based on dry matter

Table 6.5 Technical standards for Type B oat hay grading (T/CAAA 002-2018)

Quality parameter	Grade			
	1	2	3	4
NDF %	<50	≥50, <54	≥54, <57	≥57, <60
ADF %	<30	≥30, <33	≥33, <35	≥35, <37
Moisture %	≤14			

Note Type B oat hay is characterized by containing 15% water-soluble carbohydrates (WSC, dry matter basis). The content of neutral detergent fiber, acid detergent fiber and crude protein are all based on dry matter

6.2.3.2 Current Quality Indexes Widely Used for Forage Quality Evaluation (RFV, RFQ, Milk2006 and Milk2016)

An "index" of the quality of a given forage is a single number which accurately reflects the combination of its potential voluntary intake and nutritional value (Schwab et al. 2003). Either observable animal performance (e.g. daily gain or milk production) or voluntary intake and nutritional value should be the theoretical basis of the forage quality index. One of the widely used methods for the pricing of alfalfa hay is

Table 6.6 Technical standards for alfalfa silage grading (DB41/T 1906-2019)

Quality parameter	Grade			
	1	2	3	4
pH	≤4.3	>4.3, ≤4.6	>4.6, ≤4.8	>4.8, ≤5.2
Ammonia-N, total N %	≤10	>10, ≤15	>15, ≤20	>20, ≤30
Lactic acid %	≥75	<75, ≥60	<60, ≥50	<50, ≥40
Acetic acid %	≤ 20	>20, ≤30	>30, ≤40	>40, ≤50
Butyric acid %	0	≤2	>2, ≤10	>10
CP %	≥20	<20, ≥18	<18, ≥16	<16, ≥15
NDF %	≤35	>35, ≤40	>40, ≤44	>44, ≤45
ADF %	≤30	>30 ≤33	>33, ≤36	>36, ≤37

Note Lactic, acetic acid and butyric acid are expressed in terms of mass ratio in total acid; crude protein, neutral detergent fiber, acid detergent fiber, and crude ash are in terms of dry matter

Table 6.7 Technical standards for alfalfa hay grading (T/CAAA 001-2018)

Quality parameter	Grade				
	1	2	3	4	5
CP %	≥22	≥20, <22	≥18, <20	≥16, <18	<16
NDF %	<34	≥34, <36	≥36, <40	≥40, <44	>44
ADF %	<27	≥27, <29	≥29, <32	≥32, <35	>35
RFV	>185	≥170, <185	≥150, <170	≥130, <150	<130
Weed content%	<3	<3	≥3, <5	≥5, <8	≥8, <12
Ash	≤12.5				
Moisture %	≤14				

Note RFV = DMI(%BW) × DDM(%DM)/1.29 Among them, dry matter intake DMI(%BW) = 120/NDF(%DM) Dry matter digestibility DDM(%DM) = 88.9–0.779ADF(%DM). The content of crude protein, neutral detergent fiber and acid detergent fiber are all based on dry matter

Table 6.8 Technical standards for whole plant corn silage grading (GB/T 25882-2010)

Quality parameter (%)	Grade		
	1	2	3
NDF	≤45	≤50	≤55
ADF	≤23	≤26	≤29
Starch	≥25	≥20	≥15
CP	≥7	≥7	≥7
Moisture	60–80		

Note The content of crude protein, starch, neutral detergent fiber and acid detergent fiber are all based on dry matter

Table 6.9 Technical standards for alfalfa meal grading (NY/T 140-2002)

Quality parameter	Grade			
	1	2	3	4
CP %	≥19	≥18	≥16	≥16
Crude fiber %	<22	<23	<28	<32
Ash %	<10	<10	<10	<10
Carotene (mg/kg)	≥130	≥130	≥100	≥60

Note The content of crude protein, crude fiber, ash and carotene are all based on dry matter

relative feed value (RFV). RFV is an index that combines the vital nutritional factors of intake and digestibility having NDF and ADF as predictors of forage quality (Weiss 2002). Within the context of temperate forages, the NDF content is correlated with intake and ADF with the digestibility of the forage, particularly alfalfa. More precisely, according to the estimate based on the intake potential (predicted from NDF) and digestible DM (predicted from ADF) of alfalfa hay, the index classifies forages. Research on voluntary feed intake, digestion and utilization together with the development of routine in vitro digestibility and fiber analysis methods serves as the fundamental cornerstones of modern forage evaluation. As a result of the continuing research of fiber fraction, the Relative Forage Quality (RFQ) index was developed to have the same mean and range as RFV (Horrocks and Vallentine 1999; Undersander 2003). For estimating intake as well as the total digestible nutrients (energy) of the forage, RFQ uses fiber digestibility. The RFQ index is an improvement over the RFV index for those that buy and sell forages, and it better represents the performance that can be anticipated from ruminants fed those forages.

Milk2006, milk per ton index is the most commonly used corn hybrid ranking index at present to evaluate relative performances of silage corn hybrids based on the estimated milk yield using calculated energy intake from corn silage (Schwab et al. 2003). NRC (2001) was used to calculate the energy concentration of corn silage, and the potential DMI was based on NDF concentration and NDF digestibility. Since NIRS calibrations are available for Milk2006, reputed forage analysis laboratories have included the Milk2006 index in analysis packages. Milk2006 index has further improved to Milk2016 for alfalfa and grasses by including total tract NDF digestibility (ttNDFD). Total Tract NDFD uses the rate of digestion (kd) and in vitro uNDF to estimate the rate of passage. ttNDFD has been shown to be a better estimate of dairy cow performance than NDFD at a single time point (Lopes et al. 2015). Thus, Milk2006 and Milk2016 are commonly used to evaluate the quality of corn silage and alfalfa/grasses produced in China at present.

6.2.4 Forage Quality and Evaluation Gaps

- At present, most ruminant farms in China use corn stalk silage and usually whole plant corn silage is used by larger scale farms. Most of the supply comes from advance contacts with neighboring corn farmers due to a scarcity of crop land. This causes more variations of silage supplied and may affect the diet formulation strategies. Thus, the quality of the silage needs to be improved and the quality evaluation systems also need further improvements.
- For plantation and harvesting, particularly for forage and roughage, the level of mechanization is low. Therefore, Chinese alfalfa is varying in quality, with limited farmland that can be planted and harvested. Substantial losses occur during the drying phase of alfalfa leaves, if a flattening system does not occur during harvest. Thus, it should stabilize the quality of the locally processed alfalfa.
- The quality and safety assessment method, in particular for ruminant feed like TMR and roughage, is still under construction. The engineering technology center and biological potency and safety evaluation for swine and poultry in China have been completed (USDA GAIN report 2019). However, modern feeding systems for ruminants, including commercial feed, fresh forages, as well as other by-products, can be more difficult to launch. Standard industry research and development of systems for ruminant feed assessment is behind the one for monogastric animals in China. More new ruminant products are now being introduced and more research into ruminant feeding stuffs and additives is progressing. Thus, the ruminant feed quality framework should be completed and revised as a matter of urgency.
- The database of common feed resources should be improved and updated. Feed ration is mostly based on the formula feed nutritional value database, which was established in 2004. As reported, major progress in recent years with ruminant feeds includes imported DDGS, steam-flaked maize, oat grass, ryegrass, wheat silage, haylage, whole cotton seeds and canola meal (Service and Management 2006). The current feed database should be supplemented with relative nutritional parameters of those feed resources. In addition, China should also update the database parameters for common feed and forages. As well as variations between regions, breeds, planting and processing with harvesting and storage, more nutritional varieties should be added. The national feed database for dairy cows is even more necessary to meet the demands of scale for dairy cows and lower pollution from waste and manure.

6.2.5 Latest Developments and New Directions for Improving Forage Quality and Evaluation

- Continuing research and knowledge dissemination regarding forage quality evaluation and quality improvement resulted in improved gain and milk production of ruminants over the last decade. China has a vast territory, and it has more than one type of climate due to different geographical zones. Thus, the establishment of regional level quality standards for commonly used forages is one of the most important steps taken over the last few years. There are several regional level quality standards applied in evaluating forage quality and still some of them are under the trial stage.

- There are many research studies has been done and available in the literature regarding the quality improvement of commonly used fresh and conserved forage resources, evaluation of novel underutilized plant resources as potential feed resources for ruminants and development of new indexes for forage evaluation. Conserved forages such as silages and hay serve as primary components of ruminant diets and research studies relating forage conservation process improvement (Wang et al. 2015, 2017; He et al. 2019), investigating feeding value of novel conserved feed resources (Ameen et al. 2019; Wang et al. 2019; Zhang et al. 2019b) and improvement of nutritive and fermentation quality of ensiled forages (Chen et al. 2019; Zhang et al. 2019a; He et al. 2020) are of primary concern.
- In addition, the development and validation of new tools in assessing forage quality are also reported in the literature (Yangfei et al. 2013; Gallo et al. 2016; Tharangani et al. 2021). According to recent research findings, the integrated index-based approaches have been proved to result in more accurate assessments of the overall quality of the silage. Corn silage quality index (CSQI) (Tharangani et al. 2021) and Alfalfa Silage Quality Index (ASQI) (Tharangani et al., unpublished data) are recently developed indexes that combine silage nutritional parameters, fermentation parameters and measured milk yield of lactating dairy cows fed silage-based diets into a single term for evaluating and grading of whole plant corn silage and alfalfa silage, respectively. This integrated approach comprises a four-step procedure: choosing appropriate silage quality parameters among commonly used silage quality parameters, normalizing parameter values to scores, determining parameter weights, and integrating normalized scores into the final index. Multiple linear regression analysis has been used to select the most important silage quality parameters that relate to the milk yield of lactating dairy cows fed silage-based diets. During the scoring of parameters, standardized scoring functions were used to score silage quality parameters and normalize the measured parameter values before they are integrated into the index. The index values were subsequently converted to quality scores and grading of silage has been done accordingly.

- Corn Silage Quality Index (CSQI)

Six silage quality parameters [i.e., NDF digestibility after 30-h in vitro incubation (g/kgNDF), and concentrations (DM basis) of starch, crude protein, ether extract as nutritional parameters and ammonia, and lactic acid (DM basis) as fermentation parameters] were selected and integrated into the final index among commonly used silage parameters. Final corn silage quality scores (CSQS) were ranged 0–100 and based on the CSQS, five quality grades of silage as poor, fair, average, good and excellent (grade mean index score of 51, 62, 69, 78 and 89, respectively) have been reported (Fig. 6.4). Further, the CSQS was able to explainthe variability in milk production (i.e., every 1-unit increase in CSQS, the milk yield increasedby 0.2 kg/d; R2 = 72) (Fig. 6.5) with high accuracy and precision of prediction (i.e., 0.51 of mean square error, 3.21 of root mean square error of prediction and 0.91 of the concordance correlation coefficient) when the diet is containing minimum 30% corn silage. CSQI has become an important focal point in evaluating whole plant corn silage quality produced within the country and according to the reports on the quality and safety of whole plant corn silage in China (2018 and 2019), CSQI has been successfully applied for the whole plant corn silage quality evaluation and grading.

- Alfalfa Silage Quality Index (ASQI)

Alfalfa Silage Quality Index is composed of four silage nutritional parameters [i.e., crude protein, ADF, digestible neutral detergent fiber content after 30-h in vitro incubation of silage (dNDF30) and ash as DM basis] and three fermentation parameters (i.e., lactic acid, acetic acid ammonia as DM basis) that relate to the measured milk yield of lactating dairy cows fed alfalfa silage-based diets. The new index has been capable of better explaining forage quality since fiber fraction (i.e., dNDF30 as DM basis) represents total NDF content, rumen undigested NDF content after 240-h incubation and NDF digestibility (in vitro NDF digestibility after 30-h incubation). Final alfalfa silage quality scores (ASQS) ranged from 0 to 100 and the distribution quality

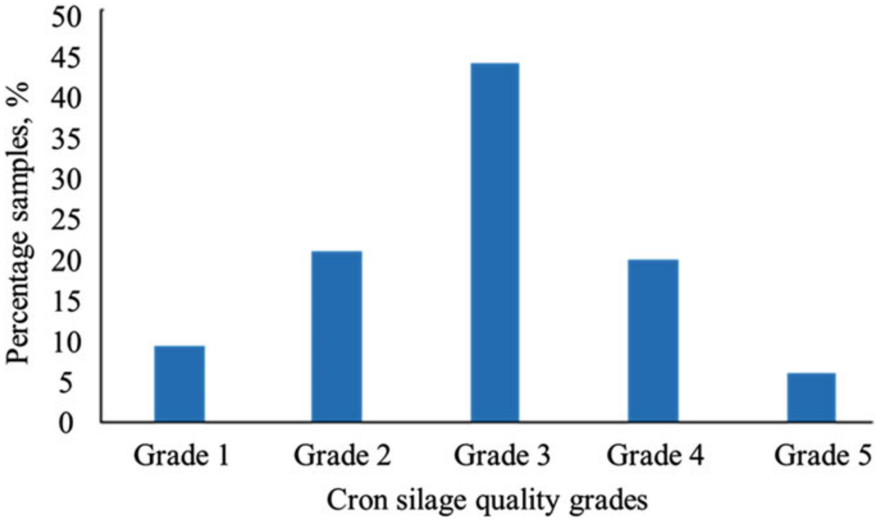

Fig. 6.4 Distribution of corn silage samples (n = 195) among five quality grades (Grade 1 to Grade 5) according to the new corn silage quality index scores (CSQS). Corn silage quality scores 10% higher or lower than the average were considered Grade 3. The remaining four grades were split according to the average increase of 20 percent. Silage quality decreased as grade number increased. Grade 1 silage thus represented the excellent silage quality having the top 20% of the samples and Grade 5 represented the worst 20%

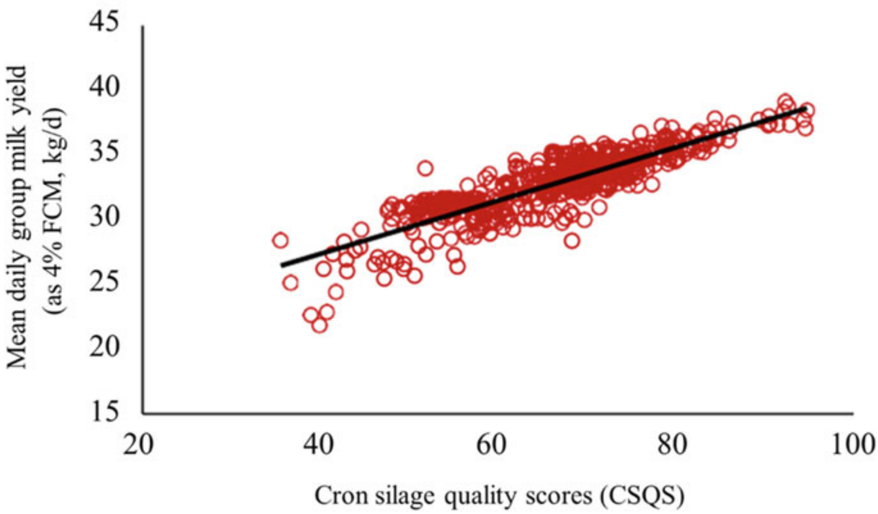

Fig. 6.5 Relationship between CSQS and observed mean daily group milk yield (as 4% FCM, kg/d) (n = 195)

scores of alfalfa silage samples used to develop the alfalfa silage quality index (n = 137) is shown in Fig. 6.6. The correlation between ASQS and measured milk yield (as 4% FCM) has been shown as significant (R2 = 0.43; $P < 0.001$) (Fig. 6.7). Thus, ASQI could be used by farmers and industry people as a new tool to assess the overall

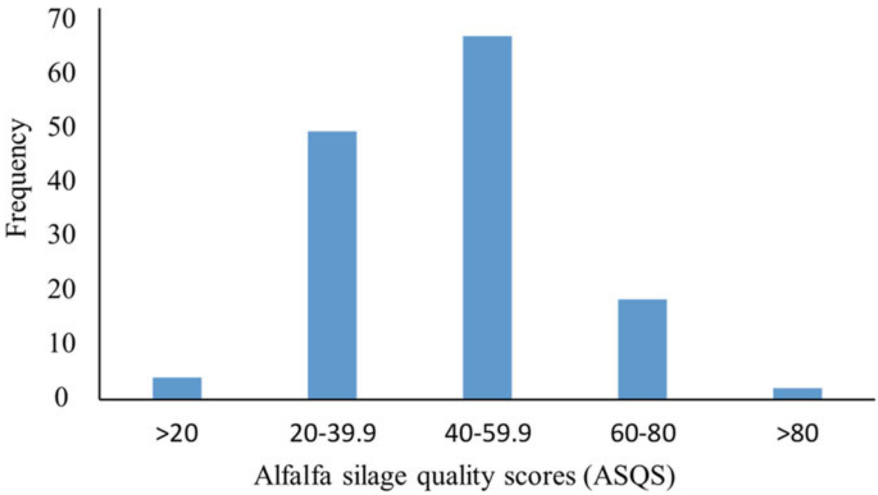

Fig. 6.6 Distribution of quality scores of Alfalfa silage samples used to develop the alfalfa silage quality index (n = 137)

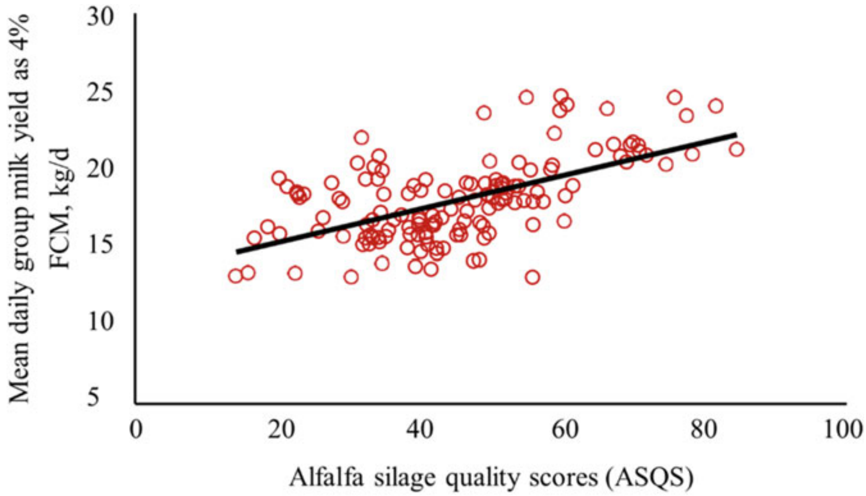

Fig. 6.7 Relationship between ASQS and observed mean daily group milk yield (as 4% FCM, kg/d) (n = 137)

quality of the alfalfa silage with high accuracy if and when it became available as software in near future.

- According to USDA report (2019), one of the most important factors that positively influences farmers' willingness to pay is their awareness regarding forage quality. This indicates the critical importance of extension services in raising awareness of the likely benefits of feeding animals with improved forages, as well as on how to assess forage quality with high precision and how to use accurate quality related data in diet formulation strategies.

6.2.6 Summary

Both fresh and conserved forages serve as primary ingredients in ruminant rations and extremely variable in its quality. Forage quantity and quality terms, as well as diet formulation strategies affect milk yield and animal gain. Since feed cost is the most important factor in livestock production, enhancing the availability of quality forages year-round and preferably on-farm is the key in increasing the productivity of animals and reducing feed cost per unit output. Thus, forage quality has to get more priority and be linked to animal nutrition. For this, many aspects of the forage production process need to be considered, including the use of improved forage varieties, forage management and agricultural practices, forage planning and preservation (seasonality, climate change), mechanization, feed testing and education/training. The constraints mentioned in this chapter need to be carefully analyzed for the different regions of the country, as each has its characteristics, agro-ecological as well as institutional, social, market and infrastructural.

6.3 Research Status and Control of Fungi and Mycotoxins in Forage

Mildew often occurs during the process of forage production and utilization. Over half of the forage losses are caused by mildew. Fungi can consume many nutrients in forage, which will cause serious economic losses and lead to mycotoxin contamination. Mycotoxins are secondary metabolites produced by some toxigenic fungi under suitable conditions (suitable nutrients, temperature, and humidity). At present, over 400 kinds of mycotoxins are known while the most common and important mycotoxins include aflatoxins produced by Aspergillus species, fumonisins, zearalenone, T-2 toxin, deoxynivalenol (DON) produced by the Fusarium species, and ochratoxins produced by Penicillium and Aspergillus species. These mycotoxins have caused great harm to animal production and human health. It is of great economicand social significance to prevent and degrade mycotoxins. The toxic effects on ruminant, occurrence and limit standards, accumulation and influencing factors, and prevention and detoxification measures for fungi and mycotoxins in forages are discussed in this chapter.

6.3.1 Toxic Effects on Ruminants

Mycotoxins can have great toxic effects on ruminants, which mainly includes two main effects. First, they can cause adverse effects on animal health and production performance. Mouldy feed can affect the food intake and production performance of animals, and mould spores have potential respiratory risks for animals and farm workers. Mycotoxins in silage can cause animal malnutrition and flora imbalance, and further cause acidosis, reduced food intake, weight loss and mild diarrhoea. Aflatoxins can cause a decrease in milk yield and milk quality for dairy cattle, a decrease in feed efficiency and weight gain rates for beef cows, and compromise dimmune and ruminal functions and liver malfunctions. Metabolism pathways, somatic cell counts, blood parameters and immunity could also be negatively influenced by forage containing mycotoxins. In comparison to monogastric animals, ruminants were found to be less sensitive to mycotoxins. DON, nivalenol and T-2 toxin can be metabolized into low-toxicity substances in the rumen. Zearalenone has little effect on ruminants, but some studies suggest that zearalenone will lead to infertility and reduce milk production. Second, some mycotoxins can be metabolized or transformed into animal-derived products, thus causing harm to humans. Afltoxin B1 (AFB1) is the most well-known mycotoxin that can be transformed into aflatoxin M1 and enter milk. On the other hand, some studies have shown that fumonisin B1, T-2 toxin, DON and zearalenone can also enter milk through the complete blood-milk barrier.

6.3.2 Occurrence and Limit Standards

Mycotoxins are widely found in feed and forage materials. Under suitable conditions, poor management and processing practices could cause high levels of mycotoxins in forage, which results in great losses to the international and domestic feed and animal husbandry trade. Two thirds of feeds and feedstuffs globally contain at least one mycotoxin and that about a third of feeds and feed materials contain more than one mycotoxin. In China, the highlevels of AFB1 in corn and its by-products, DON contamination of wheat bran and DON and zearalenone contamination in Distillers dried grains with solubles (DDGS) are causes of concern. Mycotoxins could also be detected in silage, but the levels detected for aflatoxin, DON, T-2 toxin and zearalenone were low in China, while Type B trichothecenes and Penicillium toxin deserve further attention. In a single feed sample, different mycotoxins often appear at the same time. Driehuis et al. (2008) showed that DON and zearalenone appeared simultaneously in 44% of dairy cow diets, especially silage and compound feed. In feed, DON and zearalenone also have strong correlations with T-2 toxin and HT-2 toxin. The detection rates of fumonisin B1 and zearalenone and of fumonisin B2 and B1 in silage in Asia and Oceania were also significantly correlated. In view of the commonness and harmful effects mycotoxins in forage, various countries have issued corresponding limit standards. The newly revised hygienic standard for feed in 2017 stipulates the limit standards for AFB1, ochratoxin A, zearalenone, DON, T-2 toxin and fumonisin (B1 + B2). The maximum content of aflatoxin B1 in corn processing products and peanut cake (meal) was not more than 50 μg/kg, while it was not more than 30 μg/kg in other plant feedstuffs. The AFB1 content in concentrated supplements is more strictly limited to 20 μg/kg for calves and lambs and 10 μg/kg for lactating animals. With the exception of its content in corn and related products, the content of zearalenone in other plant feedstuffs is limited to 1 mg/kg. The limits of zearalenone in corn and its processed products (except corn husk, spray corn husk, cornpulp dry powder, corn distiller's grains products) and concentrated supplements for calves, lambs and lactating animals were not more than 500 μg/kg. The limits of ochratoxin A in cereals and compound feeds were 100 μg/kg. The limits of DON in plant feed materials and the concentrated supplements for calves, lambs and lactating animals were 5 mg/kg and 1 mg/kg, respectively. The limit standard of T-2 toxin in plant feedstuffs was 1 mg/kg. The limit of fumonisin in feed material and concentrated supplements for calves and lambs were 60 mg/kg and 20 mg/kg, respectively. In contrast, the restrictions on aflatoxin in foreign countries are more stringent. The European Commission (2002) has issued the recommended content standards for several common mycotoxins in feed. Among them, the limit standard of aflatoxin B1 in complete feedstuffs for dairy cattle is 5 μg/kg; the FDA of United States (2011) has issued a limit standard for the total amount of aflatoxin in feed and proposed a limit guide for DON and fumonisin, with the limit standard for the total amount of aflatoxin in cow feed being 20 μg/kg.

6.3.3 Accumulation and Influencing Factors

Environmental conditions, such as excessive humidity, extreme temperatures, humidity, drought and other climatic conditions, insect pests, ineffective crop systems and poor field management, which may stress the crops, have very important effects on mycotoxin contamination of corn and other crops, resulting in fungal infection and mycotoxin production. Furthermore, due to the impact of global warming, the species of toxin-producing fungi and the mycotoxin content in maize and wheat are continually changing.

In temperate climates, Aspergillus spp. are usually considered storage fungi, and aflatoxin is also thought to be produced in forage mainly under storage conditions. However, in hot and humid areas, such as tropical areas or during especially dry and hot summers in temperate areas, the risk of Aspergillus infection of crop seeds, such as corn ears in the field, is significantly higher than that during storage (Council for Agricultural Science and Technology, 2003). Underfield conditions, insect pests, a high planting density and a low fertilization level may increase the risk of aflatoxin production, and drought stress can also increase the risk that the aflatoxin content will exceed the standard limits in field maize. If silage is not processed properly, aflatoxin can also be detected in the silo, and then the content of aflatoxin will increase during the process of aerobic degeneration.

Plant diseases, including ear rot and stem rot in maize and ear blight in wheat, are related to Fusarium and the corresponding mycotoxins in China. Sowing dates and harvest times that are too late can promote DON contamination in silage maize. Intercropping can also affect contamination by Fusarium toxin because Fusarium can survive in the soil in crop residues and spread during crop rotation. For raw feed and feed materials, unlike the higher aflatoxin content observed in tropical areas, the positive detection rates of DON and zearalenone are higher in temperate areas than in tropical areas.

Field fungi and mycotoxins are supressed to varying degrees in silage. Aflatoxin contamination decreases during ensiling. A study by Mansfield and Kuldau (2007) and others research showed that even if the number of Fusarium oxysporum spores is halved in harvested silage materials, live spores are rarely detected after ensiling. Decreases in DON, zearalenone and fumonisin contents in silage was also detected. Correspondingly, Penicillium, Monascus and Trichoderma species were usually found after ensiling. Among these species of fungi, *Penicillium paneum*, *Penicillium roqueforti*, *Aspergillus fumigatus*, *Monascus ruber* and *Byssochlamys nivea* and the mycotoxins produced by these strains (for example, PR Toxin, mycophenolic Acid, and roquefortine C) were well tolerated under the low pH and anaerobic conditions of silage.

6.3.4 Prevention and Detoxification Measures

Through the improvement of cultivation modes and processing technologies, mycotoxin contamination of forage can be effectively prevented. Changes in cultivation modes include planting resistant varieties and observing suitable sowing times, and appropriate cultivation measures include fertilization, weeding, necessary irrigation, proper crop rotation and field pest control. During the process of making hay, the moisture content should be quickly reduced to below the safe water content to prevent mildew, and dehydrated in the shed is better than that in the field. Long-term preservation of hay under good conditions can maintain low levels of mycotoxin. The most important measure to prevent mycotoxin contamination after silo opening is to strictly isolate silage from oxygen during ensiling. The use of oxygen blocking membrane could delay the occurrence of Aspergillus fumigatus after aerobic exposure of silage from 7 to 14 days when compared with the use of ordinary poly ethylen membranes. It is important to have a high density of silage in the silo because air contact is inevitable during storage and feeding, and this high density mitigates air penetration. Another important factor is silage transfer efficiency during feeding. Maintaining a high silage reclamation rate can minimize the amount of air entering the raw materials underneath the surface silage. Ultimately, if preventive measures do not work, visible moldy feed should be discarded.

To reduce mycotoxin contamination in forage, inorganic adsorbents (minerals like as bentonite, zeolite, montmorillonite, and hydrated sodium calcium aluminosilicate; polymers such as organic glycans and other resins) are most commonly used to adsorb a variety of mycotoxins to prevent the uptake of mycotoxins by livestock and the movement of mycotoxins into the blood. The disadvantage of inorganic adsorbents is that no adsorbent can simultaneously adsorb a variety of mycotoxins, and although the adsorption effect is particularly good for aflatoxin, this effect is relatively poor for other mycotoxins. Moreover, the effect of the adsorbent may be reversible, the conjugate with the mycotoxin may be reseparated in the digestive system, or the effect of the adsorbent may be nonselective and a large amount of nutrients may be adsorbed to cause nutrient loss.

Chemical methods can also degrade mycotoxins, but most chemical reagents are expensive and toxic, and thus it is not feasible to use them in forage. The potential of organic acid, which are usually used in forage, especially silage, in degrading mycotoxins deserves attention. However, the degradation by organic acids is incomplete and results in the production of many other metabolites. AFB1 can be converted to AFB2 and AFB2a bylactic acid. Citric acid, benzoic acid and propionic acid also have degradation effects. These reactions involve only the hydration of the 8,9-olefinic bond in the aflatoxin structure. The metabolites generated are less toxic than AFB1, but their effects onruminants are still unknown.

In addition, some biological method, including the use of bacteria, fungi and enzymes, have shown potential in the biodegradability of specific mycotoxins. For silage, lactic acid bacteria additives are promising for reducing mycotoxin production and loss. Lactobacillus plantarum (screened out in some studies) can produce 3-phenyllactic acid, which is able to inhibit the proliferation of fungi. *Lactobacillus plantarum* could produce phenylacetic acid and 2-propenyl ester. Bacteriocin extracted from lactic acid bacteria also had a significant effect on reducing aflatoxin. Lactic acid bacteria can perform the biosorption of mycotoxins such as those produced by some yeast or yeast extracts, thus reducing the risk of mycotoxin poisoning. Although most lactic acid bacteria additive products do not take into account the factors reducing mycotoxins, lactic acid bacteria themselves are nontoxic and exist in high abundance in silage and cow rumens, which can improve the fermentation of silage, inhibit the reproduction of toxin-producing moulds and reduce the toxicity of mycotoxins and thus have high application value.

6.3.5 Summary

Contamination of forage grasses by mycotoxins is a serious problem worldwide. Strict limits have been formulated for aflatoxins, and other common mycotoxins have also been limited. It is difficult to reduce the content of mycotoxins in forage with individual preventive measures. Therefore, the prevention and detoxification of mycotoxins in the field and during processing and feeding should be combined, and appropriate strategies and effective measures should be selected according to the actual situation.

6.4 Research Status and Control of Nitrate and Nitrite in Forage

6.4.1 Nitrate and Nitrite Hazards to Ruminants

Different concentrations of nitrate are usually found in forage. Nitrate itself has no toxic effect on livestock but can cause livestock poisoning when reduced to nitrite. The nitrate in forage can be reduced to nitrite by rumen microorganisms. Normally, rumen microorganisms use nitrite as a source of nitrogen and further convert it into ammonia, thus forming microbial proteins, which do no harm to ruminants. However, when ruminants ingest forage with a high nitrate content, the nitrate will be largely reduced to nitrite by rumen microorganisms. Nitrite will be absorbed into blood through the rumen wall and combined with haemoglobin to form methaemoglobin, which causes haemoglobin to lose its oxygen-carrying capacity and leads to tissue hypoxia. Excessive nitrate intake by ruminants can cause a variety of hazards, such as abortion, performance degradation, and liver dysfunction, and in severe cases, can lead to the death of livestock.

At present, China has developed relevant restriction standards of nitrite in feed and stipulated the content of nitrite in raw feed materials related to the by products

Table 6.10 Guide to using stored forage with various nitrate contents (Adams et al. 2016)

Forage nitrate content, dry matter basis				Comments
As Nitrate Ion (NO_3)		as Nitrate-Nitrogen (NO_3–N)		
%	ppm	%	ppm	
0–0.44	0–4400	0–0.1	0–1000	Safe under most conditions
0.45–0.75	4500–7500	0.1–0.17	1000–1700	Gradually introduce to ration Feed some concentrate Test all feeds and water Dilute to 0.40% NO_3 or 0.09% NO_3–N or less in total ration dry matter Restrict single meal size
0.76–1.00+	7600–10,000+	0.17–0.23+	1700–2300+	Possible acute toxicity Feed in a balanced ration with concentrate included Dilute to 0.40% NO_3 or 0.09% NO_3–N or less in total ration dry matter Restrict single meal size

of nonmeat products should not be higher than 15 mg/kg (as estimated by $NaNO_2$, GB 130782017). However, no relevant technical standards have been established for the content of nitrate in forage and livestock intake limit. According to previous studies, the safety of feeding should be considered when the content of nitrate in forage (measured by nitrate nitrogen) exceeds 1000 mg/kg. There is a risk of acute poisoning when the nitrate content exceeds 1700 mg/kg in forage. At this level, the forage should be combined with other feeds to dilute the nitrate and reduce the risk of poisoning (Table 6.10).

6.4.2 Inducement Factor of Nitrate Accumulation in Forage

Nitrate nitrogen is the form of nitrogen available for forage growth and the main source of nitrogen taken up by plants from soil. Nitrogen in fertilizer can be converted into ammonium and nitrate nitrogen and can be absorbed by plants for the synthesis of forage protein. Therefore, a certain amount of nitrate can be detected in forage. Under suitable climate and soil conditions, forage can absorb large amount of nitrate and synthesize protein under the energy drive of photosynthesis, which generally does not cause a large accumulation of nitrate. However, when grass forage is under environmental stress, such as insufficient light and drought, photosynthesis is weak, the nitrate absorbed by forage cannot be reduced in time to synthesize protein, and the rate of absorption of nitrate nitrogen exceeds the rate of assimilation in the body, which will lead to excessive accumulation of nitrate (Rashid et al. 2019).

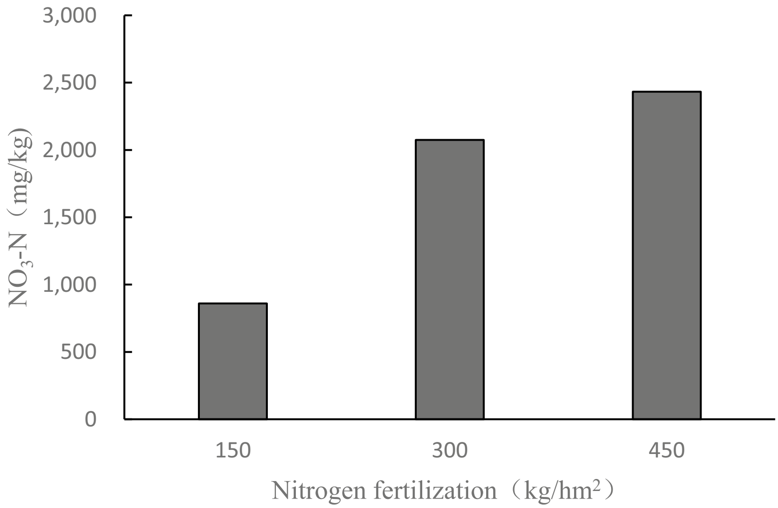

Fig. 6.8 Effects of nitrogen fertilization levels on nitrate nitrogen contents of *Sorghum bicolor* × *S. sudanense* (Bai et al. 2020)

A large amount of nitrogen fertilizer is also an important inducer of increases in nitrate content in forage. The practice of producing forage has proven that increasing the amount of fertilizer is an effective means to increasing the yield of forage. To achieve a high yield of grass forage, a large amount of fertilizer is generally used. However, this kind of high-yield cultivation technique also tends to lead to excessive nitrate content (Fig. 6.8). In addition to fertilization management factors, excessive application of livestock excreta, such as manure and urine, to soil also cause increases in the nitrate content in forage. This scenario occurs because a large amount of waste, such as manure and urine, is produced during livestock breeding, and to treat this livestock waste, a large amount of manure is often applied to land-producing forage, resulting in an increase in the soil nitrogen level. The nitrogen in faecal urine is decomposed into ammonia nitrogen in soil, which is converted into nitrate by nitrifying bacteria. The application of a large amount of faecal urine leads to an increase in nitrate nitrogen in the soil, which is then absorbed by forage, resulting in an increase in its nitrate content (Driehuis et al. 2018). At present, although a large number of researchers have attempted to address the excessive accumulation of nitrate in forage from the perspective of cultivation technology, forage with high nitrate content still exists in a wide range in actual forage production types.

In addition, the content of nitrate in forage is also affected by forage species, growth stage, forage parts and other factors. Nitrate easily accumulates in forage and crops such as ryegrass, Sudan grass, forage corn, forage sorghum and forage oat. At the early vegetative growth stage, the content of nitrate in these forage types is high. However, with the prolongation of the growth stage, the content of nitrate in the forage decreases gradually. In terms of the accumulation of nitrate in different forage parts, nitrate tends to accumulate in poorly lit stems (especially underpart stems) and underpart leaves with insufficient light. The reason for this accumulation may be that compared with that from the upper leaves, the light energy obtained from the stems and the underpart leaves is insufficient, and the activity of nitrate reductase decreases, leading to the accumulation of nitrate. Taking advantage of the accumulation and distribution of nitrate in forage, to improve the safety of raw forage materials, corresponding measures to reduce the content of nitrate can be taken during harvest.

6.4.3 Prevention and Control of Nitrate Poisoning in Forage

As mentioned above, when the nitrate content in forage products is high, limiting feeding is an effective method to address livestock poisoning, but the application scope of forage is inevitably limited. Therefore, the first option is to eliminate the risk of nitrate poisoning by reducing the nitrate content during forage production and preparation. According to the distribution rule of nitrate in the forage growth process and different parts of forage, the nitrate in raw forage materials can be reduced by adjusting the forage harvest method. For example, in one study, the content of nitrate in corn decreased significantly from the late stage of milk ripening to the waxy ripening stage. As the whole corn harvest stage was wax, the content of nitrate was reduced by extending the harvest stage. In addition, the content of nitrate in the underpart stalk of forage was higher than the average level of the whole plant. The content of nitrate was reduced by increasing the stubble height. However, considering factors such as yield, quality and herbage, the application of the adjusted harvest method in practical production is limited, and it is more reliable to reduce the nitrate content in forage products by processing and adjusting measures.

At present, ensiling is an effective method to degrade nitrate in forage. After anaerobic fermentation, part of the nitrate will be degraded. Compared with that of producing hay, the rate of nitrate degradation during ensiling was higher, and a lower content of nitrate remained in the silage. The degradation of nitrate in silage is related to the water content of raw materials, storage temperature and the use of additives. The nitrate degradation rate at a high moisture content or of wilted silage is higher than of haylage; temperatures below 15°C are not conducive to the degradation of nitrate in silage; alkaline additives such as urea are conducive to the degradation of nitrate. However, when the nitrate in forage is at a high level, it may degrade and produce a high concentration of nitrogen oxide in the silo, causing harm to humans and livestock. Therefore, how to degrade nitrate safely and effectively during ensiling needs to be addressed in the future.

6.5 The Hazards of Pesticide Residue on Forage and the Progress of Detection Technology

Forage grass refers to herbaceous plants whose stems and leaves can be used as feed for herbivores, including grass hay, straw, green fodder, and silage. As the main source of roughage for ruminants, forage can provide energy, control feed intake, and maintain the normal rumen physiological function. It has played an important role in ruminant breeding.

During the process of forage grass growth, pesticides should be sprayed frequently to removed weeds and prevent pests and diseases. Abuse of pesticides, use of banned pesticides, mowing in pesticide safety intervals, etc., which often result in the pesticide residues in forage products exceeding the prescribed maximum residue limit (MRL). Exposure of livestock to the contaminated forage grasses will not only induce a variety of diseases and even death, but also seriously affect the quality of livestock products and endanger human health and lives. The pesticide residues in feed and forage currently reported are mainly organochlorine, organophosphorus and pyrethroid pesticides. Organochlorine pesticides are known to be neurotoxic and cytotoxic, which mainly damage the central nervous system, liver, kidney and other parenchymal organs, interfere with the normal functions of the immune system and reproductive system, and have carcinogenic, mutagenic and even teratogenic effects. Organophosphorus pesticides mainly combine with cholinesterase in animals to produce phosphorylcholin esterase, which inhibits the action of cholinesterase to decompose acetylcholine, resulting in nerve conduction interruption and poisoning. Pyrethroid pesticides are the most widely used pesticides and belong to endocrine disruptors. Ruminants seriously exposed by pyrethroid have potential toxicity to their reproductive, immune, nervous and cardiovascular systems. Wen Chaowen has reported a case of a farmer in YunNan who accidentally fed grass sprayed with organophosphate pesticides. In the case, many beef cattle suffered from diarrhea, salivation, muscle tremors, and foaming at the mouth after feeding the contaminated grass. Ye Erken also reported the sudden attack, spasm and death of a dairy cow due to ingestion of grass contaminated with trifluralin pesticide during the grazing. Tang Chao reported on the symptoms and treatment of organophosphate poisoning in rabbits due to pesticide residues in forage. Due to excessive pesticide residues in forage grass, poisoning deaths of cattle, sheep and meat rabbits frequently occur, which has caused huge economic losses to livestock and poultry farmers. The establishment of a rapid and accurate detection method for pesticide residues in forage is of great significance to ensure the quality and safety of animal products.

Many pesticide residue detection technologies have been reported. During the whole process of detection, sample pretreatment is a key step in testing, which directly affects the accuracy and reliability of test results. There are many sample pretreatment technologies for pesticide residue detection, including Solid phase extraction, Solid phase microextraction, Matrix dispersion solid phase extraction, Microwave assisted extraction, Gel permeation chromatography and QuEChERS. Among them, QuEChERS (Quick, Easy, Cheap, Effective, Rugged, Safe) is a new rapid sample pretreatment technology developed in recent years for the detection of agricultural products. QuEChERS utilizes the interaction between the absorbent and impurities, thus achieving the purpose of removing impurity and purifying. Wang Fengen established QuEChERS combined with gas chromatography-tandem mass spectrometry (GC–MS/MS) for the simultaneous determination of 10 pesticide residues including dichlorvos, acephate, dimethoate, atrazine, acetochlor, malathion, fenthion, chlorpyrifos, cypermethrin and deltamethrin in forage. The method has been applied to the determination of pesticide residues in 100 batches of feed products in Shandong Province, and the results showed that the method was rapid, accurate and high recovery. Wu Jieshan established a rapid screening method for 283 pesticides based on QuEChERS combined with gas chromatography-quadrupole-time-of-flight mass spectrometry (GC-QTOF), which could screen and quantitatively detect multiple pesticides in fruits. For the instrument analysis technology, according to the reported literature, the traditional detection methods for pesticide residues are mainly gas chromatography (GC), gas chromatography-tandem mass spectrometry (GC–MS), gas chromatography-tandem mass spectrometry (GC–MS/MS), and liquid chromatography-tandem mass spectrometry (GC–MS/MS, LC–MS/MS), etc. The high-precision confirmation methods have accurate, stable and reliable results. Using methanol-hydrochloric acid solution as the extraction solvent, Wu Jianping screened 51 pesticide residues in grain feed through positive and negative switching by UPLC-Q Exactive. The method is rapid and sensitive with the recovery of 50.61–109.49%. Cao et al. compared the differences of matrix effect and methodological between GC–MS/MS and GC-TOF/MS in the multi-residue detection of 208 pesticides in fruits and vegetables, and proposed the characteristics and application of the two instruments in pesticide residues detection. At the same time, in the research on rapid detection technology, novel detection technologies such as surface enhanced Raman spectroscopy (SERS) and enzyme-linked immunoassay (ELISA) are another development direction of pesticide residue detection technology. Based on the high sensitivity and good specificity of immunoassay, ELISA and other rapid screening methods have been applied to detect pesticide residues in food and feed. The rapid analysis of pesticide residues in agricultural products through SERS combined with chemometric tools has also become the focus of research.

Most of the existing methods for detecting pesticide residues in agricultural products are applied to cereals, fruits and vegetables, edible fungi, etc., while the research on pesticide residues in forages is relatively few. At present, China has only released two relevant standards for the detection of pesticide residues in forage grass “Determination of HCH and DDT in Feeds” (GB/T 13090–2006) and” Animal feeding stuffs-Determination of residues of organophosphorus pesticides- Gas chromatagraphic method (GB/T 18969–2003). The backwardness and lack of detection standards for pesticide residues in forage grass have brought great hidden dangers to the quality and safety of forage grass and livestock products.

With the rapid development of science and technology, great progress has been made in sample pretreatment technology and instrument analysis technology for pesticide residue detection. Professional instruments have gradually developed from conventional GC and GC–MS to novel GC–MS/MS and GC-QTOF. The rapid upgrading of equipment has significantly improved the sensitivity and detection throughput of the established method, and the goal of "multi-residue, high-throughput" has been achieved. The existing pesticide residue detection technology can simultaneously carry out multi-residue analysis on nearly a thousand kinds of pesticide, thereby greatly saving detection time and improving detection efficiency. The rapid development such as surface enhanced Raman spectroscopy, plasmon resonance analysis and near infrared spectroscopy has effectively improved the detection level of pesticide residues. Therefore, it is urgent for us to participate in and solve the problem of establishing and developing a rapid, sensitive and high-throughput method for the detection of various pesticide residues in feed and forage.

6.6 Quality and Safety Supervision and Management of Forage Products

The quality and safety of forage products are related to the animal husbandry production and food safety. Additionally, they have a large impact on the social and economic order, industrial economic development, and people's legitimate rights and interests. The Chinese government leads the supervision and management of forage product quality and safety. The main functions of supervision and management are to safeguard the vital interests of people, implement the laws, regulations, and technical standards of quality, improve the product competitiveness of industries and enterprises, enhance the quality awareness of enterprises, and establish a social credit system. China's quality supervision is mainly divided into four levels: enterprise internal supervision, state supervision, industry supervision and social supervision, which are, respectively, implemented by the enterprise itself, state organs, industry competent departments and social organizations.

At present, China has gradually established a relatively sound governing system of quality and safety for forage products, involving a quality standard system, inspection and detection system, science and technology support system, demonstration and promotion system, laws and regulation system and other aspects, and vigorously promoted the construction of a standardization system for forage products and the implementation of a product certification system.

6.6.1 The Control of Quality and Safety of Forage Products

With the development of industrialization and modern agriculture, a large amount of material wealth has accumulated. At the same time, it also brought about problems such as resource depletion and environmental pollution, which have seriously affected the survival and development of human beings. To protect human safety and the ecological environment, it is necessary to follow the principles and laws of modern ecology and ecological economics to develop animal husbandry production for scientific development. Moreover, with the improvement of living standards and the enhancement of health awareness, people pay more attention to the quality and function of livestock products. The pursuit of livestock products gradually changes from quantity to quality. Nutrition and feed are important factors affecting the quality of products. As the feed source of animal husbandry production, the quality and safety of forage products are closely related to the quality and safety of livestock products, so it is necessary to control the forage production process. Therefore, it is necessary to control the process of forage production. Therefore, it is necessary to formulate the standards, production processes, management systems and technical services specifications for various products. The implementation of a certification system is a scientific and fair method to implement standards and technical specifications. The State Council promulgated and implemented the 'Regulations of the People's Republic of China on Certification and Accreditation' on November 1, 2003, and the state implemented a unified supervision and administration system for certification and accreditation.

Certification refers to conformity assessment activities in which a third-party certification body certifies the products, services, or management system in accordance with the relevant technical specifications and the mandatory requirements or standards of the relevant technical specifications. Quality certification is a form of product quality supervision. Certification represents safety, quality, and reputation, which is a quality control and supervision system adapted to the highly developed market economy. In addition, quality certification is an effective mechanism to indirectly control product quality for the government. It has the function of guiding consumers to consume and can promote the improvement of product quality and market competitiveness of enterprises. Accreditation refers to conformity assessment activities in which accreditation institutions recognize the competence and professional qualifications of certification institutions, supervision institutions, laboratories and personnel engaged in accreditation and auditing activities. China's certification agencies, such as agricultural product quality and safety centres, green food development centres, and organic product development centres, must be authorized by the State Council of China's Certification and Accreditation Administration.

China's forage product certification is mainly carried out under the certification system of agricultural products. At present, the certification of agricultural products in China is mainly divided into product certification and system certification. Product certification mainly carries out the certification of pollution-free agricultural products, green food certification and organic agricultural products. The forage products used as roughage mainly belong to the category of pollution-free agricultural products and organic agricultural products. Pollution-free agricultural products refer to unprocessed or initially processed edible agricultural production whose production area, production process and product quality meet the requirements of the relevant national standards and specifications: establish and improve the quality and safety system through the certification of pollution-free agricultural products and implement the quality and safety control of the whole process of agricultural products, from the origin environment, input products, production processes, processing, storage, and transportation to market access. The certification of pollution-free agriculture is a government action, and the certification is free of charge. Green food refers to safe and high-quality edible agricultural products and related products produced in a good ecological environment, produced according to green food standards, under full quality control and with the right to use the green food labels. Green food certification is based on green food industry standards. Organic agricultural products are produced and processed according to the principles of organic agriculture and certified and issued by legal organic product certification authorities. Organic products are pure, natural, pollution-free, safe, and nutritious products, which are produced and processed according to the standards formulated by Organic Agriculture and the International Organic Sports Federation (IFOAM). A strict production quality management system, production process control system and tracking system must be established during production and processing. In addition to organic food, organic products also include a variety of truly natural, pollution-free, high-quality, safe nonhuman food products, such as feed, biological pesticides, fertilizers and other organic production materials.

In the system certification of forage products, hazard analysis critical control point (HACCP) certification, good manufacturing practices (GMP) certification and good agricultural practice (GAP) certification are mainly carried out in China. HACCP certification is mainly used to ensure the preventive management system of food safety, emphasizing the use of preventive measures in the production process to minimize possible food safety hazards, rather than relying on post-inspection to ensure the safety of products. Since 1991, China has implemented the HACCP system in the field of agricultural product quality and safety. In 2002, HACCP and its certification were applied to the livestock and poultry product processing industry and feed production industry.

GMP certification is mandatory fir food production and storage regulations formulated and promulgated by the government, which is the basis for the establishment and implementation of HACCP. The system requires enterprises to meet the hygienic quality requirements according to the relevant national laws and regulations in terms of raw materials, personnel, facilities and equipment, production process, packaging and transportation, and quality control and to develop a set of operational specifications to help enterprises improve the sanitation environment, find problems in the production process in a timely manner, and improve them. Since 1988, China has formulated GMP standards for enterprise quality management involving food, veterinary drugs, and other fields.

The core of GAP certification is the standardized production and management of agricultural products. GAP is mainly aimed at the production of primary agricultural products. It formulates and implements its own operating specifications, encourages the reduction of the use of agricultural chemicals and drugs, pays attention to animal welfare, environmental protection, human health, safety, and welfare, and ensures the production safety of primary agricultural products. The system mainly involves field crop cultivation, fruit and vegetable cultivation, cattle and sheep breeding, dairy cattle breeding, pig breeding, poultry breeding, livestock and poultry highway transportation and other agricultural industries. GAP certification in China started relatively late. In 2003, related certification work began to be carried out in the production process of some cultivated agricultural products.

6.6.2 The Quality and Safety of Standard System of Forage Products

The standardization management system in China is government-led. The government is responsible for the approval and release of standards and the supervision of the implementation of standards. The 'Law of the People's Republic of China on the Quality and Safety of Agricultural products' stipulates that the quality and safety standard of agricultural products is a mandatory technical standard. It is stipulated by law that the quality and safety standard of agricultural products is an important basis for the quality and safety management of agricultural products. The agricultural product quality safety standard system is based on product, processes, services, and management. It involves all links of agricultural products, prenatally, production, postpartum, throughout the entire process of agricultural production. There are many kinds of agricultural products, and forage products, as a kind of agricultural product, have their own characteristics of production technology, product quality characteristics, storage and processing technology.

At present, the technical standard framework of national standard, industry standards, local standards, group standards and enterprise standards has been preliminarily formed in the field of forage product production in China. The organization, implementation and supervision of the standards have been strengthened through administrative law enforcement, product certification and the establishment of standardized production demonstration areas. According to the quality and safety standards of agricultural products, the quality and safety standards of forage products can be roughly divided into: (1) Standards of safety and hygienicity mainly refer to the maximum allowable or maximum residue limits of toxic and harmful substances such as pesticides in grass products; (2) Standards for the input category of the forage industry, mainly referring to the quality standards of seeds and seedlings, fertilizers, pesticides and feed additives; (3) Standards for resources and environment mainly refer to the standards of forage germplasm resources, grassland resources and ecological environment; (4) Standards for plant protection and quarantine mainly refer to the standards of plant quarantine and epidemic prevention, diagnosis and prevention; (5) Standards for management mainly refer to the criteria for the safe use of forage industry input, safety control specifications for forage products, and the standards for product packaging, identification, storage and transportation; (6) Standards for product quality specification mainly refer to the grading standards for the quality and specification of forage products; (7) Standards for production technology mainly refer to the technical rules for planting, harvesting and processing; (8) Standards for analysis methods mainly refer to the technical specifications for analysis and testing of nutrient components; (9) Standards for terminology mainly refer to the terminology of forage product quality and safety. The establishment and continuous improvement of the standard system play an important role in ensuring the quality and safety level of products and improving the competitiveness of forage products.

According to the current standardized management system in China, the National Technical Committee for Standardization of Animal Husbandry is the organization that formulates and revises the national and industrial standards for forage, which is responsible for the centralized work of standardized technologies in grass seed, forage products, grassland construction and other professional fields. In 2010, China issued a total of 9 national or agricultural forage product standards and more than 40 testing methods standards. Since then, the development of forage standards has accelerated. More than 40 forage product standards have been included in the 12th Five-Year Plan for Animal Husbandry Standard System, and different forage products and quality standards of different types have been established. In recent years, the number of local standards and group standards for forage products has also increased significantly, which greatly supplements the lack of technology not covered by national standards and industry standards and improves the overall standardization level of the forage industry.

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Chapter 7
The Status of the Forage Utilization Industry in China

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Since the founding of the People's Republic of China, the total annual output of agriculture, animal husbandry and their related industries has grown at an average annual rate of more than 10%. The total annual output has increased from less than 40 billion yuan in 1949 to more than 10 trillion yuan in 2019. After 70 years of gradual development and radical re-adjustments, the internal agricultural structure of China has changed from a singular planting-oriented and grain-oriented to a comprehensive and coordinated multi-dimensional composite structure of agriculture, forestry, animal husbandry and fishery.

Animal husbandry plays important roles in Chinese national economy, and its development is directly linked to Chinese agricultural output and economic status. 70 years ago, the animal husbandry industry accounted for approximately 11.6% of total agricultural output in China. Since the strategic adjustments in the agricultural structure that began with the reform and opening, the figure has reached 33.3% today. With the improvement of people's living standards, the demand for meat, eggs and dairy products has increased significantly, accelerating the development of these industries. However, as a proportion of the total agricultural output, the animal husbandry industry in China still lacks behind developed countries, such as the United States (50.2%), Australia (50.9%) and the United Kingdom (59.5%). It is estimated that per capita intake of meat, eggs and milk in developed countries is 2–3

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times more than that in China. Thus, more efforts are required to develop the animal husbandry industry in China.

The rapid development of ruminant production calls for refinement and optimization in feed industry. As one of the most important factors in ruminant production, forage cultivation and processing is continuously improving in China. Recently, both government and private sector have poured money into animal husbandry industry. More and more large-scale farms using advanced technology, and forage enterprises continues to emerge, which promote the development of this industry. Hence, China is on the path to becoming a leader in the ruminant industry.

7.1 Forage Utilization in Dairy Feeding

7.1.1 Why is Forage Important in Feeding Dairy Cows

Ruminants are uniquely advantaged in using forage compared to monogastric animals. Ruminants and monogastric animals mainly differ in the anatomy of their stomachs. Monogastric animals have a simple stomach, whereas ruminants have a multiple chamber stomach that includes rumen, reticulum, omasum, and abomasum. A diverse number of microorganisms encompassing bacteria, protozoa and fungi inhabit the rumen. These microorganisms digest and utilize forages as well as volatile fatty acids (VFAs) and proteins which are used by cows to meet their maintenance and production needs. The rumen enables ruminants to digest high fiber forage and hence feed on fewer concentrates than monogastric animals.

In high-producing dairy cow herds, farms are known to include 40–60% forage in the rations. It is the most important component in the diet because of the dramatic impact on rumen health, dry matter intake and overall nutrient consumption. The rational inclusion of forages in the diet can preserve rumen health to promote rumen fermentation and finally improve milk production. It is worth noting that if forage quality is compromised, the feed digestibility might decrease, leading to lower feed intake and consequently reduce milk production and profitability (Nasrollahi et al. 2015). Other benefits include lower feed costs, higher milk components (primarily milk fat percentage), better cow health, lower culling rates, and increased cow longevity (Elgersma et al. 2006). Specifically, balanced forage feeding can decrease incidences of rumen acidosis and related metabolic disorders that exacerbate foot problems and decrease cow longevity in the herd. And, a major reason for using forages in diets is the economic benefit of forages, which are typically cheaper than purchased grains and concentrates, further enhancing income over feed costs.

7.1.2 The Common Forages Used in the Diets of Dairy Cows

Forages can be fed as fresh pastures, cut forage crops or conserved hay, silage or haylage. The most widely-used forages in the total mixed ration (TMR), as well as their chemical composition, are listed in Table 7.1. Corn silage, alfalfa hay and oat hay are the most commonly used forages in dairy farms because of their high quality, while straws used rarely in large-scale farms in China due to their poor nutrition quality.

Corn silage, an excellent source of energy, is the most common forage in dairy farms. They can reduce the cost of energy component in the diet, as well as serving as a good source of digestible fiber. The quality of corn silage is very important, as it determines the amount of forage to be used. Moreover, it affects the digestibility of forage and dry matter intake (DMI), which ultimately influences milk production and lactating efficiency.

The following details outline basic steps to prepare high quality corn silage for dairy cows. (1) Spend time to get the equipment ready and maintain them timely, such as greasing equipment and sharpening knives. This should be done well in advance of the anticipated harvesting date. (2) Advanced planning is equally important for the timely harvest of the crop at the proper moisture content. Timely harvest is at the core way to control the dry matter content of corn silage. Suitable moisture content promotes well fermentation and decreases storage losses. (3) Silage needs to be chopped at the right length to guarantee proper packing, eliminate oxygen, and expeditiously establish a good fermentation process. However, the chop length should not be too short so that it can encourage the chewing of cud in cows. On the other hand, corn kernel processing is necessary to improve starch accumulation and optimize starch digestion in the rumen. (4) Silos should be filled quickly to help eliminate air from the silage. This should be done within a week to prevent dark brown and black bands in the silo. The silages should then be tightly-packed as much

Table 7.1 The chemical composition of forages widely-used in China

Item	CP%	NDF%	ADF%	RFV
Alfalfa Hay	20.23	41.93	31.08	143.51
Alfalfa Haylage	20.39	42.33	30.45	139.93
Corn Silage	9.53	48.09	28.94	128.35
Wheat Silage	12.92	52.97	31.56	112.95
Peanut Vine	9.29	49.98	37.50	111.09
Leymus Chinensis	5.55	63.59	42.05	82.13
Oat Hay	6.98	58.26	34.96	98.46
Rice Straw	5.35	71.54	45.66	69.35
Millet Straw	6.86	61.24	35.87	92.59
Wheat Straw	3.05	83.62	54.03	52.07

Source Liu et al. (2018)

as possible to promote quick fermentation and limit the growth of yeasts and molds associated with loosely packed silage. The bunkers or piles of silage should then be covered with plastic tarps, and tires could be placed on top immediately after filling to secure the tarps. The sides of the bunkers should also be lined with plastic. Packing and sealing of silage help decrease the size of oxygen pockets, resulting in an excellent profile of fermentation end products that the cow can use to produce more milk. (5) Allow the silage to ferment at least 3 months before feeding. The unfermented feed has a high concentration of fermentable sugars and can cause cows to go off-feed. Moreover, the longer the silage takes to ferment, the higher the digestibility of starch is achieved. (6) During feeding the silage, a smooth surface should be maintained. This helps minimize the exposure of silage to oxygen and hence avoid secondary fermentation. In the presence of oxygen, yeast metabolizes lactic acid, a strong acid that keeps the silage pH low. When the pH increases, undesirable fungi and bacteria will grow and further spoil the silage. This spoilage translates into dry matter losses that can be as high as 10% when silage face management is poor.

7.1.3 How to Appropriately Use the Forage in Feeding Dairy Cows

In nature, diverse vegetation provides different nutrients for animals. However, the nutritional needs of confined livestock cannot be met by a single type of feed. Therefore, in order to rationally use the available feed resources and provide sufficient nutrients via dietary means for dairy cows, it is better to feed TMR, which is a combination of different feedstuffs that are prepared under available feeding standards such as NRC to meet animal's nutritional demands for maintenance and production performance while ensuring better feed conversion efficiency and low cost per unit of animal product produced. The main goal of feeding a TMR diet is to ensure the dairy cow consumes the nutrients required for each bite it takes. The diet should include good quality forages, a balance of cereals and grains that provide energy, proteins, vitamins, and minerals. The feed resources should not only be of good quality but also be consistent and safe. It is important to follow certain feed formulation principles when preparing a TMR. (1) Nutritional principle: It is the basic principle in designing the formulation of compound feeds. The feed ingredients used in a TMR should be selected carefully so that the formulated diet is as close as possible and guarantees the nutritional needs when feeding. (2) Safety principle: the TMR must be safe for feeding the animals and the feed ingredients should be free of molds, rancidity, pollution, and untreated toxins. (3) Economic principle: A properly formulated feed should be done at a low cost to achieve the farm's economic and social benefits.

Most dairy herds are fed a TMR that includes forage around 50% with the aims of providing sufficient nutrients as well as maintaining the rumen function and health in dairy cows. Here are guidelines to consider when including forages in a dairy cow ration.

7.1.3.1 Understand the Quality of the Forage

The quality of forage is one of the factors that have been shown to influence DMI and milk production in dairy cows. Forage quality can be defined as the ability of dairy cows to digest and utilize the nutrients in the forage. The higher content and digestibility of nutrients, the better quality of the forage has. The best quality and most digestible forage are made of young herbage because it contains the lowest amount of structural carbohydrates (cellulose and hemicellulose) and lignin.

The digestion rate decreases as forages grow and mature (Ball et al. 2001), limiting the amount of nutrients derived from the forage and hence lowering its quality. The decrease of forage quality can cause an impact on the amount of other dietary components that animals consume. This could especially intensify the slow passage time of forage in the gut, which might, in turn, lower the intake of not the forage as well as other feed components.

Table 7.2 shows that the forage quality declines with advancing maturity, specifically, neutral detergent fiber (NDF) and acid detergent fiber (ADF) content increase, while CP content decreases. Consequently, feeding dairy cows with a more mature alfalfa hay would result in a lower intake of CP and overall dry matter.

When formulating rations to feed dairy cows, suitable and high-quality forages should be selected based on their nutritive value. This is important because that every 1% increase in neutral detergent fiber digestibility (NDFD) of forage, the DMI and milk production of dairy cows increase by 0.17 and 0.25 kg, respectively.

Table 7.2 Effect of maturity of some forages on its quality values

Forage type	CP%	ADF%	NDF%	RFV
Alfalfa-prebud	22	28	38	164
Alfalfa-bud	20	30	40	152
Alfalfa-early bloom	18	33	43	138
Alfalfa-full bloom	16	41	53	100
Alfalfa-seed pod	14	43	56	92
Alfalfa + grass	13	39	54	101
Bromegrass-late vegetative	10	35	63	91
Bromegrass-late bloom	7	49	81	58
Corn silage-well eared	10	28	48	133
Corn silage-few ears	8	30	53	115
Sorghum silage	8	32	52	114

Source Dunham (1998)

Furthermore, individual milk components are likely to be negatively affected. Since the forage quality varies greatly, it is also advisable to consider testing its NDFD.

Although dairy farms may have different types of forages, their qualities might vary greatly. Therefore, it is important for the person involved in daily management and feeding of available forage to be attentive to detail. He or she should know the quality and nutritive characteristics of forage in the feed warehouse in order to prepare a balanced diet for dairy cows and help farm managers make informed decisions on the next batch of forages.

7.1.3.2 Improve the Consistency and Quality of Corn Silage

Corn silage can mix well in a TMR because it has been pre-processed in the field. Although pre-processing can increase the silage palatability, the quality of silage is greatly affected by various factors. Differences in starch and other nutrients between corn breeds, as well as dry matter content caused by differences in harvesting time and rain, are all worthy of paying attention to.

If monitoring and evaluation of silage are not consistent, the farm is likely to experience fluctuation and decrease in milk yield. For example, changes in silage moisture content can cause a great influence on the diet, a 5% (27 vs. 32%) difference in dry matter content for 20 kg silage was associated with 1 kg difference in dry matter mass (5.4 kg vs. 6.4 kg, respectively). Such changes can perturb the ratio of concentrate to forage and nutrient concentration, concomitantly influencing the rumen environment and subsequent milk production. Furthermore, fluctuations in starch can also have a great impact on milk production. Therefore, if high fluctuations in the nutritional content of silage are common on the farm, there is a need to adopt an all-round solution to mitigate the problems associated with it. There is a need to select the right corn variety, implement proper cultivation management, check the harvesting time, harvest management, packing management, fermentation management, bunk management and silage management to ensure the quality is not compromised and the fluctuations are within limit.

7.1.3.3 Pay Attention to the Physical Characteristic of Forage

Proper particle size distribution in a diet is an important part of ration formulation. The physical form and the particle size of forage directly affect the feed intake and performance of dairy cows (Kononoff and Heinrichs 2003; Rode et al. 1985). When the feed particles are too long, the digestion rate in the rumen will be reduced, the passage rate in the gut slowed, and the total DMI lowered. On the other hand, if the particles are too small, the time of forage stays in the rumen will be reduced, affecting the digestion rate and the rumination time. Moreover, saliva production decreases, increasing the rumen acidity and, consequently drop in milk fat. In terms of feed management, the Penn State Particle Separator (PSPS) provides a tool to quantitatively determine the particle size of forages and TMR. It can conveniently measure the particle distribution, the evenness of the mixed ration and feed sorting. This can help the farm to monitor and further understand the physically effective fiber (peNDF) of the forage and diet. The PSPS helps measure the distribution of feed and forage particles that the cow actually consumes. The focus is not only on particles greater than a particular size but also on the overall distribution of feed particles consumed by the cow. For TMR, ideally, no more than 8% of the material should be retained on the upper sieve. Guidelines for particle distribution of TMR in high producing dairy cows state that 2–8% of the particles should be in the upper sieve, 30–50% in the middle sieve, 10–20% in the 4-mm sieve, and no more than 30–40% in the bottom pan (Heinrichs and Kononoff 2013).

Forage processing, which reduces the physical size (through chopping or grinding) of a feedstuff, plays a critical role in increasing the DMI and optimizing the pass rate in the gut. Small, dense particles are quick to pass through the rumen compared to larger forage particles, which might be retained for a longer period. As the ruminal passage rate increases, exposure to the digestive processes decrease and the overall digestibility of the forage declines. However, since more feed can pass through the digestive tract, the animal increases its DMI and the net result is usually that the cow's digestible nutrient intake increases slightly. This is one of the reasons for chopping forages prior to feeding. Chopping is most beneficial when low-quality forages are fed, but forages should not be chopped into pieces that are too small, as this can result in a depression of milk butterfat.

7.1.3.4 Make Full Use of Local Cost-Effective Forage

Making full use of local cost-effective coarse feed such as *Leymus chinensis*, oat straw, rice straw, yellow wheat straw, and corn straw will greatly reduce the cost of diets. It is important to consider the different categories of animals in the herd when deciding which type of roughages to feed. For example, the energy requirements for dry cows and heifer are usually low, hence roughage with low nutritional value is recommended.

7.1.4 Conclusion

Forage plays a very important role in the diet fed to dairy cows, supporting both the chemical and physical demands of cows. On a dairy farm, the feed manager must pay attention to the quality and value of forages. It is also important to reduce the fluctuations in dietary composition, to track the quality of the forage and to timely evaluate the nutritive value. Adjustments should be made to the dietary composition as need be in order to increase the accuracy of the formulated feed and maintain TMR consistency, which can reduce the cost of the diet. Besides, controlling the forage and dietary particle size could further improve the DMI and rumen health in dairy cows.

7.2 Forage Utilization in Beef Cattle

Herbivores such as beef cattle and yak are mainly fed on grass. Therefore, forage is the key basis for herbivores feeding. It is can not only reduce the damage to grassland vegetation by grazing, but also utilize the manure generated during raising cattle by using high-quality forages, which would increase grazing capacity of land, improve soil quality, and promote the coordinated development of farming and animal husbandry.

7.2.1 Forage Usage in Beef Cattle

In 2018, beef cattle inventory was 66 million heads, and 43.97 million heads were slaughtered in China. The main beef cattle production areas were the Central Plains, the Northeast, the Northwest, and the Southwest. The forage demand in major beef cattle production areas is shown in Table 7.3.

7.2.2 Grazing

Higher palatability, tender and juicy make fresh grass an excellent feed source for beef cattle feeding. There is vast natural grassland in the north of China, with green grass period of 5–6 months, as well as mountain pastures in the south with green grass period of 6–7 months (Figs. 7.1 and 7.2). There could be three grazing seasons in a year. Spring grazing begins from April when the climate turns to warm. Cattle are driven to valleys, sunny slopes or early-sprouting grasslands at noon. At this period, cattle should be taken out late and back early to supplement with other feedstuffs. There will lots of poisonous plants in the early spring pastures. Therefore, more attention should be paid to avoid cattle eating much harmful plants during this period of grazing. In practice, hay was usually supplemented after grazing. Summer grazing begins from May when the weather turns to hot, it is also the time that grass is growing fast. The grazing zone should move to cool highland and mountain with water sources. Cattle should graze fully during this time of grazing, because the grass is rich not only at quantity but also at quality. It is best to take out early in the morning and back at nightfall. However, rotation grazing should be carried out with 5–6 days interval in summer to avoid helminthiasis, and to make better use of grassland resources, which also could prevent excessive trampling from destroying grassland ecology. The energy loss during grazing is much more important in summer because the cattle take more time at the pastures, the suitable working distance is between 4 and 5 km. At the same time, cattle should be supplemented with mineral blocks. Fall grazing begins from August or September when the grass is at lush growth period, some of which is blooming and bearing. Dry matter content of the

Table 7.3 Forage demands for beef cattle production nationwide

Areas		Forage demand/10 kt	Rank
Nationwide		2562.33	
Pastoral	Xizang	144.73	8
	Inner Mongolia	316.68	1
	Xinjiang	174.94	3
	Qinghai	126,96	9
	Sichuan	159.60	5
	Gansu	155.66	6
Northeast	Liaoning	110.67	12
	Jilin	95.34	13
	Heilongjiang	126.82	10
Eastern China	Shanghai	2.16	31
	Jiangsu	20.12	24
	Zhejiang	6.68	28
	Anhui	41.75	19
	Fujian	9.46	27
	Jiangxi	39.44	20
North China	Beijing	6.05	30
	Tianjin	6.61	29
	Hebei	125.70	11
	Shanxi	42.20	18
Central and southern China	Shandong	149.06	7
	Henan	186.39	2
	Hubei	46.21	17
	Hunan	63.23	15
	Guangdong	20.31	23
	Guangxi	30.72	22
	Hainan	10.61	26
Southwest	Chongqing	19.73	25
	Guizhou	68.16	14
	Yunnan	172.45	4
Northwest	Shaanxi	50.25	16
	Ningxia	33.65	21

Source Zhang et al. (2014)

Fig. 7.1 Beef cattle grazing in the pasture

Fig. 7.2 Yak grazing in the mountainous region

forage grass is the highest during this period of grazing. Cattle graze in the pasture for 3–4 months with the average daily gain of 0.5–0.7 kg and then can be sent to feedlot for fattening.

7.2.3 Green Hay

The main green hay used in beef cattle feeding are alfalfa hay and Chinese wildrye. Green hay is good fiber source for cattle, especially during fattening when high concentrate is fed to obtain higher daily gain. Cellulose can stimulate rumen peristalsis and saliva secretion, which could help alleviating rumen acidosis caused by high-concentrate diet. In order to balance the growth rate and disease cost, the addition level of hay is usually below 10% in the ration for feedlot cattle. There are two types of cow feeding in the practice, grazing and confinement. Green hay is more important when cows are raising in the pens that they have no chance to eat fresh grass, and the addition level of hay could increase to at least 50% in the ration. When cows graze in the pastures, green hay is usually fed as supplement during spring and winter ad libitum. For the convenience of use, green hay is sometimes processed into powder or pellets, and fed to beef cattle. Powder or pellets products can not only save the spaces during storage but also reduce the waste during feeding. Wang et al. (2010) replaced peanut seedling and cottonseed hull with alfalfa hay, and it was found that cattle fed alfalfa hay had higher daily gain than the control group. Zhao et al. (2018) found that average daily gain of growing cattle fed sorghum-Sudan grass hybrid hay and wheat straw increased by 280 g and 240 g compared to control group, respectively.

7.2.4 Silage

In the 1990s, relevant studies have shown that feeding corn stalks silage in fattening cattle can obtained good daily gain, save concentrate, reduce feed cost and improve economic benefits (Fig. 7.3). The average daily gain of feedlot cattle increased by 132.5–162.5 g higher than that of control silage, when adding lactic bacteria, ammonium bicarbonate or urea to corn stalks silage. The fattening cattle can freely consume corn silage with a dry matter content of 30.4%, and the energy utilization rate is high, and the dressing percentage can be increased by 31%. Wang et al. (2012a, b) used two biological additives to whole-plant corn silage for fattening Simmental hybrid cattle. The daily weight gain of the two treatment groups were significantly improved, and carcass quality were better than that of control group, showing a significant reduction in aging loss. The net meat rate and carcass meat production rate increased significantly. Wu et al. (2014) also shown that the use of whole-plant corn silage for feeding fattening cattle can significantly increase the daily gain, and feed efficiency.

Fig. 7.3 Silage for feeding beef cattle

Although corn silage is a kind of high-quality roughage, it should be properly matched with concentrate to improve the utilization rate. It is best to use TMR feeding. Unreasonable feeding formula may lead to metabolic disorders, reduced rumination, rumen acidosis, and abomasum dislocation.

According to the age, sex, physiological stage, growth rate and other factors of beef cattle, combined with the quality of corn silage, the silage feeding amount was calculated. Good quality corn silage can be fed in moderation, but it can not completely replace the feed. The dry matter of corn silage can account for 1/3–2/3 of the dry matter of the roughage, and feeding amount is 10–20 kg/head. For 5–6 month of calf, the amount of corn silage should gradually increase to 8–15 kg/head with 100–220 g/day rate. Eat freely throughout the day to ensure normal rumination. The number of feedings per day should not less than twice a day. Alfalfa silage can not only solve the losses caused by hay processing and rain, but also increase the diversity of alfalfa products, which will have great development potential in the future development of animal husbandry in China. According to a survey, the livestock species currently used in China for alfalfa silage are mainly dairy cows, and the feeding amount for lactating cow is 2–6 kg/head/day (dry matter).

7.2.5 *Forage Usage in Yak*

Yaks are mammals live at the highest altitude other than human, which mainly distribute in the Tibet Plateau with average altitude of 3000 m. According to a survey, more than 90% of the world's yaks are raised in China. In the past time, yak is used as a combination of agricultural production tool, agricultural product, and transportation tool, with its meat, milk, wool, and leather being as guarantee of people's livehood in the Tibet region. Because of the poor natural conditions, as a result of long-term adaptation and natural selection, yaks have the characteristics of tolerance to high altitude, cold climate, and roughage feeding. Yaks can not only graze well in plain grasslands, but also use marsh grasslands, and they can also climb high mountains and ridges, so they have great range of feed resources. In general, the natural vegetation of the Tibetan Plateau is Alpine steppe and Alpine meadow with the dominant species of Gramineae and Sedges. According to a survey, there are almost 60 kinds of grasses can be eaten by grazing yaks. With strong survival ability, mature female yak can eat 39.06 kg of fresh grass. Crossbreeding yak with yellow cattle could improve the body frame and intake of the offspring with mature female's fresh grass intake of 43.18 kg.

Growth rate of the natural grass in Tibetan Plateau shows like single peak model with peak in August to September and lowest point in middle April. There is barely grass left after grazing in cold season, which indicates that the livestock number excess the carrying capacity of the grassland (Fig. 7.4). Therefore, it is more important to supplement concentrate in winter and spring. Dry matter production of the planting forage is related to the growth period, which will reach the peak in mature as well as the nutritional values. The disappearance of the oat green hay in the rumen of yak was increased gradually from 12 to 48 h, and the turn over rate of the green hay in the rumen was 48 h. Yan (2000) shown that DMI of the grazing yak was 4.60 kg/day. Yin et al. (2019) conducted an experiment with alfalfa hay, oat hay and wheat straw, and the results shown that the average daily gain of yaks fed with alfalfa hay and oat hay was 440 g and 280 g more than that of wheat straw, respectively. Yaks grazing in the cold season will lose weight to keep survival. Xu et al. (2017a; b) showed that the grazing yak lost 12.4 kg of body weight during 135 days, however, yak with 2.6 kg of oat hay supplement gained 8.4 kg/head, which made raising yak more profitable.

7.3 Application in Goats and Sheep Breeding

According to national statistics in 2019, China has 137.2 million goats and 163.5 million sheep which produce 4.8 million tons of meat and 149.6 tons of cashmere wool. China has a long history of goats and sheep breeding. Most of the animals are still freely grazed in north China grassland or south China mountainous areas. High quality forage is very limited, goats and sheep are mostly fed on natural pasture or fed with low quality grain byproducts. With the increase of consumer demand for

Fig. 7.4 Supplement concentrate for yak after grazing

mutton and goats meat, the goats and sheep husbandry are developing toward large scale. To prevent grassland deterioration, livestock grazing is strictly controlled in the pasturing area of north China. Indoor large-scale feeding is encouraged. Single forage grass is replaced by formulated feedstuff. New techniques were developed to use unconventional feeds and to improve the digestibility of grain byproducts. Overall, the technological level of goats and sheep in China is relatively low, when compared to dairy cows and beef cattle husbandry.

7.3.1 Alfalfa

Alfalfa (*Medicago sativa* L.) is an important forage crop for herbivorous animal and rich in protein, minerals, and vitamins. This high-quality forage can be used for grazing, hay, or silage. According to a recent study in Hebei province, one hectare of mixed pasture with alfalfa (75%), *Dacty lis glomerata* L. and *Festuca arundinacea* Schreb. can meet the requirements of 51 fast-growing lambs for 150 days. Alfalfa hay supplemented with concentrated feed can be used for fattening of sheep or goats for meat production. Alfalfa hay fermented with microbes such as *Lactobacillus*,

Bacillus subtilis and *Bifidobacterium* is easy to be digested by mutton sheep and can improve the immunity of animals. In addition, alfalfa can improve the meat quality of sheep. Compared to alfalfa hay, alfalfa silage maximally reduces the nutrient loss during storage. However, some studies showed that alfalfa silage release vast ammoniacal nitrogen in a short time, so that the microbes is not able to use them efficiently. In terms of protein digestibility, alfalfa hay is better than alfalfa silage. Pelleted alfalfa can increase rumen pH of goats, relieve rumen acidosis, and improve the digestibility of fiber. However, increased pellet size would reduce DMI, so the size needs to be well adjusted. Alfalfa can be dehydrated by high temperature then grounded into powder. Supplementation of alfalfa powder increases body weight gain and improve the slaughter performance of mutton sheep. China has about 1.3 million hm^2 alfalfa, neither the quality nor the quantity meets the requirement of the developing livestock husbandry. In China, alfalfa has been widely used in dairy cow and beef cattle industry but rarely used for goats and sheep industry due to its high price. Some researchers mixed alfalfa with other low-protein hay to reduce the feeding cost, which is suitable for mutton sheep. When mixed with corn straw, the recommend proportion of alfalfa is 40% to 60%.

7.3.2 Ryegrass

Ryegrass (*Lolium perenne L.*) is high in carbohydrate, often mixed with alfalfa, which is high in protein but low in soluble carbohydrate, to produce high-quality silage. In the north of China, ryegrass grows from September to the next May, it is often planted in crop rotation with silage corn. A corn-ryegrass rotation system can annually produce 5000 kg/667 m^2 fresh ryegrass and 5000 kg/667 m^2 fresh silage corn. As estimated, 28 kg fresh ryegrass can be converted into 1 kg body mass of mutton sheep.

7.3.3 Straw

To prevent grassland degradation and soil erosion, grazing is strictly controlled in pastoral regions of north China. In most of the agricultural areas of China, commercial forage is not available, straw is the most abundant feedstuff for livestock. Straw is an agricultural byproduct consisting of the dry stalks of cereal plants such as wheat, rice, corn, sugarcane and yam after the grain or other energy storage organ has been removed. Annually, China is estimated to produce 800 million tons of straw which can be used as bio-fuel or animal feed. Before the second decade of twenty-first century, straw was used as living fuels for cooking or heating. With the widespread use of electric and fossil energy in the past 10 years, vast majority of the straw in rural areas of China were burned off in situ, the straw was wasted for nothing but causing air pollution.

Agriculture scientist has developed a series of techniques to store straw and improve its digestibility. These techniques can be categorized as: physical processing, chemical processing, biological processing, and composite processing. The length and size of the feed can significantly affect feed intake and its digestibility. Cutting, smashing, and rubbing are simplest but effective mechanical techniques to improve feeding effects and animal performance, especially when concentrated feed is insufficient. Compared to intact straw, the digestibility of smashed straw in mutton sheep can decrease as much as 1% due to the reduced gastric emptying time, however, smashing can increase animal's feed intake by 20–30% and improve the body weight gain by about 20%. Pelleting is an emerging technique in mutton sheep husbandry. Compared to powder feed, pelleted feed stays longer in the digestive tract and can be more sufficiently digested by animals. Pelleting is also a way to mix different feedstuffs to provide complete and fixed nutrients to animals. Straw is usually pelleted with hay, concentrated feed, non-protein nitrogen, minerals, and some other additives. As reported by a farm in Tianjin, fattening sheep fed with pelleted feed gains 350 g a day, which is remarkably higher than grazing sheep which gains about 120 g. Pelleting increases mass density of feed, which is suitable for long distance transportation.

In China, wheat straw, corn stalk, rice straw, cotton boll shell and some other crop byproducts are low in nitrogen, high in crude fiber. They were not used as livestock feed in the past due to low nutrients and poor palatability. Alkalization by NaOH, $Ca(OH)_2$, Na_2CO_3 or H_2O_2 is an easy and efficient way to increase digestibility and palatability of roughage. Rations contained silage, high protein feed and alkalized straw can be used for weaning lamb, growing sheep and lactating ewe. Burnt lime (CaO) is commonly used for roughage alkalization in China. Drenching 100 kg chopped straw in 200 to 500 kg water with 3 kg burnt lime for 24 to 36 h could increase the digestibility of straw by 15% to 20%.

Ammoniation increases crude protein of roughage by 4% to 6%, increases its digestibility by 10% to 30%. Like alkalization, ammoniation increases palatability of roughage, adult Hu sheep can ingest same amount of ammonized wheat or rice straw as hay. As reported, ammonized rice straw increased daily body weight gain of Hu sheep by 17.5 g.

Fresh straw especially corn stalk is often used for ensiling in large livestock farms in China. Silage can be placed in large heaps on the ground, covered by plastic films that are held down by used tires. In some farms, big underground silage pools are built using cement. The chopped straws are filled in the pool and rolled by tractor or trampled by humans to push out the air. The top is then covered by plastic films that are held down by mud. A slope is built at one side of the pool for a truck to get in and get the silage out. The silages which keep in green color is called "green silage" and keep in yellow color is called "yellow silage" and the one that treated with extra microbes such as lactic acid bacteria are called "microbial silage".

7.4 Application in Pigs Breeding

Pigs are typical omnivores among domesticated farm animal. They have neither rumen nor developed colon and cecum, so the ability of pigs to digest crude fiber is limited. Traditionally, the diets of pigs in China have long been dominated by green feed, bran and other agricultural byproducts, which lead to the local porcine breeds possessing stronger ability to digest and absorb the nutrients in grasses. In the modern feeding system, complete and compound feeds have been widely used to substitute grass feeds in large-scale farm, and improved the production efficiency and pork safety (Maes et al. 2019). However, too much application of concentrated feeds not only lead to higher breeding costs, but also have some negative impacts on pork quality, feed conversion ratio and the environment. Therefore, some researchers are trying to improve pork taste and flavor and to decrease feed-to-meat ratio by adding grasses in the diets of hybrid or local pigs.

Although many grasses, such as alfalfa, milk vetch, purslane and clover, can be used to feed pigs, alfalfa is the most reported one because of its large yield and rich nutrients. In alfalfa, protein and fiber are the most abundance nutrients. The protein content of high-quality alfalfa at the early flowering stage is over 20% (Eklund et al. 2014), which is 2.0–2.5 times of whole-grain corn. Meanwhile, the methionine content of alfalfa is about 0.15 g/kg crude proteins, which corresponds to the level of soya proteins (Wustholz et al. 2017). Due to the richness in high-quality protein, alfalfa is a high-quality feed for livestock, especially for ruminants, and some researchers try to replace soybean meal with alfalfa in the diet of pigs. Liu et al. (2010) reported that replacing 5% soybean meal with alfalfa meal in weaned piglets diets increased the daily feed intake and weight gain by 3.37% and 4.35%, respectively, and decreased the feed to meat ratio by 1.54%. Although alfalfa meal can partially replace soybean meal, its proteins coexist with some anti-nutritional factors, such as tannin and trypsin, which lead to the energy and crude protein digestibility decrease as the level of alfalfa meal increases (Eklund et al. 2014).

Fiber is another kind of important ingredient in alfalfa, and the content and composition of them also determine the energy and crude protein digestibility. For example, high fiber content can reduce the ability of enzymes to digest soluble cellular proteins. Although fibers in alfalfa can be divided into soluble and insoluble fractions, which have different fermentability, holding capacity, passage rate, and insoluble fractions, such as cellulose, xylans and lignin, account for more than 90% of the total fiber (Chen et al. 2013). The effects of insoluble fibers on the digestibility of feeds and growth performance of pigs have been studied by some researchers. Chen et al. (2014) observed that 5% alfalfa meal diet had no negative effects on the average daily gain of barrows (Duroc × Large White × Landrace), and insoluble fiber led to energy digestibility reduced with the increase of alfalfa fiber. Wang et al. (2018) reported that the insoluble fiber in alfalfa meal can affect cecal microbiota composition, stimulate the production of butyrate, and subsequently upregulate the expression of genes involving in the sensing and absorption of short chain fatty acids as well as regulation of satiety. Conclusively, fibers in alfalfa have the function to change intestinal flora and improve animal health, but too much addition will reduce the digestibility of feeds and production performance of pigs.

For improve the utilization efficiency of nutrients in alfalfa, some researchers tried to feed pigs with alfalfa polysaccharides and/or protein concentrate. For example, Zhang et al. (2019a, b) observed that adding 0.50 g/kg alfalfa polysaccharides in the diets of piglets enhanced the gut morphological development, increased the activities of amylase and protease in small intestine, stimulated the growth of beneficial microbial populations in large intestine, and then improved their growth rate and feed efficiency. Liu (2019) reported that adding 10% alfalfa polysaccharides in the diet of fattening pigs increased their average daily weight gain, slaughter rate and lean meat percentage by 14.9%, 4.0% and 6.9%, respectively, and decreased their thickness of back fat and eye muscle area by 10.0% and 8.7%. In addition, some foreign researchers reported rearing growing-finishing pigs with alfalfa protein concentrate, containing over 50% crude proteins, can elevate the white blood cell count, decrease total cholesterol level, and reduce the low density lipoprotein fraction (Pietrzak and Grela 2015), but the application has not been reported in China.

In addition to the proteins and carbohydrates, alfalfa is also rich in minerals and active substances, such as calcium, iron, manganese, carotenoids and saponins. Among them, calcium content in alfalfa is about 48 times of corn, and swine can convert provitamin A carotenoids to vitamin A. Therefore, the input of calcium, vitamin A and some other nutrients can be reduced in the diets with alfalfa addition. Although the functions of minerals and vitamins are widely studied, there are only a few studies about the bioactive substances, such as saponin. It is known that the structure of alfalfa saponins includes a sugar moiety glycosidically and a hydrophobic aglycone. Wang (2007) reported feeding 0.5% alfalfa saponins can improve the white and red blood cell counts, which might be caused by the increasing uptake of antigens stimulated by saponins (Pietrzak and Grela 2015). In addition, Shi et al. (2014) reported that inclusion 15 g/kg alfalfa saponins can increase the activity of antioxidant enzymes and promote the growth of weaned piglets. Thus, grasses also can be an important source of minerals and active substances for pigs.

Above all, high quality forage grasses contain abundant nutrients and bioactivities. Proper addition of them into diets is helpful to improve the health, growth performance and meat quality of pigs, but the best amount is different due to the influence of pig breeds and feed quality. Moreover, most of the grasses cannot be supplied stably, and the feeding effects varied with pig breeds, feed types, and addition amount. Too much addition of them will dilute the concentration of nutrients in feed and enzymes in digestive tract, and decrease the digestibility of feeds. Therefore, it is necessary to formulate forage harvesting, processing and feeding standards for different grasses and pigs.

7.5 Application in Poultries Breeding

The demand of human for animal protein in the developing world is still rising, especially for poultry products, and the cost of feed concentrates for livestock is increasing. Therefore, to meet the nutritive requirements of poultry, it is necessary to identify alternative low-cost feed resources. Forages as feed for monogastrics, including poultry, contribute to improve sustainability of animal production within farming systems: high biomass production in environments where other crops cannot compete; no or limited competition with human food requirements; high levels of protein with a desirable amino acids profile, especially lysine, methionine and other sulfur-amino acids, which for monogastrics adequately balances the limitations of cereal proteins (leaf and grain), and additional benefits from the integration of forages in the farming system (Tufarelli et al. 2018).

7.5.1 Application in Chickens

At present, the research on the use of forage by chickens mainly focuses on the model of ecologically stocking chickens in forest grasslands. The results of previous studies show that raising chickens on grassland in forests not only provides a good exercise place for the chickens, but also provides natural feed, which is conducive to promote the growth of chickens, improve muscle quality and flavor, and increase survival rate and economic benefits. Meng et al. (2016) found that the live body weight, the dressing weight, the thigh muscle weight, and the breast muscle weight were increased in Beijing-you chickens grazing chicory pasture in chestnut forest compared to that in chickens raised on bare land without forage. Furthermore, the crude ash, the essential amino acid content, and the inosinic acid content were increased, and the crude fat contents were decreased ($p < 0.05$) in the thigh and breast muscles, while the yolk cholesterol and the feed conversion ratio were significantly decreased ($p < 0.05$) in in chickens grazing chicory pasture.

In order to meet the demand for high-quality forage of poultry in winter and spring, Chinese researchers have also carried out a lot of research works on the effective use of alfalfa meal, chicory pulp and other forage products in poultry diets. Zheng et al. (2019) found that dietary supplementation of 5, 8, and 10% alfalfa meal to Beijing-you chickens had beneficial effects associated with growth performance, carcass characteristics, meat and egg quality, and intestinal microbiota. Although small changes in the dominant intestinal microbiota of Beijing-you chickens fed with or without alfalfa meal were observed, supplementation of alfalfa meal tended to stimulate the proliferation of beneficial bacteria, such as the *Lactobacillus* and *Bacteroides*, and inhibit potential pathogens, including the *Clostridium*.

7.5.2 Application in Ducks

Ducks intake much fodder succulence in practice, which showing ducks should be able to utilize forage (Jiang et al. 2012a). It is reported that feeding alfalfa meal to growing layer ducks could improve gastrointestinal tract growth and small intestinal morphology without effect on performance, which may be related to the various functions contained in alfalfa (Jiang et al. 2012a). Jiang et al. (2014) found that dietary alfalfa meal supplementation increases intestinal microbial community diversity and improves the immune response of growing egg-type ducks, although the treated groups did not significantly differ in terms of average daily gain, feed intake and gain-to-feed ratio ($p > 0.05$), and the 3–9% alfalfa meal did not affect the growth performance of the growing egg-type ducks. Jiang et al. (2012b) reported that 3, 6, and 9% alfalfa meal in diet had no significant effects on growth performance of Muscovy ducks from 14 to 49 d of age, while had significantly higher dressing percentage and lower abdominal fat percentage compared with those given no alfalfa meal.

7.5.3 Application in Geese

Goose is an herbivorous poultry. It has a strong muscular stomach, a digestive tract that is about 10 times longer than the body, and a developed cecum. The special digestive tract morphology and physiological functions enable it to effectively digest and utilize the protein and fiber components in the roughage. Appropriate addition of coarse feed in the diet can promote the healthy growth of geese and save breeding costs (Yao et al. 2016). The study found that there are many types of forage suitable for raising geese, such as alfalfa, elephant grass, king grass, ryegrass, seed foraging, white clover, chicory, etc. (Yao et al. 2016; Li et al. 2017; Zhang et al. 2017).

Goose is the most suitable waterfowl for ecological breeding. At present, ecological goose farming in China includes grass-growing geese in winter fallow, geese raising under forest, orchard ecological geese raising, corn field geese raising, etc. It is reported that the use of interplanting ryegrass and vetch in the idle period of the paddy field to raise geese can achieve growth and development (body weight and body size) equivalent to that of house feeding. The 70-day-old body weight can reach 3647.10 g, and it can improve the feed conversion rate (Song 2017). Adding forage meal to the ration or using forage meal as a compound feed ingredient to make full-price pellet feed is an important measure to ensure that the geese can eat high-quality forage throughout the year. Zhan et al. (2015) reported that alfalfa meal pellet feed can increase the intestinal length of Yangzhou goose and improve blood biochemical indexes, but it has no significant effect on growth performance, and the authors suggested that it is appropriate to add 16% of alfalfa meal to 21–42 days of age; to add 20% of alfalfa meal to 43–70 days of age. However, forage fibers are hard and rough, have poor palatability, and contain compounds such as saponins that are not conducive to the growth of livestock and poultry, limiting their full utilization. Macromolecular substances such as polysaccharides, proteins and fats are decomposed and converted into absorbable organic acids, soluble peptides and other small molecular substances through the degradation of probiotic microorganisms. Therefore, biological feed with abundant nutrients, good palatability and high viable bacteria content is obtained using fermentation technology. In addition, a large number of digestive enzymes and vitamins are produced during this fermentation process, which is beneficial to enhance the immunity of livestock and poultry. Yin and Zhou (2015) found that adding a certain amount of alfalfa meal or fermented alfalfa meal to the goose diet can promote its growth and increase the activity of antioxidant enzymes and digestive enzymes, and the effect of adding fermented alfalfa meal is better.

7.6 Application in Monogastric Animal Feeding

7.6.1 Rabbit

Recently, meat rabbit industry has developed rapidly in China, and choosing scientific feeds is one of the key factors affecting the quality of rabbit meat. When planting grass to raise rabbits, three conditions should be considered: (1) rabbits like to eat them; (2) the species adapt to local natural and planting conditions; (3) they have high yield and good quality after harvest. In feeding rabbits, adding a certain proportion of alfalfa (*Medicago sativa* L.) to their ration can promote the growth rate and reduce the cost of feed. Some researchers reported that feeding rabbits with *Lolium multiflorum* and lupin, significantly increased the feed digestibility and the level of lactic acid in cecum (Lin et al. 2019; Yang et al. 2019), so it is worth exploiting the utilization of forages in production. Full-price pellet feed has remarkable effects on promoting the growth of meat rabbits, increasing feed returns, and reducing feed costs and the mortality of young rabbits. Although ensiling is an effective method for preserving feed nutrition, silages are rarely used to feed meat rabbits, because feeding with silage can easily cause indigestion and even acidosis in rabbits. However, feeding with TMR containing silages might improve the productivity of rabbit. In China, TMR technology has been widely used in most large-scale dairy farm and obtained good effects, whereas few studies could be found in meat rabbit industry. Xu et al. (2017a; b) reported that adding 30%-35% of sweet sorghum (*Sorghum bicolor* L. Moench) wilted silage to the TMR can effectively improve the growth of meat rabbits. Woody forage has become a new kind of forage resources and it can be used to feed livestock. Adding a suitable proportion (12–18%) of mulberry (*Morus alba* L.) to the feed can significantly improve the slaughter performance, organ development and the meat quality in meat rabbits.

7.6.2 Herbivorous Fish

For herbivorous fish, green fodder is an essential factor to meet their growth needs. Green fodder is rich in nutrients and provides essential amino acids, enzymes, and hormones for fish growth. The vitamins and minerals in green fodder can compensate for the loss of vitamins during pellet feed processing and storage. Therefore, combining green fodder and pellet feed to herbivorous fish can improve the body index and the growth rate. At the same time, it can also reduce the incidence of fatty liver, regulate metabolic disorders and disorders, and improve body resistance, fish health and meat quality. In addition, this feeding method can decrease the breeding costs and improve economic benefits. At present, green fodder resources commonly used in herbivorous fish industry mainly include forage belong to *Gramineae* and *Leguminosae*, leafy vegetables, and aquatic plants. Adding elephant grass (*Pennisetum purpureum* Schum.), ryegrass (*Lolium perenne* L.), corn (*Zea mays* L.), red clover (*Trifolium pratense* L.), and Napier grass (*Pennisetum purpureum* Schum.) to the feeds of herbivorous fish have been widely used in China. Zhang et al. (2007) reported that adding 8% alfalfa meal to fish feed significantly improved the growing performance, fish meat quality and digestive enzyme activity of *C. carpio*, and Zhao et al (2011) reported that the suitable adding level of alfalfa meal was 3.5%-10%. Feng et al. (2005) reported that feeding *Pennisetum americanum* × *P. purpureum* and *Vigna sinensis sari* Var significantly improved the weight gain of grass carp. Feeding forages increased the amino acid level of back muscle of grass carp and enhanced the contents of human requisite amino acids and taste amino acids in the fish body. Using high-quality forage to raise fish can replace some concentrates, and increase fish production. At the same time, this feeding way can increase the utilization of land and improve the ecological environment.

7.6.3 Horse

Horse plays important roles in the developing of mankind society. With the development of modern horse industry, forage production is an essential factor which determines the speed, scale and degree of intensification. Horse is a kind of monogastric herbivores, and has a great demand for forages. The intake of roughage that an adult horse needs every day, is 2% of its body weight. *Leymus chinensis*, Timothy (*Phleum pretense* L.), ryegrass, mildew (*Festuca arundinacea* Schreb.), alfalfa and white clover (*Trifolium repens* L.) hay are all widely used in horse industry. Moreover, a certain proportion of pellet feed is also needed to balance the nutrition value. Oliveira et al. (2008) reported that the feed produced with *Poa annua* hay and corn soybean meal in a ratio of 40:60 could significantly improve the bioavailability of phosphorus. Moreover, adding yeast culture in alfalfa hay to feed horse can stimulate cellulose digestion, improve the digestibility of acid detergent fiber, and promote the absorption of dry matter and neutral detergent fiber to protect the health status of horses. Recently, silage gradually replaced hay as a common feed for horses due to their high nutrition value, among which crop silage is one of the most widely used in horse industry. Adding suitable proportion silage to horse feed can effectively avoid respiratory diseases caused by dust and mold.

7.6.4 Donkey

In China, increasing demand for donkey meat has led to a rapid development of meat donkey industry. Thus, meat donkey farming has good prospects in the future. The number of donkeys breeding is increasing in China and ranks top in the world, whereas the specifically nutrition standard for donkey farming has not been established. Generally, the meat donkey feed is prepared according to 75% of the nutritional requirements of horse. Compared with horse, donkey has stronger fiber digestibility. Therefore, a series of health problems would occur when feeding donkeys according to the horse feed nutrition standard. Due to small stomach volume and short feed residence time in the stomach, donkey needs to be fed frequently, and to eat a lot of low-energy forage to satisfy their appetite. Therefore, donkey feeding standard needs to consider their digestive characteristics and physiological drive. Donkey ceca have similar function with rumen. Some studies reported that feeding meat donkey with alfalfa hay can significantly increase the bacteria number and improve the fiber degradation. Whereas in practice, alfalfa have low contents in fiber and soluble carbohydrates and is difficult to be fed alone. Thereby, adding a certain proportion of alfalfa to feed can provide the volatile branched chain fatty acids necessary for the growth of ceca bacteria. Some studies reported that the feed produced with oat hay and alfalfa in a ratio of 20:80 could significantly improve the donkey ceca fiber degradation. Combining green feed and hay feed with suitable proportion can improve the meat quality, decrease the cost of meat donkey breeding, and increase breeding income.

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Chapter 8
Research Progress of New Forage and Woody Forage

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8.1 Current Forage Resources in China

Forages refer to the materials that can be ingested, digested, absorbed and utilized by livestock and poultries, promote their growth, and regulate the physiological process of animals. Forages are the material basis for survival and development of animals as well as the basis for development of the livestock husbandry industry. With rapid development of China's economy and increasing improvement of people's living standards, people have growing demands for milk and meat as well as increasing requirements for their quality. Accordingly, accelerating development of the livestock husbandry industry is an important way to solve this problem. However, shortage of high-quality forage resources, especially concentrated forage, protein forage and green forage, seriously restricts development of the livestock husbandry industry, and even causes food safety problems.

Furthermore, shortage of animal forage resources makes China's import volume of forage grass increase year by year. Oat could be taken as an example. According to data of China Customs, import volume and import price of oat are shown in Figs. 8.1 and 8.2, respectively. Although China's total yield of oat grass has increased year by year, it still could not meet current demand for forage grass of the livestock husbandry industry.

Based on current conditions of forages in China, it is of great significance to find and develop woody forage resources for development of the livestock husbandry industry and improvement of people's living standard.

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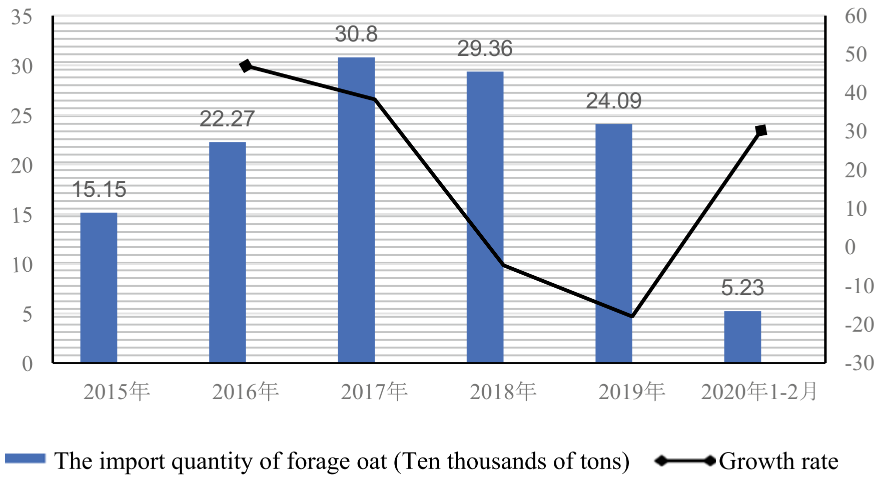

Fig. 8.1 China's import volume of oat grass from 2015 to February 2020

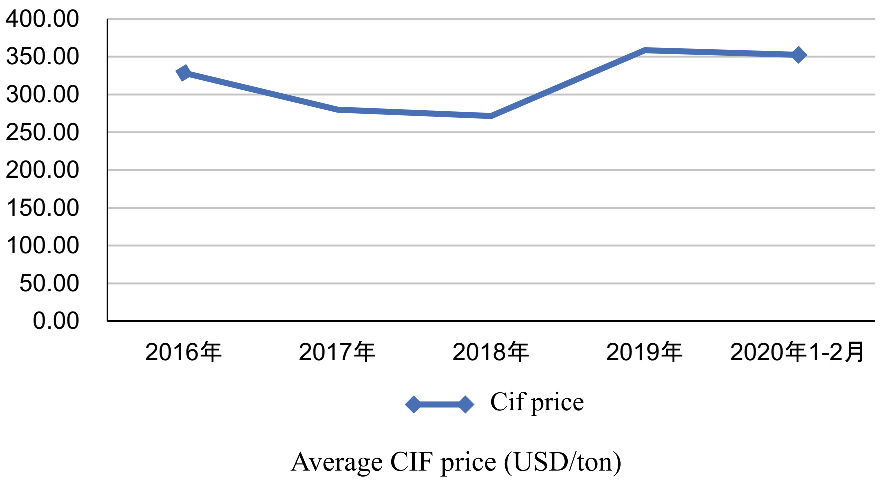

Fig. 8.2 Average CIF price of Oat from 2016 to February 2020 (USD/ton)

8.2 Value and Current Researches of Woody Forage Resources

China is one of the countries with the richest plant species in the world. Among above 8000 species of woody plants, more than 1000 species could be used as woody forages, suggesting abundant woody forage resources. Even if only 10% of China's forage-purpose woody plants are used for forage processing, it is equivalent to 1.5 times of current forage production and grain used in China. Therefore, development and utilization of woody forage resources could effectively relieve shortage of forage raw materials in China, and is of great significance to reduce forage cost.

8.2.1 Concept and Categories of Woody Forages

Woody forages refer to the young leaves, flowers, fruits and seeds of trees, shrubs, semi-shrubs and bamboo plants and their byproducts that can be directly used in grazing or feed livestock and poultries after being collected, mowed or processed, and also known as wood grass internationally. Since ancient times, there has been a tradition of feeding with woody forages in rural areas of China. Among numerous woody forage resources, China's researches on woody forages are mainly concentrated on nutritional value, feeding value and species improvement of *Broussonetia papyrifera, Moringa oleifera Lam.*, *Morus alba L.*, *Neolamarckia cadamba (Roxb.) Bosser*, *Robinia pseudoacacia*, *Hippophae rhamnoides Linn.*, *Caragana korshinskii Kom* and *Leucaena leucocephala.*

8.2.2 Characteristics of Woody Forages

Woody forages feature a long green period, long utilization period, high crude protein content, good quality, high crude fat content and high digestibility, and are rich in mineral elements, amino acids and vitamins. For one thing, compared with herbal forages, woody forages have a higher nutritional value and yield. According to researches, woody forages contain 54.4% more crude protein, 3 times more calcium and 62.5% less crude fiber than herbal forages, with similar average contents of ash and phosphorus. For another, woody forages have a longer green period and yield period. In the absence of herbal forages, woody forages could help maintain high contents of protein and mineral elements. Besides, woody forage trees enter the high-yield period in 2 to 5 years after planting. In case of proper management, they have higher and stable harvests and could be utilized for a long time. Moreover, China's woody forages are characterized by a high nutritional value, strong stress resistance and adaptability, long yield period and high yield. With broad prospects for development of woody forages in China, rational utilization and development of woody forage resources are of great significance to the development of the livestock husbandry industry and the improvement of people's living standard and ecological environment in China.

8.2.3 Nutritional Value of Woody Forages in China

(1) Hybrid *Broussonetia papyrifera*
Researchers found that *Broussonetia papyrifera* leaves contain as high as 20% to 30% of crude protein, which is three times of rice and corn and twice of wheat, with rich contents of amino acids, vitamins, carbohydrates and trace elements. After scientific production and processing, they could be made into complete livestock and poultry forages. In addition, compared with conventional forages, *Broussonetia papyrifera* has about 7.84%, 11.24% and 14.24% higher content of crude ash than alfalfa, soybean and corn, respectively. *Broussonetia papyrifera* fruits contain rich polysaccharide contents of glucose, mannose and arabinose. Therefore, *Broussonetia papyrifera* is a kind of high-quality woody forages with high contents of crude protein, crude ash and crude fat and a low content of crude fiber, and can relieve shortage of protein forage and foreign dependence in China.

(2) *Moringa oleifera Lam.*
Moringa oleifera Lam. contains rich nutrients, such as protein, amino acids, crude fiber, mineral elements and vitamins, as well as a total of 19 amino acids, including 8 essential amino acids needed by the human body. According to researches, different parts of *Moringa oleifera Lam.* have different nutritional components. Specifically, *Moringa oleifera Lam.* seed shells contain 52.36% of crude fiber; its seeds contain 37.8% of protein and 40.12% of crude fat; and its leaves contain 15.12% of sugar, with far higher contents of total flavonoids and vitamin C than other parts. In addition, *Moringa oleifera Lam.* also contains a variety of mineral elements, including Ca, Me, P, K, Na, S, in which calcium content is much higher than milk powder or fresh milk. *Moringa oleifera Lam.* is rich in multiple bioactive substances, including quercetin, kaempferol, chlorogenic acid, glucosinolate, isorhodanate, tannin, saponins, with a good medicinal value as well as hypoglycemic, hypotensive, hypolipidemic, anti-inflammatory, anti-cancer and hepatic protective effects. Due to its rich nutrients and unique application value, *Moringa oleifera Lam.* is internationally known as “tropical natural nutrition bank” and “plant diamond”.

(3) *Morus alba L.*
Morus alba L. leaves boasts rich and balanced nutrients. Dried *Morus alba L.* leaves contain 22–25% of crude protein, which is close to feeding alfalfa and 40–50% higher than other leguminous forage grass. The livestock digestibility for *Morus alba L.* leaves reaches 70–90%. *Morus alba L.* leaves contain 6% of crude fat and 25% of soluble carbohydrate, with lower contents of crude fiber and ash than other feeding leaves. Besides, *Morus alba L.* leaves are rich in anthocyanin, rutin, quercetin, isoquercetin and other flavonoids, and vitamin A, vitamin B, vitamin C, vitamin E, β-carotene, retinol and other vitamins. They also contain 18 amino acids, including γ-aminobutyric acid, aspartic acid and glutamic acid, and more than half of the total content is essential and semi-essential amino acids for animals and protein additives. In addition, alkaloid

(1-deoxynojirimycin) found in *Morus alba L.* leaves could be used to improve nutritional status of animals, with a significant hypoglycemic effect.

(4) *Neolamarckia cadamba (Roxb.) Bosser*
Neolamarckia cadamba (Roxb.) Bosser is native to South Asia and South China. The first five years are the height growth peak period, with an average annual height growth of 3.0–3.5 m; and the first 10 are the diameter growth peak period, with an average annual diameter growth of 3-4 cm. Because of its rapid growth, it is known as the "tree of miracle". Compared with *Leucaena leucocephala, Medicago sativa* and other conventional feeding forage raw materials, *Neolamarckia cadamba (Roxb.) Bosser* leaves features a high crude protein content and low water content in addition to the medicinal value. Therefore, it has the potential to be developed as forages for both ruminants and non-ruminants. According to the findings of Pal et al., mature fruits of *Neolamarckia cadamba (Roxb.) Bosser* contain large amounts of trace elements, with a low content of phosphorus. Besides, they are rich in protein and fat, which can be used to improve the nutritional status of livestock, poultries and people.

(5) *Robinia pseudoacacia*
Robinia pseudoacacia is native to the United States. Its leaves contain 19–23.3% of crude protein, 2.4–4.3% of crude fat, 13.7–15.7% of crude fiber and 3.6 g/100 g Ca. *Robinia pseudoacacia* flowers are a forage additive with a strong palatability. With a strong sprouting ability, a mowed *Robinia pseudoacacia* forest could yield up to 3000 kg/hm^2 of leaves, indicating one-time input and years of yields. With a fast growth rate, strong sprouting ability and advanced root system and certain drought and flood resistance and saline-alkaline tolerance, *Robinia pseudoacacia* is one of common tree species for soil improvement, water and soil conservation, windbreak and sand fixation and surrounding afforestation as well as one of important fast-growing timber tree species.

(6) *Hippophae rhamnoides Linn.*
With the largest planting area of *Hippophae rhamnoides Linn.* in the world, China boasts 1.37 million hm^2 of wild *Hippophae rhamnoides Linn.* and about 90% of world's wild *Hippophae rhamnoides Linn.* resources at present. *Hippophae rhamnoides Linn.* is a livestock and poultry forage resource with a variety of nutrients, rich content and a high nutritional value. Researches have shown that *Hippophae rhamnoides Linn.* leaves contain 11.47–22.92% of crude protein and 4.69% of crude fat and are rich in a large amount of trace elements, and amino acids and vitamins that are essential to animals (vitamin C mass is 1270 mg/kg). Therefore, *Hippophae rhamnoides Linn.* leaves are a good forage or forage additive. *Hippophae rhamnoides Linn.* branches and leaves could stimulate oral mucous membrane receptor of animals, and increase saliva secretion, stomach acidity, digestion and intestinal fluid peristalsis function, with significant effects in preventing and treating gastrointestinal diseases.

(7) *Caragana korshinskii Kom*
Caragana korshinskii Kom is a kind of perennial shrub that belongs to the Caragana genus (Leguminosae), with wide varieties of species. Its nutrients

have high contents of crude protein and crude fiber and rich amino acids, making it a high-quality forage shrub. According to researches, the nutritional value of *Caragana korshinskii Kom* grass meal is superior to that of silage corn, maize straw, wheat straw and national standard first-grade alfalfa powder, and could be comparable to that of alfalfa. Some researches have showed that *Caragana korshinskii Kom* leaves have a leaf protein concentrate (LPC) yield of 15.4% and LPC protein content of 31.5%, and contain a variety of amino acids. Its chemical score reaches 58.6%, which is higher than 43% of corn and 40% of wheat. In addition, *Caragana korshinskii Kom* contains anti-nutritional factors and high contents of crude fiber and lignin in its stems, which restricts its application in animal production to a great extent.

(8) *Leucaena leucocephala*
Leucaena leucocephala boasts a high foliage volume. Its tender branches occupy more than 60% of the total weight, and are available all year round. With a good palatability, they are preferred by cattle, sheep and rabbits. Dried branches could be made into grass meal and used to feed pigs and poultries. *Leucaena leucocephala* could be mowed alone or sowed with gramineous forage grass for the use of grazing. Its amino acid content is similar to alfalfa, while the carotene content (536 mg/kg) is twice higher than alfalfa.

8.2.4 Problems in Woody Forages

(1) Anti-Nutritional Factors (ANF)
In the utilization of woody forages, the utilization effect of woody forages would be affected by different harvesting sites, harvesting seasons and harvesting methods. Furthermore, the type and contents of anti-nutrient factors in woody forages, commonly including tannin, lignin, trypsin inhibitor, phytic acid, oxalic acid and saponin, would also affect palatability of animals and reduce animal growth performance and product quality. By means of affecting animals' feed intake and palatability and combining with macromolecular organic matters, these anti-nutritional factors reduce animals' digestion and absorption of nutrients in forages and impact production performance and health status of livestock and poultries, which is mainly reflected in decrease in protein digestion and utilization rates, mineral dissolution, palatability and feed intake.

Anti-trophic factors in woody forages could be processed by physical, chemical and biological methods to reduce their contents. For example, woody plants could be processed by means of silage, microbial silage and microbial fermentation to reduce the contents of anti-nutrient factors; and saponins and trypsin inhibitor could be processed by water boiling.

(2) Insufficient Parameters of Optimum Ratio and Dosage
In general, woody forages are added in proportion to basic ration of livestock and poultries or used to replace part of conventional forage raw materials under

the premise of meeting nutritional requirements of livestock and poultries. In fact, the proportion of woody forages in ration of livestock and poultries plays an important role in guaranteeing the safety of forages. Rational forage composition could maximize the nutritional value of woody forages, while avoiding the negative combination effect. For example, fresh *Morus alba L.* leaves have a higher moisture content and can be mixed with low-moisture forages. Due to the difference of demands of various animals in each growth stage and the change of seasons, the amount of woody forages in ration shall be adjusted in time to ensure adequate and balanced nutrition of livestock and poultries. Therefore, in order to further determine the optimum ratio and usage of woody forages in ration of livestock and poultries, a great number of research experiments shall be conducted in the days to come.

(3) Small Scale Planting, Immature Processing Techniques
In China, development and utilization of woody forages are still in the scientific experimental stage, and a lot of high-quality forage-purpose woody resources have not aroused widespread attention, which leads to the failure of large-scale production. Because conventional processing techniques are outdated and less innovative, with high energy consumption, both the utilization rate of woody forage raw materials and the forage conversion rate remain low in China. It is suggested to select suitable woody forage resources in the locality and artificially cultivate them on a large scale. In addition to continuous improvement of conventional techniques, efforts shall be made to accelerate the mechanization process, improve the innovation strengthen in biological fermentation technology and raise the development and utilization of woody forage resources to the strategic level during the production and development of the livestock husbandry industry.

8.2.5 Brief Summary

Woody forages have significant advantages of a high nutritional value and great development potential. Their anti-nutritional factors could be reduced by such techniques as silage and fermentation, and then woody forages could be added in an appropriate proportion to feed various animals. Sufficient development of woody plants, efficient utilization of woody forages and continuous improvement of industrial structure in practice play a vital role in establishing a grain-saving forage industry and promoting green and sound development of the livestock husbandry industry in China. To this end, we must make technological innovations by relying on scientific and technological progress, actively introduce, digest and absorb advanced techniques and equipment at home and abroad, strengthen policy guidance, and expand the planting area of woody forage plants and the scale of the processing industry, in a bid to realize large-scale and industrialized production of woody forages in China. In the future, researches will focus on applying the existing woody plant resources in the livestock and poultry industry and developing more woody forages in a mature and steady manner.

8.2.6 Ensiling Technology for Woody Forages

Woody forages could be used as quality protein sources as their relatively high protein content (more than 180 g/kg DM) and relatively low fiber content (neutral detergent fiber is about 300 g/kg DM or lower) (Table 8.1) (He et al. 2019b; Wang et al. 2019a; Zhang et al. 2019). Ensiling is an important method to preserve the moist woody forage, especially in rainy season, when drying forage is difficult. Moreover, woody forages like *M. oleifera* and *N. cadamba* were planted in tropical or subtropical regions, where the rain is plentiful almost all the year around. Therefore, an effective ensiling technology is vital for production of high quality woody forage silage. However, these woody forages are not easy to ensile without proper treatments. The moisture contents of *M. oleifera* and *N. cadamba* are too high to ensile. Nutrition loss caused by effluent might be produced during packing if ensiling directly. The number of *M. alba* lower than 5.00 $\log_{10}$ cfu/g FM, which is necessary for well-preserved silage. Furthermore, undesirable microorganisms like coliform bacteria are abundant on these forages. Exogenous lactic acid bacteria inoculants might be helpful to accelerate fermentation and inhibit undesirable microorganisms as quickly as possible. Woody forages like *B. papyrifera* are low content in water soluble carbohydrates. Therefore, developing ensiling technologies is necessary for preservation of these woody forages. More attention should be paid to key points like wilting, inoculation, ensiling time and storage temperature before or during ensiling.

Table 8.1 Chemical composition and microbial population of woody forages prior to ensiling

Item	*M. oleifera*	*M. alba*	*N. cadamba*	*B. papyrifera*
Dry matter (g/kg FM)	245	357	276	340
Crude protein (g/kg DM)	264	188	180	231
Neutral detergent fiber (g/kg DM)	257	278	303	285
Acid detergent fiber (g/kg DM)	176	161	227	183
Water soluble carbohydrate (g/kg DM)	99.0	122	50.8	18.7
Lactic acid bacteria ($\log_{10}$ cfu/g FM)	5.36	4.75	<2.00	5.47
Yeasts ($\log_{10}$ cfu/g FM)	<2.00	4.33	<2.00	5.47
Molds ($\log_{10}$ cfu/g FM)	3.71	–	–	–
Coliform bacteria ($\log_{10}$ cfu/g FM)	5.78	6.03	<2.00	5.44

FM fresh matter, *DM* dry matter, – not analyzed

Wilting

Generally, the moisture content of fresh forage is about 25%, which is too high to ensile directly. Dry matter loss caused by respiration of water soluble carbohydrates and quality loss caused by degradation of protein by plant enzymes could be reduced by wilting. Woody forages should be wilted for 5–8 h to about 65% moisture content after harvest. Fermentation characteristics including pH value, lactic acid content were significantly affected by wilting. Undesirable microorganisms like coliform bacteria could be inhibited by wilting. Research indicates that wilting has little effect on fermentation characteristics of *M. oleifera* and *N. cadamba* silage like pH value, lactic acid (Tables 8.2 and 8.3), but inhibits the activity of coliform bacteria at early stage of ensiling (Fig. 8.3) (Wang et al. 2019b). Furthermore, effluent could be avoided during ensiling process. On the other hand, the relatively dry materials

Table 8.2 Chemical compositions and fermentation characteristics of wilted and unwilted *M. oleifera* leaves silage

Items	Unwilted	Wilted	Significances
pH	3.82	3.93	NS
Lactic acid (g/kg DM)	126	105	NS
Acetic acid (g/kg DM)	1.33	9.19	**
Propionic acid (g/kg DM)	9.05	52.73	**
Butyric acid (g/kg DM)	ND	ND	–
Lactic acid bacteria ($\log_{10}$ cfu/g FM)	5.03	<2.0	**
Yeasts ($\log_{10}$ cfu/g FM)	4.80	3.15	**
Coliform bacteria ($\log_{10}$ cfu/g FM)	<2.00	<2.00	–

DM dry matter, *FM* fresh matter, *ND* not detected, – not analyzed, *significant at $p < 0.05$, **significant at $p < 0.01$, *NS* not significant

Table 8.3 Organic acids content, pH and microbial population of *Neolamarckia cadamba* leaf silage in different treatments

Item	Unwilted	Wilted	Significances
Dry matter (g/kg)	215	308	**
pH	4.18	4.19	**
Lactic acid (g/kg DM)	53.7	68.7	NS
Acetic acid (g/kg DM)	8.80	ND	**
Butyric acid (g/kg DM)	ND	ND	–
Lactic acid bacteria ($\log_{10}$ cfu/g FM)	5.79	5.20	**
Yeasts ($\log_{10}$ cfu/g FM)	2.88	3.34	**
Coliform bacteria ($\log_{10}$ cfu/g FM)	<2.00	<2.00	–

DM dry matter, *FM* fresh matter, *ND* not detected, – not analyzed, *significant at $p < 0.05$, **significant at $p < 0.01$, *NS* not significant

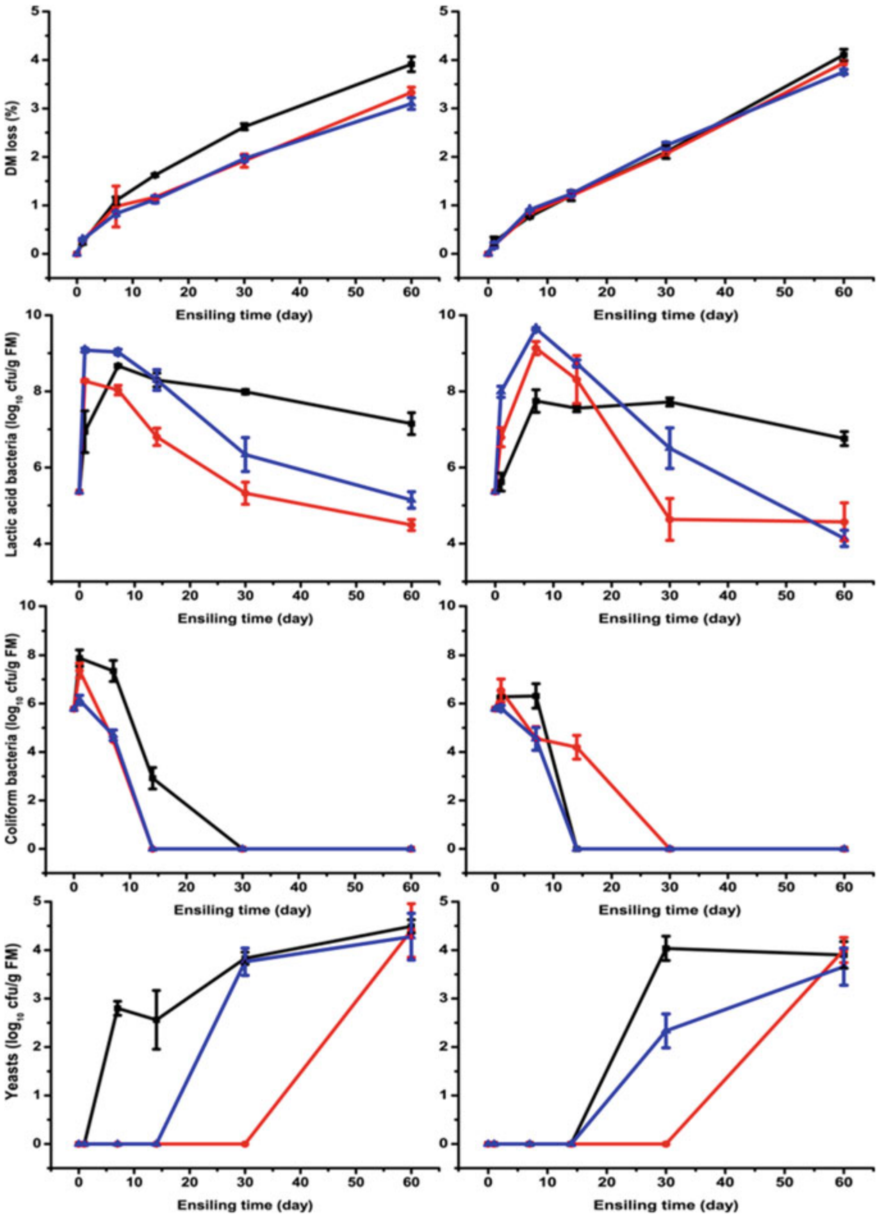

Fig. 8.3 DM loss, count of lactic acid bacteria, coliform bacteria and yeasts of unwilted (left) and wilted (right) *M. oleifera* leaves ensiled without (■, black line) or with *Lactobacillus farciminis* LF (●, red line) or *Lactococcus lactis* LL (▲, blue line) after 1, 7, 14, 30 and 60 days of ensiling, respectively

like *Morus alba* need not wilting. It is difficult to compact for very dry forages. The poorly compacted silages are more aerobically unstable due to greater risk of yeasts and moulds caused by higher oxygen and water soluble carbohydrates residue. Subsequently, the material should be chopped to 1–2 cm after wilting.

Inoculation

Lactic acid bacteria are main sponsors of silage fermentation. To accelerate lactic acid fermentation and obtain high quality, it is necessary to add exogenous lactic acid bacteria and guarantee the dominance of lactic acid bacteria at initial period of ensiling. Lactic acid bacteria strain isolated and screened from woody forage silage could be used as an effective additive to promote fermentation of woody forages. Strains in genera like *Lactobacillus plantarum*, *L. farciminis*, *Lactococcus lactis*, *Weissella thailandensis* were proved to be effective. The lactic acid bacteria powder was prepared by propagation and lyopilization in skim milk. These lactic acid bacteria strains should be dissolved in distilled water for 20 min. After that, spray it to chopped material to achieve a dose of 5 log cfu/g fresh matter. Studies have shown that lactic acid bacteria inoculants could increase lactic acid content and decrease pH value and acetic acid content of *B. papyrifera* and *M. alba* silage (Tables 8.4 and 8.5). Moreover, the addition of these inoculants also inhibits undesirable microorganisms like coliform bacteria at early stage of ensiling, thus decreases the dry matter loss and the relative abundance of *Enterobacter* in *M. oleifera* silage (Figs. 8.3 and 8.4) (He et al. 2019a; Wang et al. 2019c). Water soluble carbohydrate sources like molasses, sucrose or cellulose could be added with lactic acid bacteria to obtain a better result. After thorough mixing, the material should be packed in silos immediately. Exclude oxygen from the silage mass as quickly as possible. To obtain better silage quality, the chopped forages should be packed at high density. Generally, packing density higher than 500 kg/m^3 should be achieved. Less oxygen will decrease the abundance of aerobic microorganisms present in these woody forages. Furthermore, it is known that rapid filling of the silo minimizes nutrient loss. So seal the silos as quickly as possible.

Table 8.4 Effect of lactic acid bacteria inoculant on fermentation quality and microbial population of mulberry leaves silage

Item	Non-inoculated	Inoculated	Significances
Dry matter (%)	29.44	31.04	**
pH	4.60	4.03	**
Lactic acid (g/kg DM)	4.16	5.95	**
Acetic acid (g/kg DM)	1.07	0.84	**
Lactic acid bacteria ($\log_{10}$ cfu/g FM)	8.31	6.43	*
Yeasts and Molds ($\log_{10}$ cfu/g FM)	<2.00	<2.00	–
Coliform bacteria ($\log_{10}$ cfu/g FM)	<2.00	<2.00	–

DM dry matter, *FM* fresh matter, – not analyzed, *significant at $p < 0.05$, **significant at $p < 0.01$, *NS* not significant

Table 8.5 Effects of lactic acid bacteria inoculant on fermentation quality and microbial population of mulberry silage

Item	Non-inoculated	Inoculated	Significances
Dry matter (g/kg DM)	284	290	*
pH	4.64	4.53	**
Lactic acid (g/kg DM)	55.2	60.7	**
Acetic acid (g/kg DM)	30.6	25.6	**
Lactic/acetic acid	1.80	2.37	**
Propionic acid (g/kg DM)	16.0	13.4	**
Lactic acid bacteria (log_{10} cfu/g FM)	6.12	5.77	**

DM dry matter, *FM* fresh matter, *significant at $p < 0.05$, **significant at $p < 0.01$

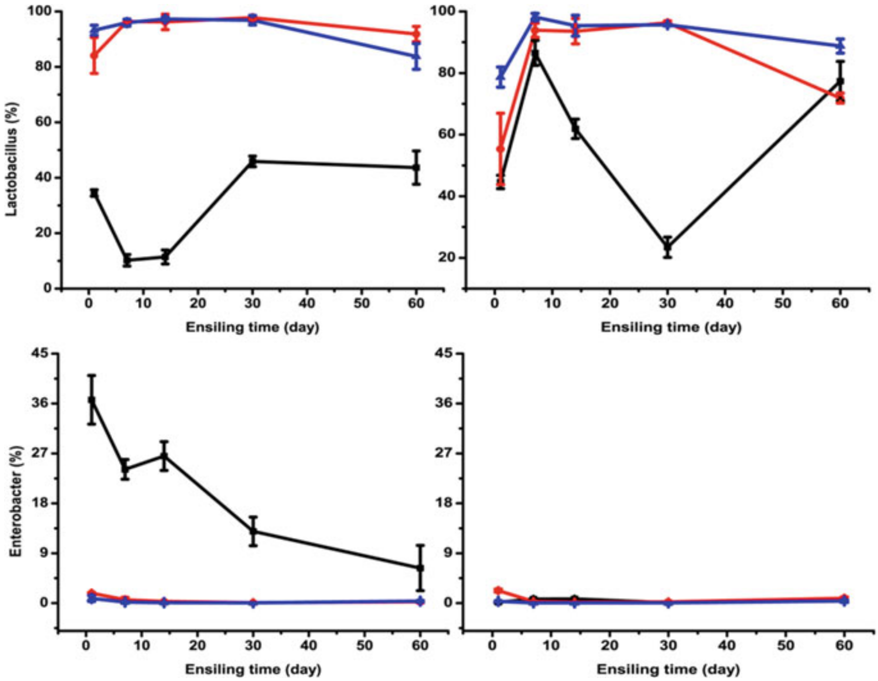

Fig. 8.4 The relative abundance of *Lactobacillus* and *Enterobacter* of unwilted and wilted *M. oleifera* leaves ensiled without (■, black line) or with *Lactobacillus farciminis* LF (●, red line) or *Lactococcus lactis* LL (▲, blue line) after 1, 7, 14, 30 and 60 days of ensiling, respectively

Chemical Additives

Chemical additives are very easy for the users and they are effective for various moisture levels. Chemicals such as formic acid, propionic acid, tannic acid and gallic acid have been added to woody forages to improve silage quality because they have good antimicrobial attributes and protein protection ability. In a published study from our group (He et al. 2019a), the addition of formic acid improved dry matter recovery and decreased pH and the number lactic acid bacteria of *N. cadamba* leaves silage (Table 8.6). Propionic acid not only enhanced the fermentation quality of the mixture of rice straw and *M. oleifera* leaves silage, but also inhibited the proteolysis by decreasing the content of ammonia-N and nonprotein-N (Table 8.7) (He et al. 2020c). The addition of 2% gallic acid also improved fermentation quality of mulberry leaves silage illustrated by lower dry matter loss, pH value, butyric acid and ammonia-N content and coliform bacteria number, higher lactic acid content (Table 8.8) (He et al. 2020a). Furthermore, tannic acid and gallic acid also increased the antioxidant activities of *M. oleifera* leaves silage (He et al. 2020b). Therefore, chemicals like formic acid and gallic acid could be used as effective additives for woody forage silage. While safety problems should be paid attention to at application.

Table 8.6 Effects of 0.2% formic acid on fermentation quality and microbial population of *N. cadamba* leaves silage

Item	CK	Formic acid	Significances
Dry matter recovery (%)	85.8	90.4	**
pH	4.03	3.80	**
Lactic acid (g/kg DM)	20.2	11.5	**
Acetic acid (g/kg DM)	59.3	ND	**
Propionic acid (g/kg DM)	ND	ND	**
Lactic acid bacteria ($\log_{10}$ cfu/g FM)	6.34	<2.00	**
Coliform bacteria ($\log_{10}$ cfu/g FM)	<2.00	<2.00	–

DM dry matter, *FM* fresh matter, *ND* not detected, *significant at $p < 0.05$, **significant at $p < 0.01$

Table 8.7 Effects of 0.2% propionic acid on fermentation quality and microbial population of the mixture of rice straw and *M. oleifera* leaves (3:1) silage

Item	CK	Gallic acid	Significances
Dry matter (g/kg FM)	243	252	**
pH	4.20	3.77	**
Lactic acid (g/kg DM)	18.1	18.2	NS
Acetic acid (g/kg DM)	7.86	6.73	NS
Butyric acid (g/kg DM)	10.0	ND	**
Lactic acid bacteria ($\log_{10}$ cfu/g FM)	7.38	5.75	**
Coliform bacteria ($\log_{10}$ cfu/g FM)	<2.00	<2.00	**
Ammonia-N (g/kg DM)	2.17	1.49	**
True protein (g/kg DM)	46.0	55.4	**

DM dry matter, *FM* fresh matter, *ND* not detected, *significant at $p < 0.05$, **significant at $p < 0.01$, *NS* not significant

Table 8.8 Effects of 2% gallic acid on fermentation quality and microbial population of mulberry leaves silage

Item	CK	Gallic acid	Significances
Dry matter loss (%)	6.08	5.35	**
pH	6.51	5.98	**
Lactic acid (g/kg DM)	22.7	66.8	**
Acetic acid (g/kg DM)	16.8	29.6	**
Butyric acid (g/kg DM)	4.10	ND	**
Lactic acid bacteria (log_{10} cfu/g FM)	7.61	6.65	**
Coliform bacteria (log_{10} cfu/g FM)	6.42	<2.00	**
Ammonia-N (g/kg TN)	7.11	1.94	**

DM dry matter, *FM* fresh matter, *TN* total N, *ND* not detected, *significant at $p < 0.05$, **significant at $p < 0.01$

Storage Temperature

A relatively high temperature is favourable to clostridium and it might induce butyric acid fermentation during ensiling. The temperature also have an influence on the fermentation quality of woody forages and proper environmental temperature is very important for microbial fermantation during ensiling. It is well known that metabolism and viability of the bacteria are limited if temperature is above the optimum. Our previous study reported that *M. oleifera* silage stored at 30 °C showed a similar pH but far more proteolysis than silage stored at 15 °C (Table 8.9). And the *Lactobacilli* were more abundant in silages stored at 15 °C (Fig. 8.5) (Wang et al. 2019c). These results indicate it is difficult to obtain high quality silage under

Table 8.9 Fermentation quality of *Moringa oleifera* leaves silage stored at different temperatures

Items	15 °C	30 °C	Significances
Dry matter (g/kg FM)	212	218	**
Dry matter loss (%)	2.25	4.62	**
pH	4.03	4.03	NS
Lactic acid (g/kg DM)	22.9	38.0	**
Acetic acid (g/kg DM)	8.16	10.1	*
Lactic/acetic acid	2.80	3.77	*
Butyric acid (g/kg DM)	ND	ND	–
Ammonia-N (g/kg TN)	9.94	33.3	**
Lactic acid bacteria (log_{10} cfu/g FM)	8.27	5.00	**
Coliform bacteria (log_{10} cfu/g FM)	<2.00	<2.00	–
Yeasts and Molds (log_{10} cfu/g FM)	<2.00	<2.00	–

FM fresh matter, *DM* drymatter, *TN* total N, ND, not detected, – not analyzed, *significant at $p < 0.05$, **significant at $p < 0.01$, *NS* not significant

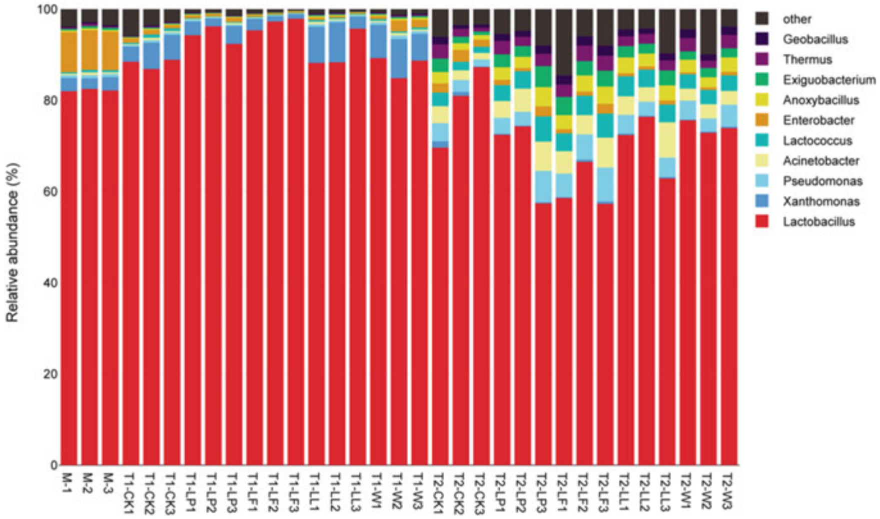

Fig. 8.5 Bacterial community and relative abundance by genus for *Moringa oleifera* leaves silage treated with LAB inoculants (M, material; CK, control; LP, *Lactobacillus plantarum*; LF, *Lactobacillus farciminis*; LL, *Lactococcus lactis*; W, *Weissella thailandensis*) and stored at 15 °C (T1), 30 °C (T2)

extremely hot and humid conditions. On the other hand, the relatively high temperature may also reduce the efficacy of a silage inoculant. Moreover, silages tend to be more aerobic unstable under higher temperature. Therefore, silages should be kept in dry, cool place and avoid direct sunlight.

Ensiling time

As is known to all, the ensiling process is divided to several phases. Fermentation quality changes with the ensiling time. Studies have shown that fermentation characteristics of *N. cadamba* and *M. alba* silage changed with the ensiling time prolonged. pH value decreased and organic acids accumulated with the ensiling time. The numbers of undesirable microorganisms like coliform bacteria became lower and lower (Tables 8.10 and 8.11) (He et al. 2019a; Wang et al. 2019b). Based on fermentation and microbial population of these forages during ensiling, 30–60 days is necessary for sufficient fermentation. During this period, check regularly for damage to the seal and repair immediately.

8.2.7 Feeding Utilization of New Woody Forage Resources

Paper mulberry, forage mulberry, moringa and so on are main woody forage resources. In China's rural areas, it has long been for feeding animals with the leaves of paper mulberry. As a new type of unconventional protein feed resources, forage

Table 8.10 Fermentation quality of mulberry leaves silage during ensiling

Item	Ensiling days					Significances
	1	7	14	30	60	
pH	7.26	6.71	5.60	4.69	4.46	**
Lactic acid (g/kg DM)	0.83	2.68	2.66	4.53	4.27	**
Acetic acid (g/kg DM)	0.11	3.60	3.45	3.50	2.75	**
Propionic acid (g/kg DM)	ND	ND	ND	ND	ND	–
Butyric acid (g/kg DM)	ND	ND	ND	ND	ND	–
Lactic acid bacteria (log_{10} cfu/g FM)	6.46	8.47	9.02	8.38	8.44	**
Yeasts (log_{10} cfu/g FM)	3.76	2.82	<2.00	<2.00	<2.00	NS
Coliform bacteria (log_{10} cfu/g FM)	6.07	7.93	6.87	4.97	3.12	**

DM dry matter, *FM* fresh matter, *ND* not detected, – not analyzed, *significant at $p < 0.05$, **significant at $p < 0.01$, *NS* not significant

Table 8.11 Fermentation quality of *Neolamarckia cadamba* leaves silage during ensiling

Item	Ensiling days						Significances
	1	3	7	14	30	60	
Dry matter recovery (%)	99.5	98.6	93.9	91.3	89.1	85.8	**
pH	4.27	4.32	4.23	4.19	4.13	4.03	**
Lactic acid (g/kg DM)	9.97	12.3	14.7	16.5	18.1	20.2	**
Acetic acid (g/kg DM)	ND	ND	ND	33.1	52.2	59.3	–
Butyric acid (g/kg DM)	ND	ND	ND	ND	ND	ND	–
Lactic acid bacteria (log_{10} cfu/g FM)	5.85	7.35	7.33	7.11	7.66	6.34	–
Coliform bacteria (log_{10} cfu/g FM)	6.44	5.77	<2.00	<2.00	<2.00	<2.00	–

FM fresh matter, *DM* dry matter, *ND* not detected, "–" not analyzed, *significant at $p < 0.05$, **significant at $p < 0.01$

mulberry has high ecological value and feeding value, and its development prospect is very broad. Moringa leaf has high protein content and rich nutrition. It can replace a certain amount of protein feed in animal feed, which is a hot spot in the development of woody feed resources.

Woody paper mulberry (*Broussonetia papyrifera*)

Woody paper mulberry feed for growing pigs

The new woody forage usually contains some bioactive substances, which has a positive effect on animal health. For example, the leaves of paper mulberry contain a variety of flavonoids, alkaloids, polysaccharides, unsaturated fatty acids and other active components, which can resist oxidation and inhibit the expression of tumor genes such as breast cancer and prostate cancer. The main problem of woody forage is that the content of crude fiber is high, especially in the branches and leaves with longer growth period, and the lignin content increases significantly, which is difficult to be digested and absorbed by monogastric animals. At the same time, many kinds of woody forage, such as the leaves of paper mulberry, contain some anti-nutritional factors, which will affect the digestion and utilization of nutrients. The tannin content in paper mulberry leaves was 15.5 mg/g, which was more than twice that of alfalfa. Tannin has a strong binding effect. When combined with various nutrients in the diet, such as crude protein, polysaccharides, minerals, etc., insoluble precipitates will be formed, which will reduce the available nutrients of livestock and poultry, and affect the palatability of feed. Fermentation technology can reduce the crude fiber content of woody forage, increase the content of short chain fatty acids and sugars, significantly reduce the content of tannin and other anti-nutritional factors, and improve the protein quality. The fermented woody forage can be used in ruminant livestock such as cattle and sheep, as well as pig and poultry feed with good effect.

8.3 Effect of New Woody Forage in Cattle and Sheep Feeding

The paper mulberry branch and leaf can be used as an important forage for cattle and sheep. The rumen degradation rate of the paper mulberry was 86.77 and 94.29% at 24 and 48 h, which could provide more protein and higher digestibility for ruminant. The average daily food intake of West African dwarf sheep was 0.04 kg higher than control by adding the leaf of paper mulberry composition directly to the basic diet ($p < 0.05$). At the same time, the blood routine test did not show abnormal changes. Compared with the conventional feed group, the black goat was fed with the paper mulberry silage feed, and the body length was longer than that of the control group, and the average feed cost of a black goat was significantly lower than that of the control group ($p < 0.05$). However, for Sahan crossbred sheep, the protein feed was replaced by silage hybrid paper mulberry leaves. With the increase of the replacement quantity, the excretion of the sheep increased with the same daily weight gain, and the feed digestibility decreased. The milk yield was increased by adding 4, 8 and 12% paper mulberry leaves to diet of Holstein dairy cows, and that of 12% addition group was the highest of all.

Moringa stem can be used in dairy cattle and beef cattle production, and could promote animal growth and improve animal health and improve meat quality and milk quality. The best addition rate in dairy and beef cattle was 6%. Moringa feed could significantly improve milk production, increase the milk fat rate, the total solid content of milk, reduce the number of milk cells; improve the growth performance of beef cattle, increase the output of rumen volatile fatty acids, change the proportion of volatile fatty acids, increase the proportion of propionic acid, reduce the proportion of acetic acid, and improve the blood antioxidant index and the antioxidant index in meat ($p < 0.05$). The ratio of unsaturated fatty acids in meat was increased and the ratio of n-6: n-3 was decreased.

The content of alkaline and neutral amino acids in mutton could be increased by adding 47% of mulberry leaves to diet. Feeding mulberry as green feed to sheep can effectively improve the micro ecological environment of rumen, promote the growth and reproduction of the rumen fiber decomposing bacteria, improve the feed intake of mutton, and improve its production performance. Forage mulberry can also be used for feeding sheep after silage. Cut forage mulberry at 70–100 cm and dry them to reduce water content below 60%, then add lactobacillus to make silage, which can be used as silage for ruminant animals such as cattle and sheep. After drying, mulberry can be used as high-quality feed in sheep diet, which can replace some fine feed such as bean cake and corn. The economic benefit of adding mulberry leaves to feed the fattening sheep was higher than that of single corn grain, and the palatability of the feed was improved.

Caragana microphylla is a legume shrub with large yield, wide distribution and rich protein content. The crude protein of Caragana microphylla can reach 23% at flowering stage, and it also contains many bioactive substances, which has high nutritional value. The branch of Caragana microphylla could be processed to high quality green roughage feed by the method of flat stubble, which could effectively solve the problem of high quality roughage feed shortage for sheep, so as to provide support and guarantee for changing the traditional grazing mode in the pastoral area and realizing intensive management. The addition of 30% Caragana microphylla to the diet of sheep does not affect the growth performance of the animals, but also increases the breeding income. Although the addition of Caragana microphylla to the diet of mutton had no significant effect on its growth and slaughter performance, from the perspective of economic benefits, 30% of the added amount could improve the income of the farmers.

The branches and leaves of anthocephalus chinensis are dense, the leaf area is large and the edible parts for ruminants are more. Fresh anthocephalus chinensis has good palatability, and the effect of feeding Ledo black goat directly is good. The different proportions of silage to diet could improve the growth performance, slaughtering performance and meat quality of black goat during the fattening period. The effect of replacing the whole plant silage corn with 50% of silage anthocephalus chinensis was better.

8.4 Effect of New Woody Forage in Pig Feeding

The woody forage fresh leaf, or dry leaf powder could be used in pig feeding. The apparent digestibility of total energy, crude fat, crude protein and nitrogen-free extract of paper mulberry in the diet of growing pigs was different from that of corn, wheat bran, soybean meal and rice, but the protein content was only lower than that of soybean meal, and the digestibility of crude protein was close to that of corn. The addition amount of leaves less than 20%, could improve the meat quality and average daily gain of growing finishing pigs, and reduce the breeding cost. Many studies have found that 10–15% leaves of paper mulberry can significantly increase the average daily gain of fattening pigs. When the ratio reached 10%, the back fat thickness decreased significantly ($p < 0.05$), the free amino acids and sodium glutamate which could improve the meat quality increased significantly, and the meat color was also improved; when the ratio reached 20%, the average daily gain decreased significantly.

Moringa leaves can be used in pig production, which can promote animal growth and improve animal health. At the same time, it can improve meat quality. The optimum amount of moringa was 6%. Moringa feed can significantly improve the growth performance of finishing pigs, improve the conversion efficiency of feed, reduce the thickness of back fat, improve the antioxidant indexes in blood and meat, increase the proportion of unsaturated fatty acids in meat, and reduce the ratio of n-6:n-3.

8.5 Effect of New Woody Forage in Poultry Feeding

Poultry could digest some woody forage fresh leaf or dry leaf powder. Hybrid paper mulberry is mainly used in the production of geese, high-quality chickens (chicks and breeders) and laying hens. Adding 1.5–2% paper mulberry leaves to the feed can enhance the immunity of 3–9 weeks old layers to Newcastle disease, and can also immunize 4–9 weeks old layers from H5N1 avian influenza. Adding different levels (0.5, 1, 1.5, 2%) of paper mulberry leaves in the middle laying period could increase egg weight, and the 2% group had the best effect ($p < 0.05$); The egg production rate was improved in all experimental groups, but there was no significant effect on feed intake and feed / egg ratio ($p > 0.05$). The yolk color, eggshell relative weight and eggshell thickness of 1.5% addition group were significantly better than those of control group ($p < 0.05$). When 2–6% paper mulberry leaf powder was added to the diet of Liangfeng chicken, the serum albumin content was significantly increased, the protein production of synthetic muscle was promoted, and the growth performance was improved.

Goose is a kind of herbivorous poultry and it can intake some woody forage silage. There was no significant difference in egg weight, dead panning rate and egg laying rate of Wanxi White Geese fed with silage paper mulberry branches and leaves replacing 25% rice bran ($p > 0.05$); there were no significant differences in the qualified rate of breeding eggs, fertilization rate and hatching rate of fertilized eggs between the control group and the experimental group ($p > 0.05$); there were also no significant differences in egg shape index, Haugh unit and eggshell thickness ($p > 0.05$), but the yolk color was significantly improved ($p < 0.05$). It is suggested that the branches and leaves of paper mulberry silage can be used as feed materials for goose breeding in winter and spring.

Moringa belongs to high fiber feed. The recommended addition ratio of moringa in Qingyuan geese diet is less than 6%. The carcass rate, breast muscle rate, leg muscle rate and abdominal fat rate of 70 days old Qingyuan geese were significantly affected by adding different amounts of moringa stem powder in diet. With the increase of moringa adding ratio in diet, the carcass rate of geese showed a downward trend ($p < 0.05$); when the dosage of moringa stem powder reached 6%, the leg muscle rate of geese was significantly higher than that of the control group ($p < 0.05$); when the dosage reached 10%, the abdominal fat rate was significantly lower than that of the control group ($p < 0.05$). The chest muscle rate was significantly higher than that of the control group ($p < 0.05$). Moringa leaf also has no negative effect on Wenchang chicken production.

As animal feed, forage mulberry not only can effectively alleviate the shortage of traditional protein raw materials, but also can effectively improve the quality of animal products and increase the content of amino acids and fatty acids in meat products. In the production of broilers, adding mulberry leaf powder not only increased the daily feed intake of broilers, but also reduced the contents of intramuscular fat and saturated fatty acids, and increased the contents of total unsaturated fatty acids and ω—3 polyunsaturated fatty acids. Adding 10% mulberry leaf powder to broiler diet can effectively improve the average daily gain and feed conversion rate of broilers. At the same time, adding only 3% mulberry leaf powder to broiler diet can significantly reduce the contents of thiobarbituric acid reactive substances and volatile basic nitrogen in muscle, and improve the meat quality of broilers. The results showed that the activity of alanine aminotransferase (ALT) in serum was significantly decreased, the total protein in serum was increased, the contents of total cholesterol and triglyceride in serum and liver were decreased, and the antioxidant level of serum and liver was increased. At the later growth stage of bearded chicken, the addition amount of mulberry leaf powder in diet was increased to 10%, and that of fermented mulberry leaf powder was increased to 20%, and it did not affect the production performance and was beneficial to improve the quality of bearded chicken. In the production of laying hens, adding mulberry leaf powder to the diet can effectively improve the color of egg yolk and improve the sensory properties of eggs. With the increase of mulberry leaf powder in the diet, the effect is more obvious. Adding mulberry leaf powder to the diet of laying hens can significantly reduce the broken egg rate, but with the increase of mulberry leaf powder, egg production and feed utilization rate have a downward trend; adding mulberry leaf powder to layer diet can significantly increase the content of polyunsaturated fatty acids and ω—6 fatty acids in yolk, which is conducive to improving the nutritional value of eggs. Adding mulberry leaf powder to the diet of laying hens can improve the proportion of fatty acids in egg yolk, improve the flavor and taste of eggs, and the appropriate addition amount is 5–7.5%. Adding 10% mulberry leaf powder to layer diet can effectively reduce the concentration of ammonia in chicken manure and improve the breeding environment of chicken house. In addition, adding 1.5% mulberry leaf powder to the diet of laying hens can completely prevent and control chicken pecking habit. However, when the mulberry leaf powder is too high, the laying rate and egg quality of laying hens will be reduced.

Forage mulberry is widely used not only in chickens and ducks, but also in meat geese. Adding a small amount of mulberry leaf powder in Qingyuan goose diet can reduce the serum triglyceride and serum cholesterol content. When the mulberry leaf powder ratio is more than 3%, the production performance of geese will be reduced. When the amount of mulberry leaf powder is more than 6%, the contents of serum glutamic pyruvic transaminase and serum globulin of Qingyuan goose will be significantly increased. After feeding Wanxi White geese with mulberry leaf powder, the feed to weight ratio and production performance were significantly reduced, but the abdominal fat rate was significantly reduced, and the half eviscerated rate, full eviscerated rate and slaughter rate of Wanxi White geese were increased.

Adding seabuckthorn tender branches and leaves in diet could promote chicken weight gain, reduce feed consumption, increase the content of amino acid and protein in chicken, improve the quality of chicken and enhance the immune capacity of animals.

8.6 Others

The new woody forage is also used in rabbit and other livestocks. Adding 10%, 20%, 30% hybrid paper mulberry in the diet of meat rabbits significantly increased the average daily gain, but had no significant effect on the average daily feed intake; the total protein content in serum was significantly increased, but the albumin and globulin content had no significant effect; the content of IgG and IgM in serum was significantly increased, and the content of IgA in serum with 30% hybrid paper mulberry diet was significantly increased. It significantly reduced the incidence rate and mortality rate of meat rabbits, and significantly improved the rate of meat rabbit growth. In conclusion, hybrid paper mulberry feed can improve the growth performance, serum biochemical indexes and health status of meat rabbits.

Anthocephalus chinensis could be used in rabbit production. There was no adverse effect on the production performance of ELA rabbits fed with different proportions of anthocephalus chinensis leaf powder instead of peanut seedling powder; the slaughter rate and half eviscerated rate were significantly higher than control when the replacement ratio was 20%, and the other slaughter performance differences were not significant.

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Chapter 9
Research Progress of Integrated Ecological Cycle Models of Forage Planting and Livestock Breeding

Lin Meng, Yuan An, Zhongbao Shen, Xiusheng Huang, Weibo Han, Zhiming Xu, and Mingli Zheng

9.1 Connotation and Significance of the Integration of Forage and Livestock

9.1.1 Connotation of the Integrated Forage and Livestock Production System

The integrated forage and livestock (IFL) production system is the main development direction of modern circular animal husbandry. This system allow for cleaner production and sustainable agriculture. The negative effects of environmental pollution from livestock breeding are a global ecological problem, and the IFL system is an effective livestock production method that could help to solve this problem. In the IFL system, forage planting and livestock breeding are integrated into a whole system by optimizing the production structure of forage and livestock, in which the raising livestock numbers are based on forage production, and forage planting and livestock breeding reach a balance. Meanwhile, organic wastes coming from livestock are transformed into fertilizers and are circularly used in forage planting. The core of the

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IFL system is the scale matching of forage planting and livestock breeding to guarantee the energy and nutrition supply for livestock breeding and maintain ecological balance. In the IFL system, forage planting meets the livestock requirement, and the organic fertilizer required by forage planting mainly comes from the organic waste of livestock. Forage land is the main accommodation of livestock organic waste, which effectively avoids organic waste-induced environmental pollution, improves the ecological environment, and increases economic benefits.

The aim of the IFL system is to safely produce livestock production and maintain environmental health by integrating forage production and livestock production into a complete system. The combination of land resources, forage planting, and livestock breeding will greatly improve forage production, livestock production, and organic waste utilization, and, therefore, greatly decrease environmental pollution. Thus, the IFL system matches the requirements and targets of cleaner production, which not only meets the needs of forage and livestock products, but also uses natural resources rationally to reduce organic waste and improve resource utilization to protect the ecological environment.

9.1.2 Function of the Integrated Forage and Livestock Production System

The IFL system improves the development of animal husbandry in an ecological and efficient manner, and its recycling of resources meets demands for the sustainable utilization of natural resources and the environment. This technique could play an important role in the sustainable and healthy development of livestock production.

(1) **Optimizing the production system of livestock breeding, guaranteeing high-quality forage supply, and satisfying the needs of livestock breeding**
Based on the balance of forage planting and livestock breeding, the IFL system comprehensively considers the livestock number, forage digestibility and nutritional quality, and nutritional needs of livestock to coordinate forage production. These can greatly guarantee forage supply and satisfy the needs of livestock breeding for high-quality forage production. Meanwhile, the IFL system can reduce the cost of forage transportation and increase economic efficiency.

(2) **Strengthening the management of forage planting, livestock breeding, and environmental protection in the IFL system, and ensuring product quality and ecological environment safety**
The IFL system considers the relationships among land resources, forage planting, livestock breeding, and environmental control to ensure high ecological and economic efficiency. The four factors are closely associated in terms of number, scale, layout, production process, utilization and transformation, and organic waste recycling route. The production process, product quality, and harmless treatment of organic waste can be effectively controlled,

which effectively ensures production efficiency, product quality, and ecological environment safety.

(3) **Realizing clean circulation and maintaining the health of the ecological environment**
Agricultural organic waste is an important agricultural resource and is one of the main components of the IFL system. By converting organic waste into organic fertilizer for forage planting, the IFL system greatly decreases production costs and increases the economic benefits. Thus, the technology for recycling organic waste is a key point in IFL systems. It plays an important role in effectively decreasing the environmental pollution of livestock manure and reducing the use of chemical fertilizers in forage planting to reduce non-point source pollution.

(4) **Increasing intensive production level and improving land use efficiency**
The land supply is very short in China owing to less land resources and a large number of people; particularly, there is less land for forage planting. On one hand, the implementation of the IFL system can intensify forage and livestock production and increase the utilization efficiency of land resources per unit area. On the other hand, the IFL system is very flexible and can excavate land resources from multiple sources, such as low-yield farmlands, winter fallow fields in southern China, sparse forests, and orchards, to establish a forage production system. This will greatly increase land use efficiency and productivity, and play an important role in supporting livestock production with high quality, high efficiency, and sustainable development.

9.2 Integrated Ecological Cycle Models of Forage Planting and Livestock Breeding

9.2.1 Modeling Principles

The construction of an integrated optimization model of grass and livestock should always follow the principle of sustainable ecology. Based on the development ideas of the modern grass and animal husbandry industries, we should adhere to the integrated development ideals of the primary, secondary, and tertiary industries to form a series of circular economic industrial chains, including the development of forage resources; efficient processing, conversion, and utilization; trading market development, grass and animal husbandry informatization; and livestock product production, so as to improve the added value of grass and livestock products and achieve the environmentally friendly, resourceful, efficient, and safe integrated development of modern livestock. The scientific construction of a modern integrated optimization model of grass and livestock should adhere to the following principles.

9.2.1.1 Principles of Clear System Elements and Boundaries

According to certain principles of ecology and economics, the integrated management system of forage and livestock will be an organic combination of technology systems in space and time, and include the structure of certain land management units, including water and soil resources, herbaceous plants, livestock and poultry breeding, product processing and transportation, and service. We should also highlight the various resources, production processes, and other factors of the system, so as to develop the system structure toward multiple components, multiple levels, multiple timings, and multiple products with high efficiency.

9.2.1.2 Principles of System Stability

Based on the principles of ecology and ecological economics, we will consider the unification of biological and ecological characteristics, and the economic principles of each species in the integrated system of grass and livestock, with reasonable structure, perfect function, and strong ecological stability.

9.2.1.3 Principles of Harmony and Win–Win for Both Ecology and the Economy

According to the food chain and niche principles of the IFL system, the multilevel utilization and efficient transformation of substances, as well as the mutual promotion and coordinated development of production factors of forage and livestock, can be realized by adjusting the composition and time structure of the system. In addition, the principles of market economics will be applied to realize the multi-stage processing of forage, livestock, and poultry products, so that the system can achieve a win–win situation of ecological and economic coordination with high efficiency and stability.

9.2.1.4 Principles of Efficient Resource Recycling

From the perspective of the system coupling ecological cycle, the resources, environment, and production factors in the integrated system of forage and livestock should be reasonably allocated for the safe treatment of solid organic wastes from large-scale livestock and poultry manure and other solid wastes under the integrated optimization model of forage and livestock, and the solid–liquid separation of animal manure using biogas fermentation can also be realized to produce high-quality organic fertilizer.

9.2.1.5 Principles of Safety and Efficiency of Forage and Livestock Products

Strengthening the standardization of the forage and livestock product production process and the ecological production environment, and integrating the safe and green standardized production and management technology into each stage of the production process is essential to ensure high-quality, efficient, green, and safe livestock and forage products.

9.2.2 Pattern Types

The combination of forage planting and livestock breeding is an ecological agriculture model that closely connects the planting and breeding industries. It uses manure produced by livestock and poultry as the fertilizer source for forage growth. The planting industry provides feed for the breeding industry and absorbs the wastes of the breeding industry. Accelerating the development of circular agriculture with combined planting and breeding is important for improving the efficiency of agricultural resource utilization, protecting the agricultural ecological environment, and promoting the green development of agriculture (Yang and Chen 2018). With the continuous expansion of the scale of livestock and poultry breeding in China, environmental pollution during the breeding process has become increasingly serious, which has affected the sustainable development of various industries (Huang 2018). The accelerated development of circular agriculture can be achieved by a combination of planting and feeding. Strengthening combined planting and feeding and promoting the reduction, reuse, and utilization of agricultural production wastes can improve the efficiency of agricultural resource recycling, curb and reduce agricultural non-point source pollution, and promote sustainable agricultural development. This can be implemented to realize high-efficiency, safe, resourceful, and environmentally friendly agricultural modernization, with obvious economic, ecological, and social benefits (Yang and Chen 2018). At present, farmers in China are exploring and innovating a variety of new integrated ecological cycle models of forage planting and livestock breeding. One common process is shown in Fig. 9.1.

9.2.2.1 Integrated Cycle Models of Forage Planting and Ruminant Livestock Breeding

Ruminant livestock are the main consumers of forage. The basic principle of the integrated cycle models of forage planting and ruminant livestock breeding is based on farms as the core and waste (dung) resource conversion as the main means to build a large-scale ruminant livestock breeding–ruminant livestock products–safe treatment and resource utilization of manure–organic fertilizer production–pasture planting–pasture processing and utilization–biogas energy recycling agricultural

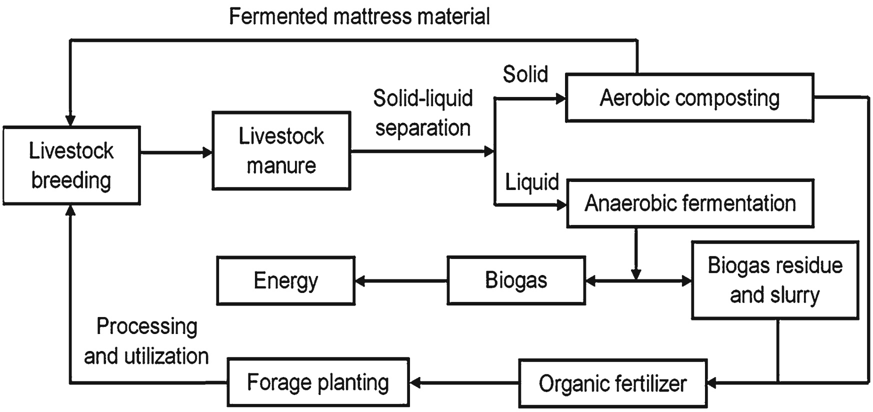

Fig. 9.1 Integrated ecological cycle model of forage planting and livestock breeding

model industry chain. Related companies use biogas fermentation and organic fertilizer production to increase the utilization rate of livestock and poultry manure, expand green pasture planting areas, expand ruminant livestock breeding, reduce environmental pollution, and improve farmers' health and income. It is important to realize the 'closed circulation' of waste in the entire park by connecting all of the processes and initially forming a green agricultural breeding demonstration park featuring recycling and ecologicalization (Li et al. 2020).

9.2.2.2 Integrated Cycle Model of Forage Planting and Pig Breeding

As a monogastric omnivorous livestock, pigs have limited forage utilization capacity. Therefore, matching the appropriate scale of forage planting land that is sufficient to absorb farming manure is key to realizing the development of the integrated forage planting and pig breeding cycle. When the land for forage planting is insufficient, livestock and poultry manure is converted into organic fertilizer, biological protein, biogas energy, and other commodities for circulation through biological engineering treatments to ensure resource utilization. When the land for planting supporting pasture is sufficient, the surplus pasture can be processed into hay, silage, and other grass products for circulation. In addition, large-scale pig breeding companies and nearby large-scale pasture planting companies signing agreements on manure elimination and pasture supply is also a common forage–pig integrated breeding cycle model in China.

9.2.2.3 Integrated Cycle Model of Forage Planting and Poultry Breeding

With the improvement of production and living standards, high-quality, nutritious, and pollution-free green food has become a new choice for consumers. Among them, meat and egg products from grassland-raised ecologically stocked poultry are more favored by consumers. Small-scale farming companies, such as family farms in China, are also constantly exploring the implementation of the integrated cycle model of forage planting and poultry breeding. The current, more mature models include the 'rice–shrimp–grass–poultry' model, that is, after the rice and shrimp are harvested, rye grass and other forages are sown in the rice fields, and the pastures are used to graze poultry. After the poultry is harvested, the poultry manure and grass roots are returned the soil to plant rice and begin the next cycle, thus forming an annual high-efficiency cycle planting model (Xie and Chen 2018; Yang et al. 2019). The 'forest–grass–poultry' model chooses woodlands with suitable canopy closure to build artificial grassland, and adopts a combination of house feeding and grass stocking to breed poultry. Most of the manure produced is consumed by the grassland in the forest, and the remaining part is processed. After the safe treatment of oxygen composting, organic fertilizer is produced for the use of grassland and other crops in the park, thereby realizing a high-quality development model of circular agriculture.

9.3 Typical Cases

9.3.1 Integrated Ecological Cycle Model of Forage Planting and Cow Breeding in the Warm Temperate Zone

The Modern Farming (Group) Co., Ltd. was established in Wuyuan County, Bengbu City, Anhui Province in September 2005. This area has a transitional monsoon climate in the warm temperate zone. It is a semi-humid agricultural climate zone located in the Huaihe River Basin, with four distinct seasons and a humid climate, on the Qinling–Huaihe Line. The company is specialized in dairy farming and milk production. On November 26, 2010, the Modern Farming Co., Ltd. was successfully listed on the Hong Kong stock exchange, becoming the first enterprise worldwide to be listed on the market with dairy farming resources. Relying on the global initiative of the 'grass-planting, dairy farming, milk processing integration' model, the company has developed into one of the largest domestic dairy farming enterprises, processing, producing, and supplying high-quality milk products. The company has built 26 million head of stock with 230,000 cows, with a daily output of nearly 3600 tons and an annual output of 1.3 million tons of fresh milk. Based on the goal of resource recycling and zero waste discharge, the company has built a green recycling industrial chain of 'forage planting–dairy farming–manure treatment–biogas power generation–biogas fertilizer returning'.

The model adopted by this company conforms to the development requirements of the industry, and is also a breakthrough in solving the problem of large-scale livestock farm manure treatment. At the same time, to fulfill its social responsibility, the Modern Farming (Group) Co., Ltd. also prioritized the problem of sewage treatment. Purple Pasture Co., Ltd. was established in Wuhe County, Bengbu City, in August 2011. It is a large-scale modern agricultural enterprise specialized in planting, processing, and selling high-quality forage, with four branches: Purple Pasture Co., Ltd. (Bengbu), Purple Pasture Co., Ltd. (Zhangjiakou), Purple Pasture Co., Ltd. (Alukerqin), and Purple Pasture Co., Ltd.

9.3.1.1 Model Contents

The company has invested 600 million RMB Yuan for the construction of a 6666.67 hm^2 alfalfa planting base in Wuhe County, Bengbu City, a 20,000 hm^2 oat grass base in Zhangjiakou, a 5333.33 hm^2 alfalfa oat base in Chifeng, and a 600,000 ton barren silage base in Fuyang. Purple Pasture Co., Ltd. is a partner of Modern Farming (Group) Co., Ltd. and Flag Dairy Co., Ltd., and provides 100,000 tons of alfalfa silage, 200,000 tons of oat silage, 60,000 tons of corn silage, 100,000 tons of barren silage, 30,000 tons of alfalfa hay, and 80,000 tons of oat hay for customers across the country every year, with an annual sales volume of 500 million RMB Yuan. At present, the company has more than 500 formal employees, and has achieved 66.67 hm^2 per capita planting harvest and 2 million per capita output value in 2018.

The recycling economy of 'biogas slurry organic fertilizer returning to the field, forage feeding cows' has been accomplished in Bengbu, which not only achieves economic benefits, but also solves the problems of resource reuse and environmental protection. The technical method is as follows: cow dung was treated using a medium-temperature anaerobic fermentation system. The fermentation time was 20–25 days in the fermentation tank, and the fermentation temperature was35°C–38 °C. After the safe treatment of cow manure, biogas, biogas residue, and biogas fertilizer were produced. Among them, biogas is used for power generation and biogas boilers. After anaerobic fermentation, it is pumped into a solid–liquid separator, and the solid material is further dried into a biogas residue, which is used as bedding material for the cowshed. The liquid material enters the regulating tank, part of which is pumped into the regulating tank for backwashing the main fecal canal, and the other part enters the biogas fertilizer temporary storage tank. Biogas fertilizer is transported to the grassland by pipeline and applied as an organic fertilizer according to the growth needs of the pasture (Fig. 9.2).

The company uses plug flow reactor technology to treat cow manure, and the biogas residue and biogas fertilizer are comprehensively utilized to utilize the cow manure through a biogas power generation system. With biogas technology as the link, the biogas, breeding, and planting technologies are optimized and combined to achieve the multi-stage utilization of energy and good material circulation, forming a sustainable ecological agricultural system without pollution. For example,

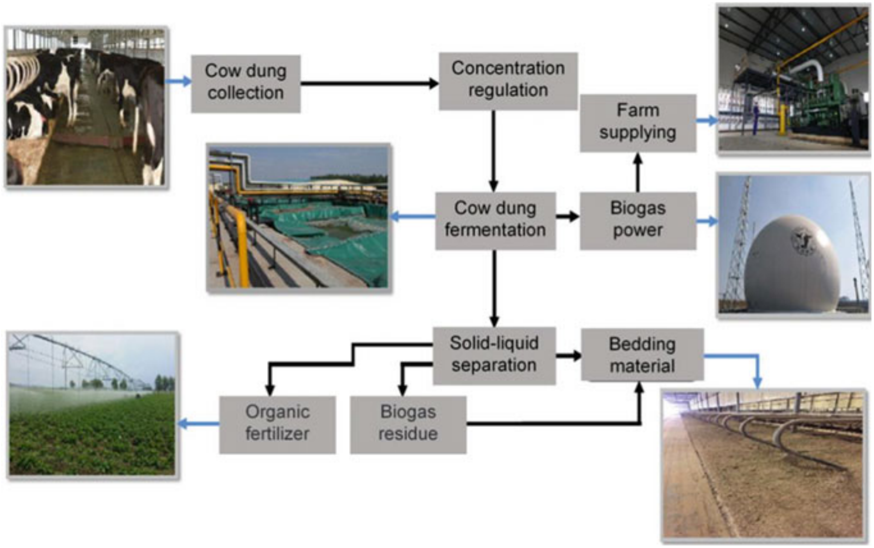

Fig. 9.2 The process and utilization pattern of cow manure fermentation

Hefei Ranch has realized the agricultural circulation models of 'farm–cow manure–power generation–farm', 'farm–cow manure–biogas residue–farm', and 'farm–cow manure–biogas fertilizer–feed grass base–farm'. The energy flow and material flow system in the project area is realized by taking the biogas project as the link. Biogas can be used as heat and power to supply solar energy greenhouses and living service facilities directly. Biogas residue was used for bedding material. Biogas fertilizer is used as a nutrient solution for soilless cultivation or directly used as a liquid fertilizer in farmland. Therefore, the circular economic model of 'making the best use of the material and making the best of the land' has been achieved.

9.3.1.2 Benefits and Effects

(1) Economic benefits: The company has actively used a model of combined planting and breeding, a green cycle with zero emissions, to treat the manure of 10,000 dairy cows, and produce 140 million m^3 of biogas, 5.7 million tons of biogas fertilizer, 1.8 million m^3 of biogas residue, 720,000 tons of steam converted from biogas, and 61 million kW of power annually. This increased the annual efficiency by more than 160 million RMB Yuan, reduced carbon emissions by 320,000 tons/year, and improved the potential value of carbon trading to about 7 million Yuan. Using biogas slurry, Bengbu Purple Pasture Co., Ltd. grass saves more than 5 million RMB Yuan of chemical fertilizer investment every year, the land after using biogas slurry gradually becomes a loose granular structure, and the yield of alfalfa reached 15,000 kg dry matter/hm^2.

(2) Ecological benefits: The company has actively explored a new sustainable ‘combination of planting forage and breeding livestock, green cycle’ development model with zero emissions, and has invested 1.2 billion RMB Yuan to build 18 sets of waste water recycling treatment stations, large-scale biogas power generation facilities, and biogas fertilizer comprehensive utilization facilities. The fermentation biogas heating power generation and safe treatment model are adopted to absorb, digest, and treat the manure of 10,000 dairy cows.

9.3.2 Integrated Ecological Cycle Model of Forage Planting and Cow Breeding in the Cold Temperate Zone

Harbin Wanjiabao Juanshan Cow Base Co. Ltd, located in Duiqingshan town, Songbei District of Harbin, belongs to the temperate continental monsoon climate with four distinct seasons, with a long, cold, and snowy winter. It planted 200 hm^2 of silage and 100 hm^2 of alfalfa, and 2000 heads of Juanshan cows introduced from Australia, including 1100 heads of lactating and dry cows and 900 heads of reserves and calves. It is the same investment body as Heilongjiang Wanjiabao Fresh Milk Investment Co., Ltd., forming a one-stop industry of planting, breeding, processing, sale, and distribution (Figs. 9.3 and 9.4).

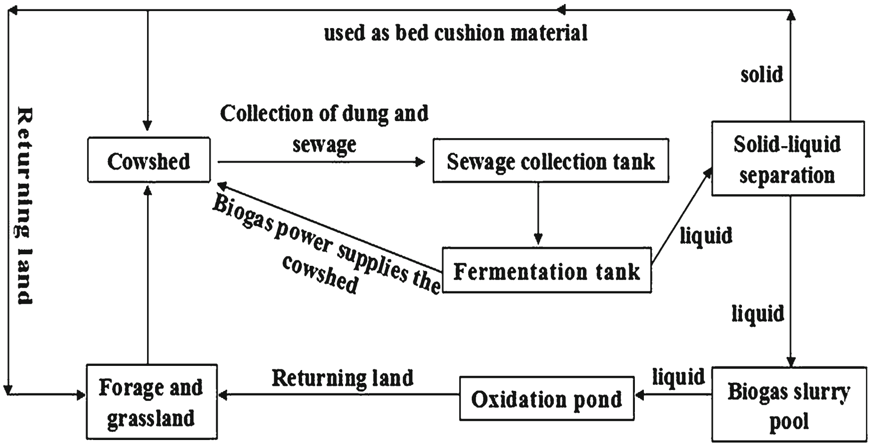

Fig. 9.3 Integrated ecological cycle model of forage planting and cow breeding in Harbin Wanjiabao Juanshan Cow Base Co., Ltd.

Fig. 9.4 Outline of integrated ecological cycle of forage planting and cow breeding in Harbin Wanjiabao Juanshan Cow Base Co., Ltd.

9.3.2.1 Model Contents

Forage production and feeding: The company cooperated with the professional forage companies, planted 200 hm^2 of silage corn and 100 hm^2 of alfalfa, and prepared the scientific feeding diet according to the nutritional needs of Juanshan cows.

Collection of dung and sewage: The recycled water from the milking hall is used to flush the manure from the waiting area and the dung into the dunghill in the middle of the cowshed. The manure and urine in the cow house are moved to the middle dung ditch using an automatically controlled dung scraper. Domestic garbage is connected to the gutter through pipelines. The total sewage volume is approximately 80 tons per day. The solid content is 6–10%, including cow dung, cow urine, rice husk, household garbage, and waste liquid from the cleaning of milk tanks.

Biogas project: The sewage flushed through the waste ditch, after passing through the grille, is concentrated in the sewage collection tank. After being evenly stirred in the sewage collection tank, it is pumped to the biogas fermentation tank, with a volume of 120 m^3.

A fully mixed medium-temperature fermentation tank was adopted with about 1400 m^3 of the fermenter. The fermentation temperature is 38–39 °C, and about 300 m^3 of gas per day can be produced. The fermenter is round and insulated, and is placed outdoors. The airbag is located above the fermenter with a double membrane. A biogas boiler is used for biogas combustion, and a biogas slurry and residue pool with a volume of 120 m^3 is needed for temporarily storing the solid–liquid mixture discharged from the fermenter.

Returning farmland to use: Solid–liquid separation was realized for the slurry mixture from the fermentation tank. The solid content of the mixture was about 8%, the solid content after separation was less than 1.5%, and the water content of the biogas residue (solid part) was less than 35%. Two biogas slurry pools were prepared with 1200 m^3 of the first-stage pool and 3000 m^3 of the second-stage pool. After solid–liquid separation, the biogas slurry is pumped to the oxidation pond, stored for the winter, and returned to the field in the spring, summer, and autumn by pipeline. The biogas residue, dried quickly in summer, is used as a bedding material for cows, and for mature compost to be returned to the field in winter. In this company, about 9000 tons of biogas slurry and 15,000 tons of biogas residue were returned back into the silage corn and alfalfa fields over 2–3applications per year.

9.3.2.2 Benefits and Effects

(1) Economic benefits: At present, the planting and management of silage corn and alfalfa are undertaken by Wanjiabao Agricultural Branch. Corn and alfalfa cultivation and storage are accounted for independently. For example, the order price of silage in 2019 was 495 Yuan/ton. The price of silage alfalfa is RMB 1200 Yuan/ton, which is 10%–20% less than the market price. This is reflected in savings of 600,000 RMB Yuan for 10,000 tons of silage maize and 400,000 RMB Yuan for 1000 tons of alfalfa. The total purchase cost saved 1 million Yuan, and the return fee for reducing organic fertilizer in the pasture is 305,000 Yuan. Through the combination of planting and feeding, the total economic benefits of this company are about 1.305 million RMB Yuan per year.

(2) Social benefits: This model can not only promote the development of silage corn, alfalfa, and other forage crops, but can also reduce the pressure of straw treatment and increase farmers' income.

(3) Environmental benefits: This model can effectively turn the waste and other pollution sources into organic fertilizer, and thus solve the contradiction between animal husbandry and its environment impacts.

9.3.3 Integrated Cycle Model of Forage Planting and Cattle Breeding in the Cold Temperate Zone

Longjiang Yuansheng Food Co., Ltd., is located in Longjiang County, Qiqihar City, Heilongjiang (47°40′ N, 123°37′ E). This region is known as the golden corn planting belt, golden cow breeding belt, and black soil belt. The company itself plants 333.33 hm^2 of alfalfa, and cooperates with professional forage production cooperatives to plant 1000 hm^2 of silage corn and 600 hm^2 of alfalfa to provide high-quality coarse forage. Approximately 3000 heads of purebred black cattle have been imported from

Australia and New Zealand, and now the number of cultivated black cattle has reached 8000 heads. The company has been approved by the Ministry of Agriculture and Rural Affairs, and the General Administration of Quality Supervision, Inspection and Quarantine of the People's Republic of China (AQSIQ) to introduce live black cattle from overseas. The company has implemented the integrated development pattern from pasture to dining table, and formed the whole industrial chain development pattern of Longjiang black cattle with integrated breeding; frozen refined production; base improvement; high-quality cattle fattening, slaughtering, and processing; marketing and sales, and chain catering. The company's main business income reached 928 million RMB, the net profit after tax was 90 million RMB Yuan, and the total tax paid was more than 26 million RMB Yuan. The company has registered 'Longjiangheniu', 'Longjiangxueniu' and 'Longjianghuaniu' as living brand trademarks and product trademarks, and is rated as a 'national key leading enterprise of agricultural industrialization', 'national demonstration area of quality and safety of export food agricultural products', 'national beef core breeding farm', and 'national standardized beef cattle demonstration farm'.

9.3.3.1 Model Contents

High-yield artificial forage was planted on abandoned land, farmland, and low-yield farmland to support drylot feeding beef cattle. After the treatment of drying and stacking fermentation, manure can be used in artificial cultivated grasslands and natural grasslands to achieve the integration of forage planting, livestock breeding, and resource recycling (Fig. 9.5).

The company mainly adopts the forms of planting forage by itself and by order of forage production cooperative. The perennial alfalfa, annual silage corn, and oats were planted mainly for producing green forage and silage to feed the purebred black cattle and cultivated black cattle. The purebred black cattle were raised uniformly, and the improved cattle were raised by farming cooperatives and scattered farming households. Beef cattle were fed silage corn, alfalfa, natural grasses, straw, and a scientifically formulated diet. After the safe treatments of feces drying, stacking, and fermentation, the manure could be returned to the artificial and natural grasslands.

9.3.3.2 Benefits and Effects

(1) Economic benefits: Each poor household can sell four cultivated beef cattle calves with a body weight of 200 kg/head, and can get an income of 12,000 RMB Yuan/head, and the total costs, including the forage and feed charges, disease prevention and control fees, and labor costs, were about 4420 RMB Yuan/head. The average annual net income for each poor household is approximately 9508 RMB Yuan. For the enterprise, slaughtering and processing a purebred Huaniu has an output value of 100,000 RMB Yuan, profit of 30,000 RMB Yuan, and tax revenue of 5000 RMB Yuan; slaughtering and processing

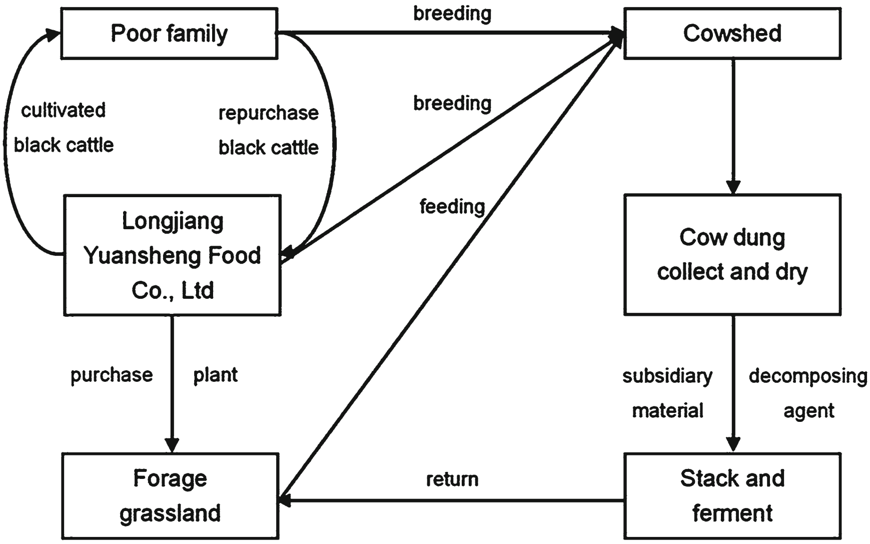

Fig. 9.5 Diagram of integrated cycle model of forage planting and cattle breeding

a (improved) high-grade beef cattle has an output value of 60,000 RMB Yuan, profit of 8000 Yuan, and tax of 2000 Yuan according to the calculation of 1800 RMB Yuan/kg of A5 grade beef, and 800–1200 RMB Yuan/kg of A3 grade beef.

(2) Ecological benefits: Manure can be used as fertilizer for forage grasslands. It can effectively solve the environmental requirements of the breeding industry and promote its ecological and healthy development.

(3) Social benefits: The model of government and leading enterprises leading poor families to an increased income is poor, and Longjiang Yuansheng Food Co., Ltd signed a cultivated cattle repurchase agreement so that the company is responsible for buying back fattening cattle.

9.3.4 Integrated Ecological Cycle Model of Forage Planting and Sheep Breeding

Fujian Haihongda Ecological Agriculture Co., Ltd. was established in 2014. It is a provincial-level livestock and poultry breeding standardization demonstration farm and a key leading municipal-level enterprise of agricultural industrialization in Sanming City, Fujian Province. The company uses the surrounding woodland and mountain ridge fields to grow forages on a large scale, including 80 hm^2 in the rotation grazing area of the circulation woodland and 40 hm^2 in the mountain ridge pasture area. It is committed to the large-scale, intensive, and standardized breeding of black goats under the ecological planting model.

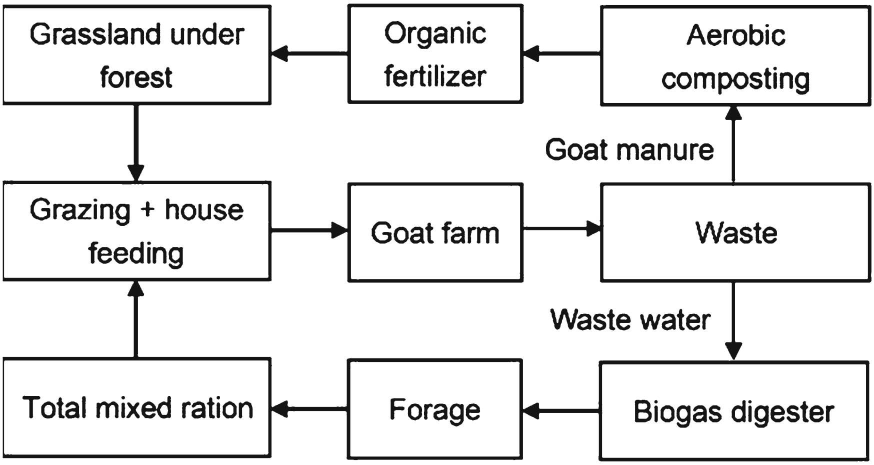

Fig. 9.6 Integrated ecological cycle model of forage planting and black goat breeding

The company has established a 'company + poor households' model of raising sheep to alleviate poverty through a breeding model that combines grazing and house feeding in the fields and mountains and planting grass under the forest in accordance with the national precision poverty alleviation policy.

9.3.4.1 Model Contents

This technical model mainly chooses *Pennisetum purpureum* cv. Guiminyin, *P. americanum* × *P. purpureum* cv. Minmu No. 6 and *P. purpureum* cv. Reyan No. 4 to establish 40 hm^2 artificial grasslands for the implementation of ecological breeding technology. More than 3000 black goats per year were raised with a combination of rotation grazing and house feeding. The utilization rate of grassland and the production performance of black goats were both increased. Manure from farms and other agricultural wastes are collected and retorted, or biogas systems are used for anaerobic fermentation and organic matter degradation to produce biogas slurry and re-apply it to grassland and farmland. Thus, an integrated cycle model of forage planting and sheep breeding was established (Fig. 9.6).

9.3.4.2 Benefits and Effects

(1) Economic benefits: In the past three years, the company has planted about 40 hm^2 of artificial grassland, produced about 300 tons of hay annually, and raised about 3000 black goats. Although the annual average increase in cost is 660 RMB Yuan per goat for forage production, labor, fuel power, depreciation, and

other costs, the annual total economic benefit is 6 million RMB Yuan, and the gross profit is 4.02 million RMB Yuan.

(2) Ecological benefits: Every 1 g of plant dry matter produced by grassland vegetation can fix 1.63 g of CO_2 and release 1.20 g of O_2. The annual carbon sequestration of understory grassland vegetation can reach 300 tons/year $\times$ 1.63 = 489 tons and release 360 tons of O_2. Using grassland to absorb manure from the sheep farm can effectively reduce the chemical oxygen demand (COD) and biochemical oxygen demand (BOD) emissions from farming. The company's 40 hm^2 of *Pennisetum* grassland can save 7740, 3600, and 3600 kg of nitrogen, phosphate, and potassium fertilizer every year, respectively. The application of biogas fertilizer to grasslands can also significantly increase the microbial diversity of the grassland soil. Studies have shown that the bacterial 16S rDNA gene and fungal SSU rDNA gene abundances in the 0–20 cm soil layer of grassland with biogas fertilizer were increased by 20.92% and 14.35%, respectively, compared to those with non-biogas fertilizer. After three years of applying the biogas slurry made by the farm, the total nitrogen, total potassium, and organic matter of the soil increased significantly compared to those in the control. Grassland establishment and scientific management have promoted the improvement of soil microbial diversity, improved the physical and chemical properties of the park's soil, and played an important role in the management of soil erosion and restoration of the ecological environment.

(3) Social benefits: The company has established a poverty alleviation model of 'enterprise + base + poor households' by raising black goats. Comprehensive measures of 'two reductions, two exemptions and one floating', were implemented for poor households, which fully incentivized poor households to participate. The company has signed agreements with 12 households and 54 people to raise black goats on grassland under forest. Various measures, such as forage planting, black goat breeding, and employment, have helped 36 poor households with 113 people, and made positive contributions to the income of local poor households and the healthy development of the black goat industry.

9.3.5 Integrated Ecological Cycle Model of Forage Planting and Chicken Breeding Under Forest

Beijing Lvduole Agriculture Co., Ltd. is located in Zhangzhen, Shunyi District, Beijing. It is a company mainly engaged in the free-range farming and sale of Beijing-you chickens raised on grasslands under forest. It adheres to the principle of 'improving animal welfare and improving egg and poultry quality'. It is a modern agricultural industrialization company that develops a forest economy and promotes ecological agriculture. The company's Lvdudu farm covers an area of more than 65 hm^2, of which more than 15 hm^2 is used for free-range breeding of Beijing-you chickens under poplar, Chinese scholar, and Chinese ash trees. There are approximately 70 small villas and mobile chicken houses arranged evenly among the woodlands. The company raises more than 20,000 Beijing-you chickens and collects more than 1.8 million eggs every year. The company is now the China Agriculture Research System Demonstration Base (CARS-42-11-12), the Beijing-you chickens Low Density Ecological Free-Range Raising Demonstration Base, and the Animal Welfare Golden Rooster Golden Egg Award Certification Base.

As an important technical support for the company for a long time, the forest-grass compound research team of the Beijing Academy of Agricultural and Forestry Sciences (BAAFS) has developed and promoted the application of the ecological healthy stocking method for Beijing-you chickens with low-density forest grassland, and with the application of villa chicken coops, probiotic fermentation beds, and other technologies, to realize the combination of forage planting and chicken breeding under forest, and to develop agriculture with ecological recycling. The principle of this model is that we interplant chicory with higher yield and quality in the forest to build approximately 13.3 hm^2 of artificial grassland, formulate the appropriate grazing density with 2025 heads/hm^2 of Beijing chicken, and supplement with a moderate amount of feed. Chicken manure is digested by the probiotic fermentation bed technology. Finally, the breeding environment and animal welfare are improved, and the ecological forest, forage, and chicken farming circulation pattern is ultimately achieved.

9.3.5.1 Model Contents

Ecological free-range chickens with low density in forest grasslands are an important economic development model. The supporting villa chicken houses are equipped with a certain thickness of rice husks, which are evenly sprayed with probiotics, as bedding. Fermented organic fertilizer is produced by stuffing for chicken coops and other solid organic wastes by the aerobic composting method, and then returned to the field for utilization to realize ecological planting and breeding combined with recycling (Fig. 9.7).

The woodland canopy density of the base was 0.15–0.5, and the tree line spacing was more than 4 m. Chicory, a grass species, was selected for the study as it is suitable for woodland and orchard planting, with stronger shade tolerance, higher coverage, good regeneration, and chicken feeding preference. The construction and management of chicory grassland under the forest were carried out according to the local standard of Beijing, 'Technical regulation for sod-culture in orchard' (DB11/T 991-2013). When the real-time air temperature is higher than 15 °C, the average natural height of the community in the forest grassland is more than 20 cm, and then the rotational grazing of eight-week-old Beijing-you chicken can be implemented in the forest grassland (Fig. 9.8).

The specific method of rotational stocking was as follows: 667 m^2 of forest grassland, as an example, can be divided into three grazing blocks, and the suitable grazing density would be 135 heads/667 m^2 of Beijing-you chickens. Each block can be stocked for 10 days, and each grassland was stocked for 30 days in one stocking cycle, which was rotated in turn. Chickens were allowed to graze for 2 h every

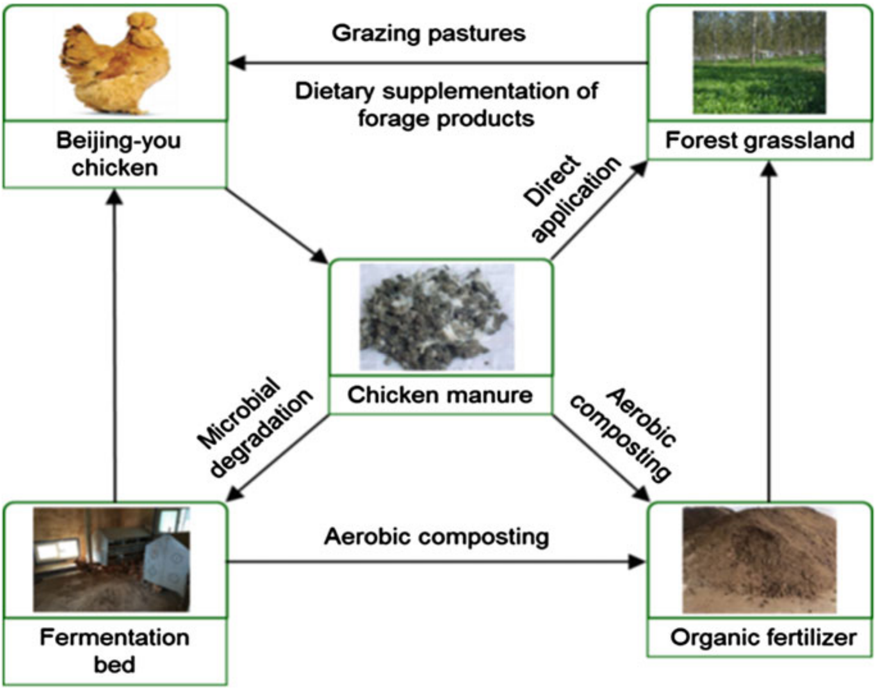

Fig. 9.7 Diagram of integrated ecological cycle model of forage planting and livestock breeding

Fig. 9.8 Realistic picture of ecologically stocked low-density Beijing-you chickens on chicory grassland under forest

Fig. 9.9 Harmless treatment and resource utilization of chicken manure in the ecological cycle model of forage planting and poultry breeding

morning and afternoon, and they were then taken back to the chicken house (the place of fixed activity). According to the normal growth of chickens of different ages, 85% of the daily feed intake of concentrate was fed, once in the morning and once in the evening, 30–40% of the daily feed intake was given in the morning and 60–70% in the evening.

At this base, the harmless treatment and resource utilization of chicken manure in the ‘ecological cycle of forage planting and poultry breeding under forest’ model were realized using three different actions. During the stocking period, about 55% of chicken manure excreted in the understory chicory grassland was consumed totally. During the period of non-stocking, about 40% of chicken manure was discharged in the hen house, and the fermentation bed of probiotics in the chicken house was used for complete digestion (Fig. 9.9).

9.3.5.2 Benefits and Effects

(1) Economic benefits: Compared to the model of raising free-range chickens on bare forest land, the ecological cycle model of forage planting and poultry breeding under the forest could significantly improve the carcass performance and meat and egg quality of Beijing-you chickens. For example, the live weight, slaughter weight, and total clean chamber weight reached 1780.32, 1598.86, and 1136.60 g, with increases of 238.02, 262.86, and 137.30 g, respectively. The slaughter rate increased from 86.62 to 89.81%. For the leg and chest muscles, the weights increased by 24.10 and 21.65%, the crude fat contents decreased by 22.7 and 17.13%, the inosinic acid contents increased from 0.81 to 1.02% and 1.19 to 1.52%, and the essential amino acid contents increased by 21.99% and 16.65%, respectively (Meng et al. 2016).

For example, 20,000 Beijing-you hens were raised in the chicory grassland of the forest at the base of this company every year. In the construction of the grassland under the forest, the cost of land plowing, seeds, mulching film, water and electricity, labor, and other costs were approximately 407.2 RMB Yuan/667 m^2. The grassland was rotated for seven to eight months per year, and the average saving on refined feed during the stocking period was more than 15%. The results show that the sales prices of chicken and egg products in the market were significantly increased. Compared to the free-range breeding of naked forest land, the annual net income of laying hens and broilers in the ecological cycle model of forage planting and poultry breeding can reach 438and 113 RMB Yuan/head, respectively, showing significant economic benefits.

(2) Ecological benefits: It has been confirmed that, compared to free-range chicken on bare forest land, raising low-density free-range chicken on forest chicory grassland has a significant effect on the physical and chemical properties of the 0–10 cm soil layer. The pH value and the contents of available nitrogen, available phosphorus, available potassium, and organic matter in the chicory grassland area increased by 5.75%, 51.83%, 13.45%, 11.24%, and 3.63%, respectively, while the soil bulk density decreased by 0.69%. The soil fertility and physical and chemical properties of the 10–30 cm soil layer also showed a tendency to improve. In addition, the community coverage of chicory grassland forests reached over 85%, which significantly improved the resistance to wind and water erosion resistance and water erosion resistance. There are also many pests on chicory grasslands, which are collected by the chickens and are a good source of extra protein. The incidence of pests and the harm rate to trees are greatly reduced, thus reducing the required frequency and amount of pesticide application.

(3) Social benefits: The company farm adhered to the application of ecological forest–forage–chicken circulation pattern and supporting technologies for many years. Therefore, the chicken egg quality markedly improved, and the breeding benefits significantly increased with no extraneous odor or pollution. In 2017, the products of this farm gained the five-star golden rooster and five-star golden eggs awards awarded by the World Farm Animal Welfare Association. In 2019, the United Front Work Department of the Beijing Municipal Party Committee pushed the farm into one of the Beijing Science and Technology Yards. Thus, the ecological model of forage planting and poultry breeding has become an important typical development model of forests with high quality in northern China.

9.3.6 Integrated Ecological Cycle Model of Forage Planting and Pig Breeding

Longyan Longma Animal Husbandry Feed Co., Ltd. is located in Xinluo District, Longyan, Fujian, with 38.37 hm^2 of the original pig breeding farm and 1550 heads of multiparous sows. The farm can produce approximately 32,000 pigs per year, including breeding pigs, and commercial pigs and piglets. The pig farm supports the construction of a biogas-generating pit with a capacity of 5000 m^3 for the biogas treatment of hoggery sewage. Since 2006, the farm has aimed at the efficient utilization of an aerobically digested effluent, and adopted the integrated ecological model of forage planting and pig breeding to realize efficient and recycling utilization of breeding waste resources.

9.3.6.1 Model Contents

On the farm, *Pennisetum americanum* × *P. purpureum* cv. Minmu 6, *Lolium perenne*, etc., are planted, with the aim of providing forage annually through a reasonable arrangement of warm-season and cold-season herbage for livestock. A large amount of forage can be pulped or fermented for feeding pigs, and the remaining grass can also be used to cultivate edible mushrooms. More than 70% of pig feces are used to produce organic fertilizers, and the remaining fecal residue and waste water are separated by a solid–liquid separator. The sewage is digested in the biogas system by anaerobic fermentation and organic substances decomposition. Then, a 20 hm^2 area of grassland was constructed to utilize the anaerobically digested effluent. This model can achieve the biological treatment of pig farm pollution by planting forage and recycling grass resources simultaneously (Fig. 9.10).

(1) Feeding pigs with forage grass: Forage grass can replace 5–10% of the basal diet to feed fattening pigs. The *Pennisetum* grass was processed in two different ways: by pulping directly or by mixing with corn, soybean meal, and microbial inoculants to make fermented feed. The processed grasses replaced 10% of the basal diet to feed fattening pigs. After 90 days, the average daily weight gain of pigs was 511.17 g and 567.59 g, respectively (Table 9.1). Compared to the control, the daily weight gain of pigs in treatment 2 and treatment 3 increased by11.00 and 45.34 g, respectively. The difference between the two groups was not significant ($p > 0.05$); however, the basal diet amount was reduced, and the ratio of feed to meat was reduced by 8.8% and 11.3%, respectively, compared to that in the CK. In addition, the total amino acids (TAA), delicious amino acids (DAA),and human essential amino acids (EAA) of pork were improved to varying degrees (Table 9.2).Using ryegrass (*Lolium perenne*) with equal dry matter quality to replace 5%, 10%, and 15% of the formula feed for feeding pigs, the total amino acid content of pork in treatment 2, in which 5% of the feed was replaced, was increased by 8.74% compared to that in the CK. DAA were increased by 8.53%.*Pennisetum* grass can also be used to feed sows at the early

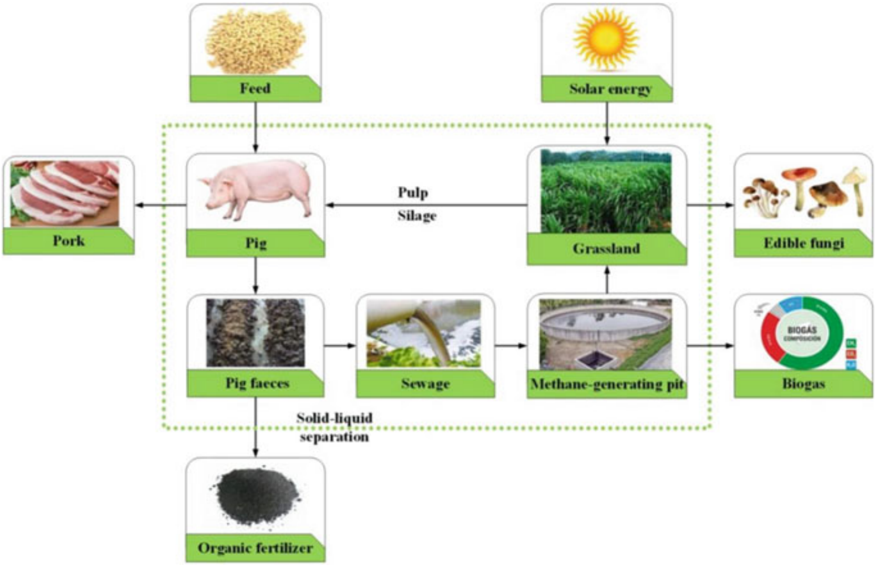

Fig. 9.10 Diagram of the integrated ecological cycle model of forage planting and pig breeding

Table 9.1 Effect on average daily gain and feed efficiency of different treatments

Treatments	Initial weight (kg)	Final weight (kg)	Gain (kg)	Daily gain (g)	Feed to gain ratio	Forage to feed ratio
1 (CK)	49.8 ± 6.02	96.8 ± 13.12	47.0 ± 1.92	522.22 ± 21.36	4.07:1	–
2	50.6 ± 6.31	96.7 ± 9.71	46.1 ± 2.62	511.17 ± 29.12	3.74:1	1:6.3
3	51.5 ± 6.44	102.3 ± 12.22	50.8 ± 8.23	567.59 ± 91.47	3.61:1	1:6.0

Notes Treatment 1: control group (CK), fed only the basal diet; Treatment 2: fed 90% basal diet + 10% fresh grass pulp; Treatment 3: fed 80% basal diet + 20% fermented feed (10% of grass pulp mixed with 10% of basal diet to make fermented feed)

Table 9.2 Amino acid contents in musculus longissimus dorsi of pigs under different treatments (g/100 g)

Items	Treatment 1	Treatment 2	Treatment 3
Delicious amino acids (DAA)	26.02 ± 0.25c	30.17 ± 0.33a	27.51 ± 0.08b
Essential amino acids (EAA)	26.14 ± 0.12a	29.86 ± 0.15a	27.28 ± 0.23a
Total amino acids (TAA)	62.98 ± 0.55c	72.20 ± 0.78a	66.20 ± 1.38b

second trimester stage. Using 2–4 kg of grass pulp as a daily supplement of fiber can improve the performance of sows and the quality of piglets, especially by adding 4 kg of grass pulp. The number of surviving fetuses per sow was 12.73, which is 2.50% higher than that in the control without grass. In addition, the rate of healthy piglets was 93.57%, which is 2.52% higher than that in the control (Huang et al. 2011).

(2) Grassland for utilizing the anaerobically digested effluent from the pig farm: In the mountainous area of Longyan, Fujian Province, the perennial *Pennisetum* turns green in mid-March, and can be irrigated by anaerobically digested effluent in April. The grass providing period is from May to November. Ryegrass is sown in September and can be irrigated by anaerobically digested effluent in October. At this time, the growth of *Pennisetum* has slowed down or stagnated as the temperature drops; thus, ryegrass can fill the gaps.

Pennisetum is a high-yield forage grass that can be irrigated by anaerobically digested effluent two to four times in one cutting cycle (30–45 d). The amount of anaerobically digested effluent required is 15–20 tons per 667 m^2 grassland, and 667 m^2 grassland can absorb about 200tons of anaerobically digested effluent in the growing season. *Pennisetum* grassland can be mowed five times, and can reach a fresh yield of 354.9–387.8 t/hm^2. *Lolium perenne* grassland in the growing season can absorb about 60–70 t/667 $m^2$of anaerobically digested effluent. The growth of *L. perenne* is relatively slow from December to January of the following year. From February to April, the aboveground temperature rose and grass grew rapidly. *L. perenne* can be mowed once in about 30 days, and six times in every growing season, reaching a total fresh yield of about 118.1 t/hm^2.

(3) Use of forage to cultivate edible mushrooms: *Pennisetum* is very suitable for cultivating edible fungi with a carbon to nitrogen ratio of 48.62. With research and development, using *Pennisetum* instead of rice straw to cultivate mushrooms could increase the economic benefits. *Pennisetum* was mowed when the plant height was more than 200 cm or had grown for more than 80 days, and then dried naturally. Regarding the nutritional quality of *Agaricus bisporus*, the TAA can reach about 24.42% at a grass to manure ratio of 6:4 (C/N = 28.66:1), higher than approximately 37.19% of the straw formula (ratio of grass to manure = 6:4), the DAA and EAA were also increased by 10.57% and 42.02%, respectively, compared to those in the straw formula (Chen et al. 2011).

9.3.6.2 Benefits and Effects

(1) Economic benefits: The crude protein content of *Pennisetum* irrigated with anaerobically digested effluent reached about 13.78%, which was significantly higher than that of the control without anaerobically digested effluent irrigation. At the same time, the average nitrate content of forage leaves was about 74.77 mg/kg, but no more than 0.25% of the nitrate safety value.

(2) Ecological benefits: *Pennisetum* grassland has been irrigated with anaerobically digested effluent for three years, which had a positive effect on grassland soil. Compared to the control, the contents of organic matter, available nitrogen, and available phosphorus increased by 189.9%, 72.4%, and 148.9%, respectively; however, the total potassium and available potassium contents decreased by 55.8% and 55.7%, respectively (Huang et al. 2007). The infiltration water of grassland on this farm was tested to obtain qualified standards by the Water Environment Monitoring Center of Fujian Province in 2009 and 2010, respectively.

(3) Social benefits: Longma original piglets have become a local dominant brand. From 2009 to the present, the pig–biogas–grass integrated ecological planting and breeding model has been established and has taken an important demonstration role in southern China. This model has been extended and applied with good effects in Long Yan City Shunfa Ecological Culture Co., Ltd. and Xiachang Pig-breeding Cooperative in Xiangcheng District, Zhangzhou, Fujian.

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Chapter 10
Research Progress of Forage Machinery in China

Yong You, Decheng Wang, and Guanghui Wang

10.1 Concept, Types, and Development of Forage Machinery and Equipment

10.1.1 Concept of Forage Machinery and Equipment

The mechanization of forage production refers to forage planting, field management, harvesting, and primary processing using mechanized means to meet the agricultural technical requirements and follow a technological route. The key to the development of animal husbandry is suitable machinery for forage production and processing.

10.1.2 Types of Forage Machinery and Equipment

The main mechanical equipment required for forage production includes:

① Forage seed harvesting and processing machinery, including combine harvester, seed harvesters for gramineous forage and legume forage, forage seed separator, sorter, awner, brush separator, pocket hole separating machine, gravity separator, stone remover, mixers, coating machine, pelleting machine, and drying equipment.

② Forage production machinery, including grassland improvement machinery, grass seed planter, forage tiller, airflow seeder, spreader, scarification and replanting machinery, no-tillage planter, water-saving sprinkler irrigation, and field management machinery.

③ Forage and crop straw harvesting machinery, including reciprocating mowers, rotary mowers, mowing modulators, drum-type mowers, finger rakes, horizontal

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rotary rakes, turning machinery, balers and loaders for square and round bales, palletizers, and bulk pickup and transport vehicles.

④ Forage drying equipment, including equipment for conveyor belt drying, drum drying, far-infrared drying, air-flow drying, superheated steam drying, and solar energy drying.

⑤ Forage processing and pelleting equipment, including forage crushers, grass pellet machines, grass cake-pressing machines, and grass block-pressing machines.

⑥ Silage harvesting machinery and silage equipment, including fixed-operation forage choppers; field operation silage harvesters; stacking, cellar storage, and silo storage equipment; bale silage and bag silage equipment.

10.1.3 Development of Forage Machinery and Equipment

The development of forage machinery in China has undergone a long process. Generally, the development process of forage mechanization can be divided into four stages:

a. Initial stage (1953–1966)
This period covers the initial development stage of the mechanization of the forage industry in China. In the initial stage, the strength of scientific research, manufacturing, and management was weak. The main development focused on grassland forage harvest, forage crushing, forage cutting, and other mechanization types. In this stage, forage machinery was widely accepted in the vast pastoral areas, and herdsmen began to adopt mechanization.

b. Adjustment and improvement stage (1967–1980)
In 1978, an agricultural machinery exhibition of 12 countries was held in Beijing, China. Well-known foreign enterprises, such as John Deere, New Holland, Claas, and other enterprises, exhibited advanced agricultural machinery. A considerable part of the exhibit was forage machinery. The advanced technology and products brought surprised China's animal husbandry machinery industry. In the following years, research institutes and enterprises of various provinces and regions conducted research and developed forage machinery, including 10 types and 20 models of forage machinery, including cutting and crimping equipment, mowers, rotary rakes, square and round balers. During this period, the direction of mechanization of grassland animal husbandry began to shift from single-operation mechanization to comprehensive mechanization and from purely pursuing the degree of mechanization to emphasizing economic benefits.

c. Market promoted herdsmen's independent development (1981–2000)
In the 1980s, after the implementation of the household contract responsibility system, the family as the business unit became one of the main modes of animal husbandry production. In the 1990s, the introduction of mowers, rakes, and forage processing machinery resulted in significant development of the forage

machinery industry. The demand for small machinery rose, although the development rate of large-scale forage machinery was slow. Although small machines were suitable for the economic conditions of pastoral areas, the disadvantages included low production efficiency, low capacity, and high energy consumption, limiting agricultural mechanization.

d. The government provided more support to herdsman to run businesses (2001–2010)
   In 2000, the western development strategy, environmental protection strategy, and agricultural industrial adjustment strategy were implemented. A series of policies, such as the large-scale return of farmland to forest, the reduction of agricultural taxes, and subsidies for purchasing machinery, were successively implemented. Good social and economic benefits were achieved, and the development of forage machinery was promoted. The market demand for forage machinery changed from small to medium. Large-scale and specialized operations became one of the main modes of animal husbandry production and management in China. The focus of forage mechanization changed from forage harvest in the past to artificial grassland construction, natural grassland improvement, forage-based farming and harvesting, irrigation, forage processing, and other projects.
e. Forage production has basically achieved full mechanization (2011–2019)
   With the continuous advancement of China's 'grain to feed' plan, the mechanization level of forage in China has been effectively improved, and the mechanized operation projects and mechanical products of the forage industry have increased year by year. In 2019, the total number of grassland machinery in China reached 70.469 million, and the total power reached 23.4023 million kilowatts, accounting for only 2.28% of the total power of agricultural machinery.

10.1.4 Current Situation of Forage Machinery and Equipment

After several years of development of forage machinery in China, forage mechanization has ushered in excellent development opportunities. At present, forage mechanization in China has been significantly improved and is continuing.

a. The laws and regulations related to the mechanization of grassland animal husbandry have been improved to support and protect the development of grassland animal husbandry mechanization.
b. The policy environment was improved to allow for innovation in grassland animal husbandry mechanization and establish a long-term mechanism to support animal husbandry and pastoral areas.
c. Investment in the mechanization of grassland animal husbandry from different sources has been increased.
d. The market for animal husbandry machinery has been strengthened to create an organic and comprehensive industrial chain of animal husbandry production,

sales, new product demonstrations, machinery leasing, maintenance networks and technical services to promote the mechanization and modernization of grassland animal husbandry.

e. The training of herdsmen has been strengthened to improve the scientific and cultural content and expand the coverage of information technology in agricultural and pastoral areas.
f. Independent innovation has been encouraged in the science and technology of grassland animal husbandry mechanization. It is necessary to establish a mechanism of combining enterprise innovation with research to form a strategic alliance of industrial technology.

However, due to the diversity of regions, climate, cultivation methods, and crops, the market demand for forage machinery in China is diverse. However, China's forage machinery has been developed based on the introduction and adaptation of foreign advanced technology, and a gap remains between China and developed countries in terms of mechanized agriculture.

a. Existing forage machinery products in China's market have a relatively low level of technology, low efficiency, and poor reliability. The level of mechanization in forage grass harvesting, processing, and storage is low, resulting in low nutritional value and quality of forage, which reduces the economic benefits.
b. Foreign countries dominate the market of high-end forage production machinery, and the competition among domestic enterprises is fierce.
c. The adaptability of agricultural machinery and forage machinery is not high, and herdsmen focus on small-scale mechanization for harvesting and storage of forage for their own use. This approach is not suitable for the sustainable development of animal husbandry.

10.2 Research Progress of Forage Seed Harvesting and Processing Machinery and Equipment

10.2.1 Forage Seed Harvesting Machinery

Domestic research on forage seed harvesting machinery started late and is in the developing stage. The scale of forage planting in China is relatively small, and most forage is grown by farmers; thus, the forage seed harvesting and processing machinery developed in China is relatively specific. The flowchart of the operation of a self-propelled forage seed harvester (combine harvester) is shown in Fig. 10.1. After the forage seed has been harvested by the combine header, it is transported to the material and air separation bin through a conveying mechanism and airflow. As the volume in the bin increases, the airflow velocity slows down, and the heavier grass seeds, stems, and leaves fall on the inclined vibrating screen due to the inertial force and gravity. After sieving, the grass seeds fall into the unloading auger, the stems and leaves are discharged, and the lighter grains and materials remain on the

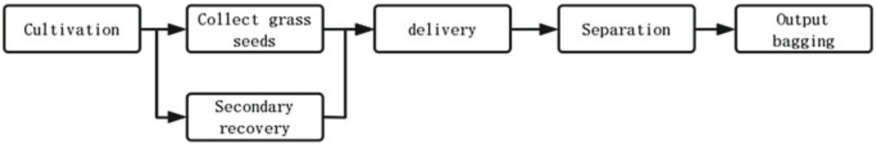


Fig. 10.1 Flowchart of the operation of a forage seed harvester

rotating screen. The material is removed by a rotary sieve; the brush and rotary sieve to rotate relative to each other. The material is brushed off and enters the unloading auger, which places the seeds into a container. This harvesting method is suitable for tall and short stems, and the loss of grass seeds is relatively low. Compared with full-feeding and half-feeding harvesting methods, the combine harvesting method has the advantages of a small grass-to-grain ratio, low power consumption, and high production efficiency.

The structure of the threshing device is shown in Fig. 10.2. It consists of a cylindrical grain roller (3) and a concave plate (6). The crop is grasped by the roller bar 8 and dragged into the gap between the roller and the concave plate (6). Due to the repeated impact and rubbing of the grain rod, the grain is removed at the front of the concave plate after the first few blows. With the decrease in the threshing gap, the gradually thinning crop layer moves in the direction of the exit, and the impact and rubbing of the crop are enhanced. When the crop is crushed, it becomes bulky, causing radial vibration. The exit gap δc at the end of the concave plate is small.

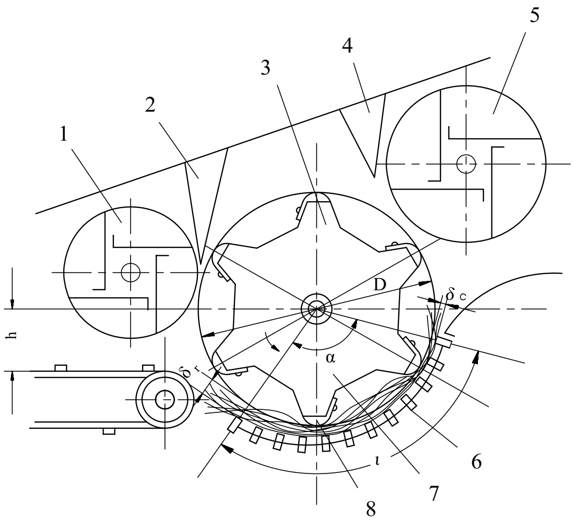
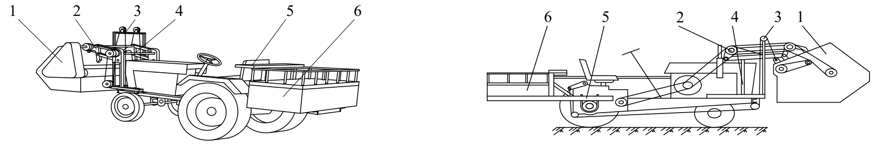


Fig. 10.2 Schematic diagram of the bar drum threshing device. 1. Feeding wheel, 2. weed baffle, 3. drum, 4. weed and grass baffle, 5. draft wheel, 6. concave plate, 7. spoke plate, 8. grain rod, δr—entrance clearance, δc—exit gap, α—concave angle, ι—concave arc length



(a) Overall structure (b) Suspension and transmission system

Fig. 10.3 Schematic diagram of the 92ZS-1.5 forage seed harvester. 1. Grass seed collector, 2. Transmission system, 3. Lifting system, 4. Front suspension bracket, 5. Rear suspension bracket, 6. Counterweight box

The straw and grain mixture is separated from the threshing device, and the grain is separated by the sieve hole due to the centrifugal force of the drum.

The 92ZS-1.5 forage seed harvester is shown in Fig. 10.3. During the operation, the forage seed falls into the sedimentation chamber behind the seed picker. When the seed box is full, the unit stops, and the valve on the side of the seed box is opened to bag the seeds manually. The seed bag can be stored on the counterweight box (6) while the unit continues to operate. The seeds are then transported back to the site for drying before subsequent treatment.

The 9ZQ-2.7 longitudinal inclined drum-type alfalfa seed harvester is shown in Fig. 10.4. It is a medium-sized harvester for direct harvesting and is suitable for large-scale operations of large and medium-sized alfalfa seed bases. The machine consists of a collection table, conveying pipe, settling chamber, fan, bagging auger, frame, and transmission system.

The Shennong 4LSC-200 forage seed harvester produced by the Tiantong Shennong Machinery Group is shown in Fig. 10.5. This machine can harvest in stages and was developed according to the crop properties and agronomic requirements

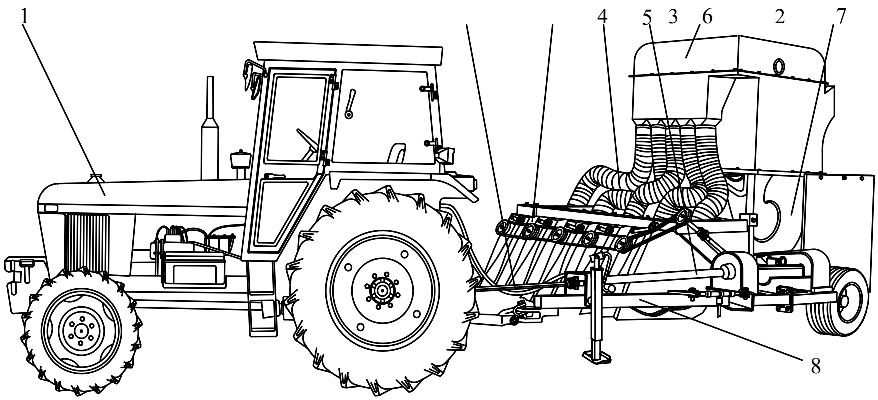


Fig. 10.4 Schematic diagram of the 9ZQ—2.7 alfalfa seed harvester. 1. Tractor, 2. Drive shaft, 3. Collection table, 4. Conveying pipe, 5. Universal joint drive shaft, 6. Settlement chamber, 7. Fan, 8. Frame

Fig. 10.5 4LSC-200 forage seed harvester

of gramineous forage. The machine is used for grass seed collection and forage harvesting and is a good example of the mechanization of forage seed harvesting. In contrast to the traditional harvesting technique of first cutting the crop and then harvesting the seeds, in this harvesting technique, the machine ingests the crop, feeds it into the machine, and then cuts the stalks and harvests the seed. “Post-cutting” results in low energy consumption and high efficiency. This technology meets the agronomic requirements of grass seed collection before the grass harvest.

10.2.2 Forage Seed Processing Machinery

Forage seed is required for planting forage and feed. Good forage seed is needed to increase forage reproduction. The mechanical processing of forage seeds can improve the quality of the seeds, increase the processing efficiency, and reduce the labor intensity, processing costs, and loss of seeds.

Drying is an important component of forage seed processing. Dry grass seed is easy to process and ensures the vitality of the seed. There are two methods of seed drying: natural drying and artificial drying. Natural drying does not require any equipment and can be achieved in sunny locations. Artificial drying is used to speed up the process of seed drying, especially in areas with high humidity. Typically hot air drying at 40–45 °C is used. Air-drying equipment includes thermal rolling dryers and steam dryers.

The grass seed cleaning process consists of the initial cleaning and secondary cleaning. The initial cleaning is performed for seeds with awns, cilia, and seed pods. These tissues on the seed coat make the seeds bulky, adhere to the seeds, and cause poor fluidity. By removing these tissues, the seed volume is reduced, the seed flow is improved, and further seed treatment and operations are facilitated. During secondary cleaning, is impurities are removed by air separation and screening.

Fig. 10.6 The 9ZZ-250ZN intelligent control equipment for forage seed processing

After drying, cleaning, finishing, and grading, the seeds are packaged and stored. There are many types of seed packing machines, and the technology and precision have been improved. The development trends of packaging machines include automatic feeding, weighing, and packaging.

The 9zz-250zn intelligent control equipment for forage seed processing is shown in Fig. 10.6. This equipment provides comprehensive seed processing technology and uses virtual instrument technology to achieve automation, intelligent management, and monitoring of the production line. The intelligent control system provides high performance, expandability, and reasonable cost.

Magnetization increases the function and activity of enzymes in seeds. It also promotes the growth of plant roots and increases the ability plants grown from this seed to absorb nutrients, thus increasing yield. Magnetization causes no external damage, little physiological damage, and is a straightforward operation. At present, research on the magnetization of seeds is still in the initial stage in China. The magnetization equipment, which provides a constant magnetic field, was developed by a team at the China Agricultural University, as shown in Fig. 10.7. Magnetization Magnetization stimulates the activity of seed enzymes, improves the quality of seeds and seedlings, increases the development of the root system of young seedlings, enhances resistance to diseases and insect pests, promotes the absorption of nutrients, and increases production and income.

Cold plasma seed treatment uses cold plasma irradiation to induce changes in the crop's phenotypic traits, improve the seed germination rate and growth potential, and increase yield.

An innovation team jointly established by China Agricultural University, Shandong Agricultural Engineering College, and Shandong Seed Co., Ltd. first proposed

Fig. 10.7 Seed magnetization equipment

the use of cold plasma as a new mutagen to induce epigenetic variation of crops to improve their yield and stress resistance. A pre-sowing treatment of the seeds with cold plasma was investigated to increase seed rejuvenation. Favorable results were obtained for sterilization and disinfection, and several studies were conducted, and the method has been used in forage crops. The cold plasma seed processing equipment developed by the team is shown in Fig. 10.8.

10.3 Research Progress of Forage Production Machinery and Equipment

10.3.1 Grassland Improvement Machinery and Equipment

In the 1960s, China began to develop grassland improvement machinery and equipment that was based on traditional farming equipment. In the last ten years, specialized grassland improvement machinery has been developed, and the type of machinery has evolved from single-purpose tool multi-purpose equipment. Most of

Fig. 10.8 Cold plasma seed treatment equipment

the domestic equipment consists of improved models of traditional farming equipment, and some are based on imported and adapted foreign grassland improvement machinery.

The 9PDQ-2.2 grassland grader is shown in Fig. 10.9. The machine can complete multiple operations such as root cutting, stubble leveling, rat hole leveling, and soil preparation at one time. It has a good profiling function and can realize the adjustment of surface roughness in the range of 0–50 mm. The typical mechanical equipment for grassland restoration in China includes the following machines and tools. The

Fig. 10.9 9PDQ-2.2 grassland grader

Fig. 10.10 Domestic drilling and spraying machine

domestic drilling and spraying machine is used to disturb the sub-surface layer of the grassland to increase soil permeability; it is shown in Fig. 10.10.

The 9BM-3.0 no-tillage forage planter is shown in Fig. 10.11. The machine innovative design the inverted T-type ditcher and the improved double-disc ditcher, which can realize peer mixed sowing and inter-row mixed sowing of grasses, legumes, and other varieties of forage seeds. It is suitable for mechanized planting and improvement of various grasslands. The 9QPY-2.2 Stellera chamaejasme weeding machine is shown in Fig. 10.12. According to the radar ultrasonic distance measurement, the cluster position of Stellera chamaejasme was obtained based on the height difference and the density difference of stems and leaves. Combined with the root cutting operation, the medicinal liquid directly acted on the root of Stellera chamaejasme to accelerate the elimination of Stellera chamaejasme.

The 2BF-3620 no-tillage planter is shown in Fig. 10.13. The machine can complete the process of cutting turf, ditching, fertilization, sowing, covering soil, repression, and other processes at a time, to achieve complete no-tillage operation, suitable for natural grassland reseeding operation in arid and semi-arid areas of China.

Fig. 10.11 9BM-3.0 no-tillage forage planter

Fig. 10.12 9QPY-2.2 *Stellera chamaejasme* weeding machine

Fig. 10.13 2BF-3620 no-tillage planter

Experimental research on the 9LSB-1.80 multi-purpose equipment for grassland improvement developed by the Chinese Academy of Agricultural Sciences has optimized the design of a no-till drill to achieve soil disturbance and grass seed drilling simultaneously for the restoration of grassland vegetation. The 9MSB-2.1 no–till drill developed by the Inner Mongolia Agricultural Machinery Research Institute integrates cutting grass, loosening soil, fertilizing, sowing, and compacting. It cuts the turf when loosening the soil and has low power consumption and high productivity, making it suitable for large-scale grassland improvement and restoration. Song et al. developed the 9ST-460 series vibration spacing scarifier for grasslands. Wang et al. have successively developed specialized grassland restoration and ecological restoration machinery, such as a grassroot cutting machine, equipment for grass cutting, planting, fertilizing, weed removal, and soil tillage.

You Yong et al. at the China Agricultural University designed a soil breakup/root cutting machine that uses the power takeoff of the tractor to power the soil cutter. The machine was used to cut the underground rhizomes of *Leymus chinensis* to restore the degraded grassland, as shown in Fig. 10.14. The productivity of the machine was 0.85 hm^2/h, the width of the surface groove was less than 13 mm, the maximum depth of root cutting was 205 mm, and the turning rate of the soil was zero. No piled-up earthor turf damage occurred. The operation decreased the soil bulk density and increased the yield of *Leymus chinensis* nearly two-fold in the same year.

Song Jiannong at the China Agricultural University and others developed the 9ST-460 series vibration interval scarifier (Fig. 10.15). The soil ridge is cut and replaced by vibration. The disturbance and damage to the grassland were relatively low, and the soil environment was improved. The experimental results show that the improved machine operates stably and reliably and meet the needs of grassland improvement. The operation reduces the soil bulk density and increases the moisture content.

The 9MSB-2.1 type no-till drill for grasslands uses a boardless plow to cut the turf and grassroots, such as *Leymus chinensis*. A chisel type scarifier is used to loosen the soil (the depth is 10–20 cm), and the seeds are sown in the groove; the cutting disc has a sharp edge to cut the turf and reduce resistance (Fig. 10.16).

Fig. 10.14 9QP-830 grass root cutter

Fig. 10.15 9ST-460 grass vibration interval scarifier for grassland

Fig. 10.16 9MSB-2.1 no- till drill for grassland

The equipment designed by the team of Wang Decheng at the China Agricultural University allows for multiple operations, such as mechanized root cutting, fertilization, and seeding (Fig. 10.17). Field experiments showed that the machine

Fig. 10.17 Machinery for root cutting root, fertilizing, and seeding grassland

achieved a root cutting depth of 100–200 mm (adjustable), a sowing depth of 0–50 mm (adjustable), and fertilization depth of 5–55 mm. In addition, the soil disturbance and vegetation damage of the grassland were significantly reduced. The team developed a deep root cutting machine for the removal of weeds such as Malacca and the restoration and growth promotion of *Leymus chinensis*. The machine is used for root cutting and rotary tillage and has important theoretical significance and practical value for promoting the sustainable development of *Leymus chinensis* grassland (Fig. 10.18).

Fig. 10.18 Lotus root crusher

10.3.2 Mechanical Equipment for Forage Planting, Fertilization, and Field Management

1. **Tillage-Harrow-Sowing (fertilizing and pressing) technology**
   First, the grassland is plowed to incorporate the grassroot layer and the loose soil layer. Then, depending on the grassland soil and turf conditions, a heavy or light harrow is used several times to create a smooth surface before sowing the seeds. This method is suitable for degraded grassland withless serious turf hardening.
2. **Rotary-Harrow-Sowing (fertilizing and pressing) technology**
   A rotary tiller is used to cut and incorporate tough grassroots and soil layers for soil preparation prior to sowing. This method is suitable for high-elevation grasslands in low-temperature areas, where vegetation residue does not decompose easily. In this type of grassland soil, the root system is clumped, the roots are intertwined, and the turf is dense; thus, a rotary tiller is better suited for soil breakup and preparation.

   Forage seed can be sown, and the land can be fertilized and compacted using the same machine to preserve moisture.
3. **Technical requirements for sowing**
   Sowing depth: no deeper than 10–15 mm.

   Sowing rate: 1–1.5 kg/mu.

   Row spacing: no less than 15 cm, generally 15–25 cm (Table 10.1).

4. **Types of seeding equipment**

(1) Drill: during the operation, the wheel rotates the seed metering wheel, and the seeds are discharged into the seed conveying pipe from the seed cup in the seed box (using the required seeding rate). The seeds fall into the groove created by the furrow opener and are covered and compacted by the compaction device. The row spacing of drills is generally 15–20 cm, and the sowing depth is 0.5–2.5 cm, which is convenient for weeding, fertilization, and mowing. Moreover, the depth of drill sowing is uniform, resulting in good seedling emergence, which enables competition with weeds. Legumes and gramineous grasses, such as alfalfa and ryegrass, are often seeded using drills.

(2) Broadcast sower: after soil preparation, the grass seeds are sown on the surface using a spreader and are lightly raked and covered with soil. Most natural grasslands are sown by aircraft. The seed germination rate and emergence rate are low, and the hard seed rate and seed amount are high.

(3) Hill-drop plante: according to a certain row spacing and hole spacing, the seeds are placed into prepared holes; the operation consists of creating furrows, seeding, covering with soil, and compacting.

The 2BM-9 no-till drill has a high-clearance frame, a parallel four-bar linkage ditcher, double-disc furrow opener, stepless speed regulation of the seed metering device with a nail wheel, and single profiling and obstacle crossing mechanism of the furrow opener. The equipment is rugged and designed to

Table 10.1 General sowing rate, sowing depth, and row spacing of different types of forages

Forage species	Sowing rate (kg/mu)		Sowing depth (cm)	Plant spacing (cm)	
	Forage harvest	Seed harvest		Forage harvest	Seed harvest
Alfalfa	0.75–1	0.25–0.5	2–3	20–30	45–60
Melilotus	1.25–1.5	0.25–0.5	2–4	20–30	60
Peas		5–7.5	4–5	30	45–60
Lespedeza	1.5–2.5	0.75–1	3–4	20–30	45–60
Leymus chinensis	2.5–3.5	0.5–0.75	3–5	30	45–60
Bromus inermis	1.5–2	0.5–0.75	2–4	15–30	45–60
Spartina compressa	2.5–3	1–1.5	2–4	15–30	45–60
Elymus dahuricus	1.5–2	0.75–1	3–4	15–30	45–60
Agropyron cristatum	1–1.5	0.5–0.75	2–4	15–30	45
Poa pratensis	0.4–0.5	0.2–0.3	Shallow sowing and compaction	15–30	30
Sudangrass	1.5–2.5	1–1.5	3–8	15–30	45
Carrot	0.75–1.25				
Beet	1–1.5		2–3		45–60
Corn	4–5	3–4	4–5	45 × 45	70 × 70
Oats		7.5–12.5	4–5	15–30	30
Barley		10–12.5	4–5	15–30	30

break compacted ground. The sowing depth remains consistent under variable working conditions, and obstacles such as stones and tree roots do not present a problem. The machine is not only suitable for no-till sowing but also seeding forage in grassland (Fig. 10.19). The damage rate of the surface is less than 25%.

The 91ZB-2.0 heavy duty forage planter has a very long outer groove wheel-type seed metering device, a straight-through-type seed conveying pipeline, a wavy agitator, and a heavy-duty V-type roller (Fig. 10.20). It is suitable for forage sowing in arid and semi-arid areas that requires specialize seedbed preparation. The equipment is suitable for sowing one or more types of seed and all types of grasses and legumes without awns in open areas. It can also be used for drilling crops.

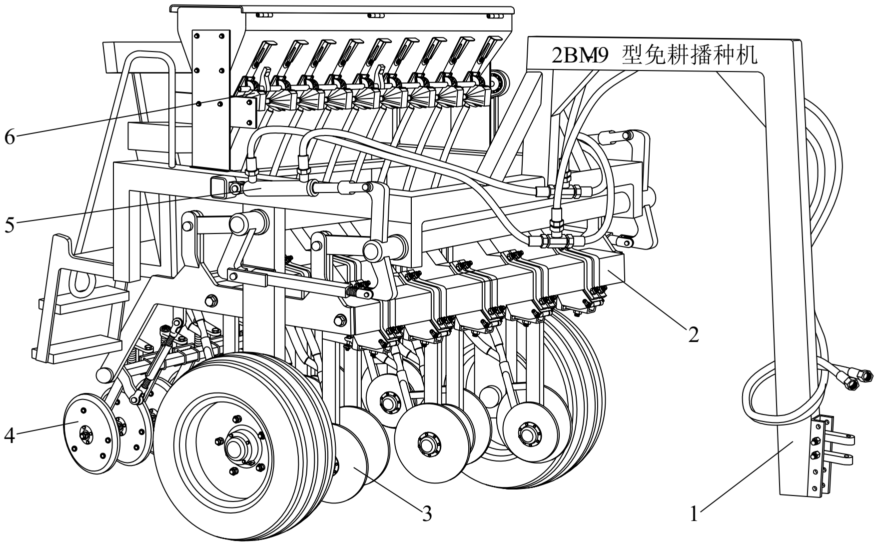


Fig. 10.19 2BM-9 no-till drill. 1. traction frame, 2. Frame, 3. furrow opener, 4. soil roller, 5. hydraulic system, 6. seed metering device

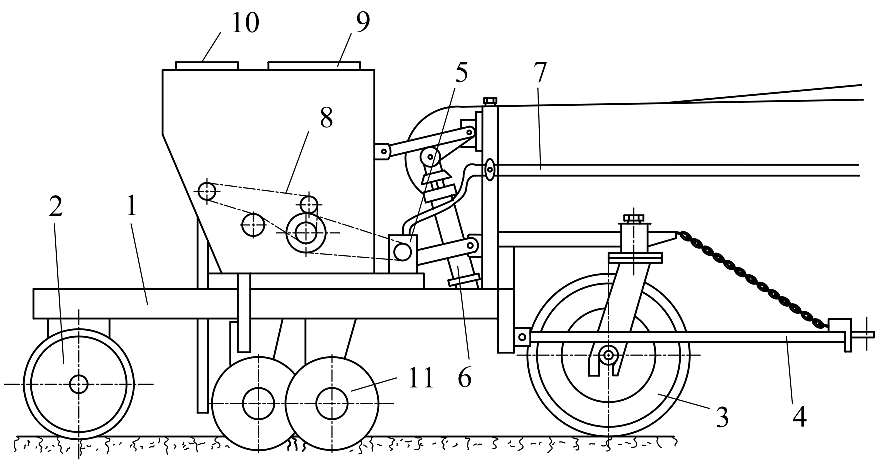


Fig. 10.20 91ZB-2.0 heavy duty forage planter. 1. main frame, 2. Roller, 3. front steering wheel, 4. traction frame, 5. hydraulic motor, 6. hydraulic cylinder, 7. oil pipeline, 8. transmission system, 9. large seed tank, 10. small seed tank, 11. furrower

5. New equipment and technology for forage grass planting

(1) Model 9MSB-2.1 no-till drill for forage seed
Working principle: The disc cutter cuts the turf and cuts off the grassroots using the scarifiers. The loosening shovel is attached to a pipe that delivers fertilizer

into the groove. Then, the opener is pressed to compact the loose soil and open the furrow so that the seeds fall into it from the seed box through the seed delivery pipe. The soil is then compacted by the secondary roller. In the no-till sowing row, the disc cuts the soil and forms a furrow with a certain width and depth. The seeds fall into the seed ditch through the seed delivery pipe, and the secondary compaction wheel covers the seed with soil and compacts the soil. The seed metering device is powered by the wheel using two-stage chain wheels, and then to the seed metering shaft through the first stage sprocket. The fertilizer discharge shaft is driven by the seed metering shaft through the first-stage sprocket.

The equipment is suitable for no-till sowing and reseeding grasslands. It cuts the turf, loosens the soil, fertilizes, seeds, and compacts.

(2) A method for seeding alfalfa on degraded *Leymus chinensis* grassland

A 9QFB-2.4 no-till drill was used to seed alfalfa into natural grassland. The proportion of alfalfa in the natural grassland was maintained by regular fertilization and mowing. This seeding method not only improved the productivity and forage quality of the degraded *Leymus chinensis* grassland and promoted nitrogen fixation in a grassland ecosystem but also provided technical support for maintaining the diversity and stability of grassland systems and establishing high-yield and stable natural grasslands.

(3) An efficient forage planting machine

The high-efficiency forage planter is equipped with a screening bin, which shakes the screen through the expansion and contraction of the air cylinder to disperse the seed and screen impurities. The air blower is directed at the bottom of the screen to separate the healthy grass seeds from the withered seeds, and the dry seeds are discharged from the air outlet by the airflow. The equipment minimizes fertilizer waste and seeding of low-viability seeds (Fig. 10.21).

6. **Field management machinery and equipment**

Due to the slow growth rate of grass seedlings, weeds can easily compete with the seedlings. Therefore, it is necessary to remove weeds and loosen the soil regularly. Field management of forage includes irrigation, weeding, fertilization, and pest control. Commonly used field management machinery and equipment include sprinkler irrigation, weeding equipment, and fertilizer applicators.

10.4 Research Progress of Forage Harvesting Machinery and Equipment

Forage harvesting is an important component of animal husbandry production. The types of harvested forage include dry forage, green forage, and semi-dry forage. The process of harvesting forage consists of several operations, such as cutting, raking, gathering, stacking, and transporting. Mechanized harvesting and hay production can minimize the loss of forage nutrients and provides high-quality forage for livestock,

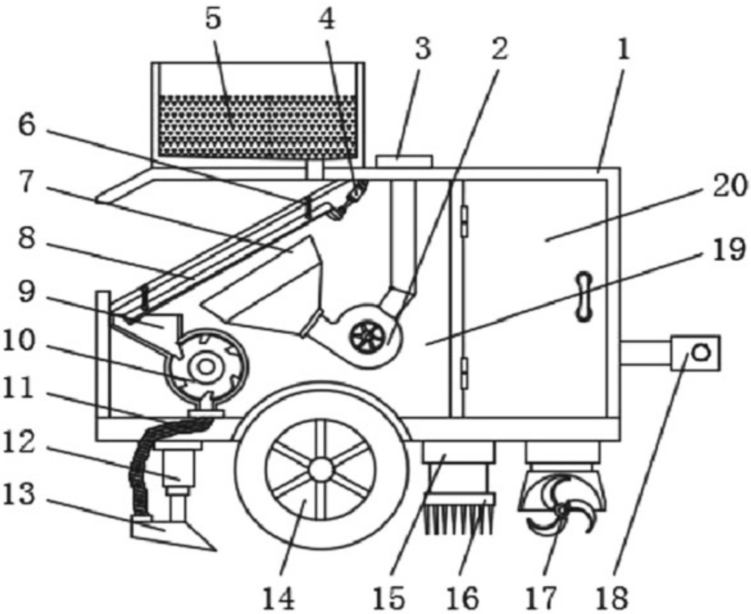


Fig. 10.21 High-efficiency forage planter. 1. fuselage, 2. blower, 3. air inlet, 4. cylinder, 5. Hopper, 6. connecting rod, 7. air outlet, 8. Screen, 9. seed feeding port, 10. seeding wheel, 11. bellows, 12. first hydraulic cylinder, 13. furrower, 14. wheel, 15. second hydraulic cylinder, 16. plow rake, 17. rotary blade, 18. traction head, 19. screening bin, 20. storage container

which increases the forage value and price of hay. China has mechanized forage harvesting, but some problems remain, such as a low degree of industrialization, lack of basic research, poor linkage between traditional and mechanized production technology, and low applicability and reliability of the production equipment. The use of intelligent forage harvesting machinery is the development direction.

10.4.1 Mowers

According to the working principle of the cutting mechanism, mowers are divided into reciprocating and rotary mowers. A reciprocating mower has a fixed blade and a reciprocating blade for cutting the forage, using the principle of supported cutting. A rotary has a high-speed rotating cutter to cut plants, using the principle of unsupported cutting. The cutting speed can reach 50–90 m/s at high-speed operation. The characteristics and scope of application of the two mower types are as follows.

Mowing and conditioning is the first step of forage harvesting. Conditioning prevents leaf twigs from falling off, increases water evaporation by crushing the stems and leaf cuticles, significantly accelerates the drying rate of the forage after harvest, and reduces forage harvest losses. The conditioning mechanism can be a bar or roller, which is used for the conditioning of gramineous and legume forages, respectively. The structure of the conditioners is shown in Figs. 10.22 and 10.23 (Table 10.2).

International research on mowers began earlier, and in the 1970s, research on mowing and conditioning machinery in developed countries was mature. At present, the primary mower manufacturers include John Deere, New Holland, AGCO in the United States, Kuhn in France, Claas in Germany, and MacDon in Canada. Research on mowers and conditioners in China started late, but progress has been rapid. Numerous studies on and improvements in foreign machinery for forage planting in China was conducted. High-efficiency mowers and conditioners have been used for large alfalfa planting areas, such as the Hebei Plain. For the mountainous and hilly areas in Ningxia, Gansu, and other areas in China, several small self-propelled

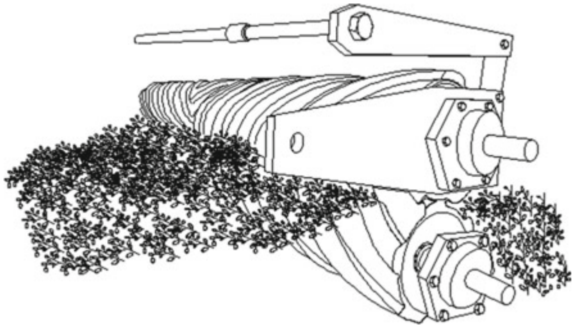


Fig. 10.22 Roller conditioner

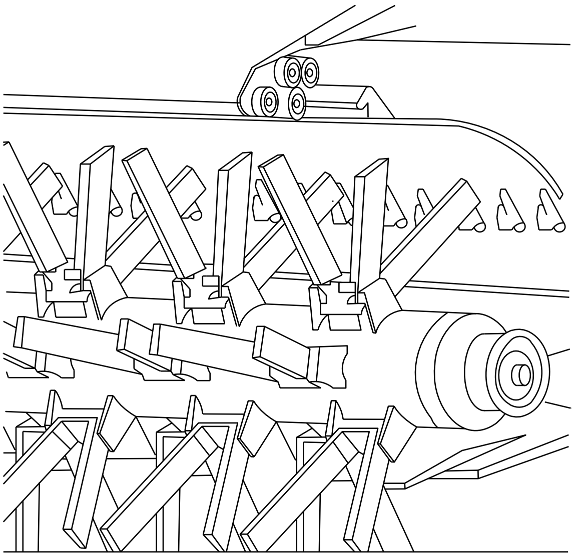


Fig. 10.23 Bar conditioner

Table 10.2 General performance characteristics of reciprocating mowers and rotary mowers

Machine type	Cutting speed (m/s)	Operating speed (km/h)	Power consumption per meter cutting width (kW/m)	Cutter drive mode	Scope of application
Reciprocating	1.6–2.0	6–9	1.5	Crank connecting rod, swing ring mechanism, swing rod mechanism, hydraulic pressure, etc.	Natural grassland and planted grassland
Rotary	60–90	>12	5.1–8.1	Belts, gears, hydraulics, etc.	High-yield densely planted forage

mowers have been designed and developed. These mowers have flexible steering and strong climbing ability. The development of large and small types of mowers and conditioners has promoted the development of the forage grass industry in China.

China Agricultural University has developed a small mower and conditioner (Fig. 10.24) for hilly and mountainous areas. It has a profiling function. Profiling system structure is shown in Fig. 10.25. The cutter head is installed obliquely to achieve ultra-low stubble cutting. The well-designed cutter structure creates a feeding

Fig. 10.24 22.4-3 self-propelled cutting and conditioning machine. 1. runner; 2. cutter; 3. cutter head; 4. roller; 5. upper connecting rod; 6. floating spring; 7. bracket; 8. frame; 9. lower connecting rod; 10. hydraulic cylinder; 11. hydraulic cylinder base; 12. crushing roller

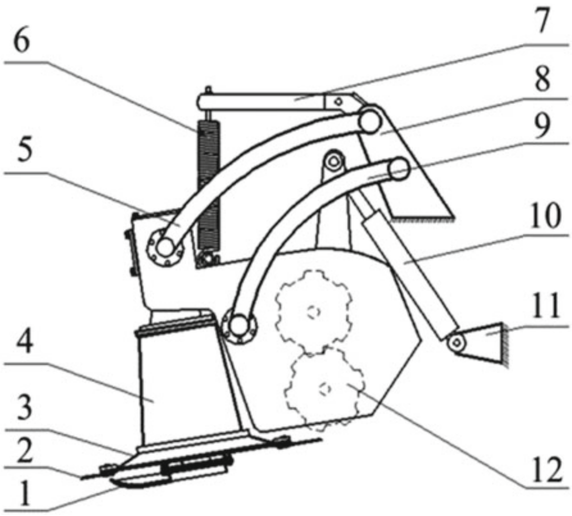


Fig. 10.25 9GZ-1.2 Profiling system structure. 1. runner; 2. cutter; 3. cutter head; 4. roller; 5. upper connecting rod; 6. floating spring; 7. bracket; 8. frame; 9. lower connecting rod; 10. hydraulic cylinder; 11. hydraulic cylinder base; 12. crushing roller

area with negative pressure. The alfalfa plants that fall down in front of the machine are lifted up and cut, which increases the adaptability of the machine.

In general, there is a lack of research on mowers and conditioners in China. Although a number of patents exist, there are few developed products. In the future, it is necessary to conduct an in-depth analysis of the design of conditioning and automatic obstacle avoidance technology to create product upgrades and improve the performance of alfalfa mowers.

10.4.2 Hay Rake

Types of hay rakes include horizontal hay rakes and lateral hay rakes according to the raking direction. The direction of the horizontal rake is perpendicular to the forward direction of the unit, whereas that of the lateral rake is parallel to the forward direction of the unit. A tedder is similar to the lateral rake.

The horizontal rotary hay rake is a widely used hay rake with good quality and high operating efficiency. This rake is generally driven by the power takeoff shaft of the tractor through a pair of bevel gears to drive the rotor. The schematic diagram of the horizontal rotary rake is shown in Fig. 10.26. When the rotor rotates, the up and down movements of the rake are controlled by the cam mechanism. The grass in front of the unit is raked to the side. When the grass is close to the edge of one side,

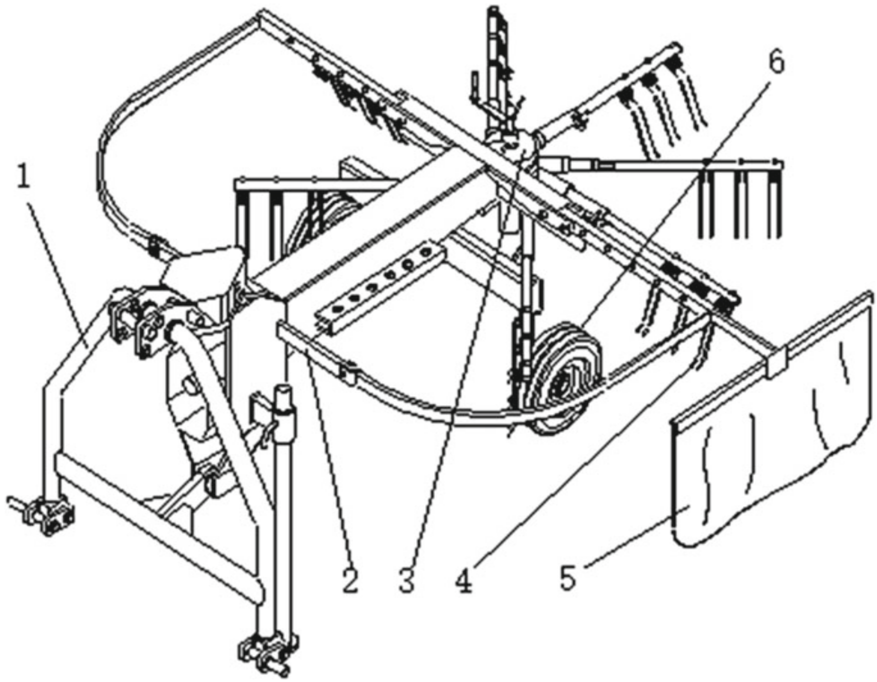


Fig. 10.26 Schematic diagram of a single-rotor horizontal rotary hay rake. 1. Suspension frame; 2. Frame; 3. Transmission box; 4. Rake rotor; 5. Grass curtain; 6. Wheel

the rake lifts and releases the grass, and strips are formed due to the grass curtain. After crossing the row, the rake returns to the raking state.

A multi-rotor horizontal rotary hay rake generally consists of 2 to 4 single rotors. Each rotor is hydraulically or mechanically controlled to rise and fall, which is achieved by a hydraulic or spring mechanism. In some double and four-line models, the operating width is adjusted by a mechanical or hydraulic mechanism.

At present, most of the hay rakes used in China are imported, and foreign hay rakes account for a large part of the market. Commonly used hay rakes in China and internationally include the horizontal rake, finger disc rake, drum side rake, and horizontal rotary rake, and the latter is the widely used type. Domestic hay raking machinery was developed relatively late. Although hay raking equipment has been developed in China, problems remain, such as poor performance and low reliability. Improving the automatic control of the rake and developing key technologies, such as hydraulic stepless adjustment of the operating height, are crucial research objectives in China.

10.4.3 Square Baler

Square baler is a kind of equipment that can compress forage into cuboid bales. It generally includes picking and feeding mechanism, conveying mechanism, baling mechanism and tying mechanism. It can complete the process of picking up, feeding, compressing into bales and knotting at one time.

The knotter is the core working part of the bundling mechanism, and its main function is to tie the wrapping bales into firm and reliable knots. Knotters can be divided into D-type knotters and C-type knotters.

Figure 10.27 is the structure diagram of D-type knotter. It is mainly composed of knotter frame, rope gripper, knotter mouth assembly, bevel gear, worm gear, worm wheel and rope take-off rod of driving rope clamping disc.

Most domestic pickup and baling equipment is imported or based on the design of foreign machinery. There is a lot of room for the development of pickup and baling equipment and the design of the components with regards to the following aspects: the use of automatic control technology for balers, improving the adaptability of the knotting devices and the balers, developing D-type double knotting devices, and improving the baling rate so that the density of the bale is $\geq 200\ \text{kg/m}^3$. Figure 10.28 shows Huade 9YQF-1.5 square baler.

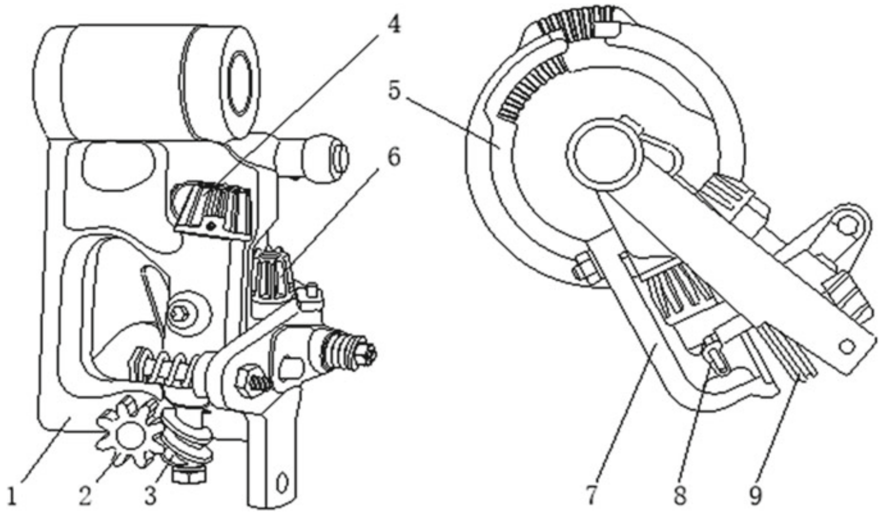


Fig. 10.27 Structure diagram of D-type knotter. 1. Knotter frame, 2. Drive worm gear, 3.Worm, 4. Bevel gear, 5. Toothed disc, 6. Small bevel gear of billhook shaft, 7.Rope stripper, 8.Billhook mouth, 9. Rope gripper

Fig. 10.28 Huade 9YFQ-1.5 square baler

10.4.4 Round Baler

At present, round balers used domestically and internationally can be categorized as internal winding round balers (Fig. 10.29) and external winding round balers (Fig. 10.30). In the first type, the forage is formed into a core as soon as it enters the baler through a transmission belt or chain. As the forage is fed continuously, the transmission belt (chain) wraps it around the core. The difference between the external and internal winding principle is that a conveyor belt, drive wheel, or steel roller is installed around the circumference of the bale chamber in the latter type. When there is enough forage in the bale chamber and all parts of the device are in contact with the forage, the forage is compressed into layers until the required density is reached.

In recent years, relatively mature manufacturing enterprises have emerged in the domestic round baler production, such as China Machinery Minor, Shanghai Shidaer, and Inner Mongolia Huade, but mostly the product based small round baler. The 5120

Fig. 10.29 Internal winding round baler

Fig. 10.30 External winding round baler

round balers (Fig. 10.31) produced by Zhongji Miele have high working efficiency and a wide range of use. The baler can process 15–30 bales per hour. It is suitable for various soft stalk crops and has an adjustable diameter and density. The 9YG-1.3A2 round (Fig. 10.32) baler produced by the Mengtuo Company is mainly used for baling dry forage, as well as rice, wheat, and corn straw. The 9YG-1.4 round baler (Fig. 10.33) introduced by Huade collects and creates round bales of hay and straw gathered into rows. Into the baling chamber using a "serpentine crimping chamber" technology, so that the round baler hydraulic system pressure is greatly reduced at the same density of the rolled bale.

Fig. 10.31 Round baler

Fig. 10.32 9YG-1.3A2 round baler

Fig. 10.33 9YG-1.4 round baler

Shandong Wuzheng and other companies have conducted research on non-stop round balers to improve the baling rate. The SMR1000H green fodder harvester and baler developed by Wuzheng is shown in Fig. 10.34. The straw is harvested and crushed by the front header, and the crushed green fodder is transported to the baling chamber to create round bales. There is a pre-storage box between the header and the baling chamber, and the net is wrapped around the bale in the baling chamber. During unloading, the green fodder is temporarily stored in the container.

Gao Dongming of China Agricultural University and others designed a logarithmic spiral round baling device (Fig. 10.35). This machine can be used for silage baling and does not clog when the forage is uneven and has high humidity and hardness (Table 10.3).

Fig. 10.34 SMR1000H green fodder harvester and baler

Fig. 10.35 Logarithmic spiral round baler

10.4.5 Green Fodder Harvester

The development of green fodder harvesters in China started relatively late. In recent years, many domestic research institutes and enterprises have conducted research, enabling the rapid development of green fodder harvesters, which have become more diverse.

Table 10.3 Specifications of the SMR1000H green fodder harvester and baler

Project	Unit	Parameter
Specification model	/	SMR1000H
Dimensions (length × width × height)	mm	6500 × 2130 × 3330
Structural quality	kg	6670
Supporting power	kw	103
Working width	mm	2000
Cutting length	mm	11/15/19/29
Bale size	mm	1000 × 850
Bale weight	kg	500

Green fodder harvesters are divided into two categories: horizontal and vertical harvesters, according to the structure of the header. In a horizontal harvester, the cutting blade cuts the crop as the harvester moves forward. The crop stalks are transported, cut, and crushed while lying down. The Zoomlion Valley King FL-3000 (Fig. 10.36) produced by Zoomlion is a typical green fodder harvester. In a vertical green fodder harvester, the cutting blade cuts the crop stalks of the upright crop. The stalks are crushed and transported. Representative models include the 9265A (Fig. 10.37) and Mu Shen 9QSZ-3000 (Fig. 10.38).

The green fodder harvesting machinery in the domestic market is highly variable, and a large gap remains between the domestic and foreign models in terms of the operating speed, working width, power loss, and stability. Domestic companies cannot compete with foreign companies at this time.

Fig. 10.36 FL-3000 green fodder harvester

Fig. 10.37 9265A green fodder harvester

Fig. 10.38 9QSZ-3000 green fodder harvester

10.5 Research Progress of Forage Processing Equipment

Research on forage processing technology in China began late, and the problems include a low output, high energy consumption, and lack of technical standards. Independent research and development have resulted in good progress of China's forage processing technology.

10.5.1 Research on Forage Drying Technology and Equipment

Types of forage drying include natural drying, solar drying, air-drying, and high-temperature, rapid drying. Natural drying includes sun drying, shade drying and trellis drying. This drying method is affected by the weather, and the drying time has a significant impact on the forage quality; in addition, leaves and debris remain after dried forage is baled. The drying rate should be high, and the drying time should be short to ensure high-quality forage and prevent the loss of nutrients.

Solar drying uses solar energy for drying forage in buildings. It has the advantages of using a clean and renewable heat source and a simple structure; however, the temperature of the drying medium varies widely, is affected by the environment, and the drying process is long. Types of solar drying include natural convection, forced convection, greenhouse drying, convection/dehumidification drying, and tunnel drying. In recent years, China has begun to use solar drying equipment for forage drying. The solar forage drying equipment developed by Hainan University uses solar collectors and electric heating wires and a multi-layer grass conveying device. A uniform wind temperature control system has been used to dry stylosanthes. The drying efficiency is 0.52 t/d, and the equipment has a simple structure, low energy consumption, and a low environmental impact (Fig. 10.39).

The solar drying equipment for forage bales developed by the Chinese Academy of Agricultural Mechanization Sciences can dry bales with leguminous and gramineous forage to improve the forage quality. The equipment is shown in Fig. 10.40.

Air-drying and high-temperature, rapid drying methods typically use drying equipment such as a hot-blast stove or hot air to increase the moisture difference between the material and the atmosphere to accelerate the loss of moisture in the forage. The main drying component is the rotary drum. The drying process is as

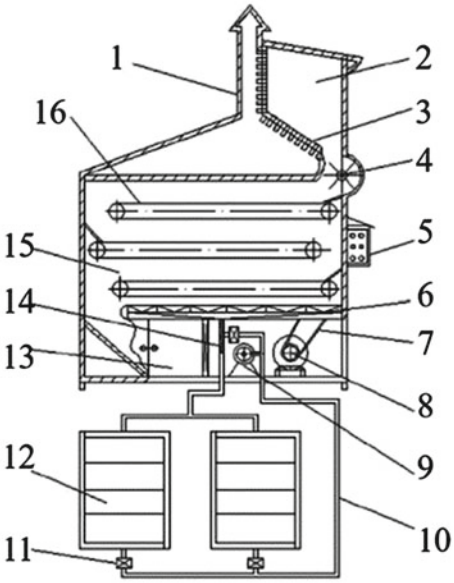


Fig. 10.39 Structure of the solar forage drying equipment. 1. Exhaust chimney, 2. Weed box, 3. Waste heat board, 4. Grass inlet device, 5. Control device, 6. Air evening plate, 7. Transmission device, 8. Motor, 9. Blower, 10. Air duct, 11. Air control valve, 12. Solar collector, 13. Hay box, 14. Electric heating wire 15. Drying chamber, 16. Grass conveying device

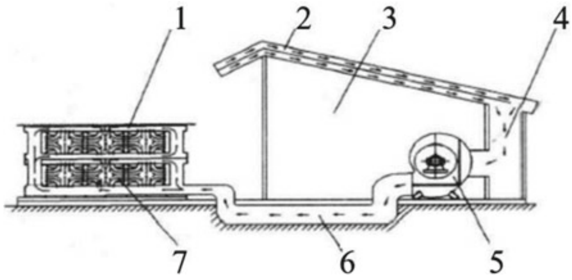


Fig. 10.40 Solar drying equipment for forage bales. 1. Bale storage, 2. Solar air collector, 3. Grass storage warehouse, 4. Air duct, 5. Fan, 6. Underground air duct, 7. Bale

follows. Forage grass with a moisture content of about 45–75% enters the drum dryer**.** The forage is continuously fed and scattered under the inner layer of the shoveling plate and moves forward in a spiral manner. As the material moves and turns, heat exchange occurs between the forage and the hot air, and the dried grass is rapidly moved out of the drum by wind action. The moisture content of the forage is reduced to 14–18%, and the forage is discharged by the screw conveyor.

Room temperature blast-drying is usually combined with natural drying. The forage is dried to a moisture content of 35–40% in the field and is then dried in a drying room equipped with several high-power blowers. The floor of the drying room has ventilation ducts with ventilation holes.

In the low-temperature drying method, a forage drying room equipped with preheating boilers, blowers, and forage conveying equipment is used. Coal or electricity are used as energy sources to heat the air to 50–70 °C or 120–150 °C and blow it into the drying room. Drying is typically achieved after several hours.

High-temperature, rapid drying refers to the use of high-temperature airflow (about 500–1000 °C) to reduce the moisture content of the forage to 14%-15% in a few minutes. Drum-type drying equipment is typically used and consists of a single drum or three drums. The method has high productivity and high drying efficiency and is widely used. Research on high-temperature, rapid drying equipment began early in developed countries, and the technology is relatively mature. The equipment has the characteristics of short drying time, high drying efficiency, and high productivity. In recent years, research on high-temperature, rapid drying equipment for forage in China has made good progress and is based on foreign research. China Agricultural University independently developed the 9G-650 type high-temperature, rapid drying equipment in 2004. It combines airflow drying and drum drying, uses a multi-stage drying process, with an inlet temperature of 400 °C, hourly moisture evaporation of 1.132 t, and a unit heat consumption of 4400 kJ/kg. The structure of the equipment is shown in Fig. 10.41.

In 2006, Northeast Agricultural University developed a quadruple drum forage dryer, which uses fuel oil as the heat source and a pre-drying section to achieve forage drying. The diameter of the drum is 3.6 m, and the drying rate is 1.5 t/h. The wind speed of the equipment alternates from low to high to low. The material passes

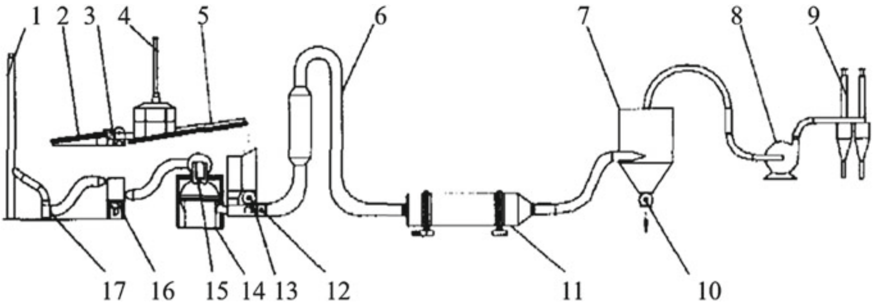


Fig. 10.41 9G-650 high–temperature, rapid drying equipment. 1. Flue gas dust removal device, 2. Raw material conveyor belt, 3. Chopping device, 4. Dust removal device, 5. Crushed material conveyor belt, 6. Air drying tube, 7. Cyclone separator, 8. Main induced draft fan, 9. Cyclone dust collector, 10. Discharge air shutter, 11. Drying drum, 12. Stirring and drying device, 13. Feeding air shutter, 14. Coal-fired hot-blast stove, 15. Heat exchanger, 16. Tube dust collector, 17. Flue gas exhaust fan

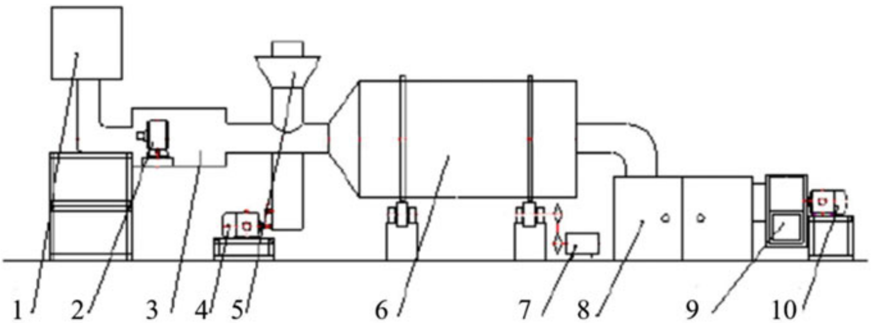


Fig. 10.42 Quadruple drum forage dryer. 1. Fuel oil engine, 2. Inlet motor, 3. Combustion chamber, 4. Feed motor, 5. Feed port, 6. Roller, 7. Roller motor, 8. Collector, 9. Outlet fan, 10. Outlet fan motor

through the outer cylinder and through the middle cylinder and is discharged from the inner cylinder. The structure of the equipment is shown in Fig. 10.42.

10.5.2 Forage Shredding Equipment

Forage shredding equipment typically uses cutting knives, which is the simplest processing method. The forage is fed into a crushing device that rotates at high speed, and the forage is cut into pieces as it is being fed between the fixed knife and rotating device equipped with knives. Shredded forage requires less energy consumption by livestock when consuming the feed and increase the feed intake rate. The schematic diagram of the shredding equipment is shown in Figs. 10.43 and 10.44.

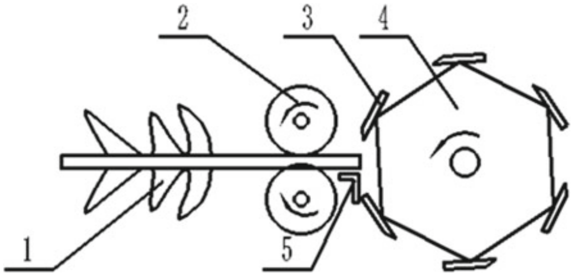


Fig. 10.43 Roller shredding equipment. 1. Forage, 2. Feeding roller, 3. Rotating movable knife, 4. Shredding roller, 5. Fixed knife

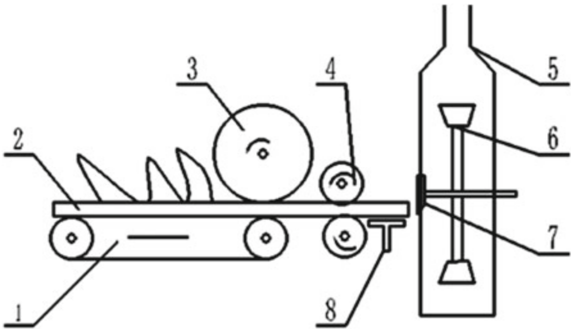


Fig. 10.44 Disc cutter shredding device. 1. Feed chain plate, 2. Forage, 3. Guide roller, 4. Feeding rollers, 5. Output port, 6. Throwing plate 7, Rotating movable knife, 8. Fixed knife

10.5.3 Feed Pelleting and Briquetting Equipment

The general working principle of the forage pelleting machine (crushing, processing, and pelleting) is that the forage is fed into the processing compartment and is crushed by a hammer. The forage is crushed in the radial direction, formed into strands, and output. The powdery material that has been crushed and separated is treated with heat and moisture, and the forage material is formed into cylindrical or other shaped particles by the pressure of the pelletizer. Pelleting prevents forage components from degrading during mixing, transportation, and feeding, ensures high nutritional value, and reduces waste. Feed pelleting increases the conversion rate of feed and ensures consumption by livestock and balanced nutrition.

The following types of feed pelleting equipment have been developed.

Cavity extrusion type: the material is squeezed through a pair of rollers with a cavity at a constant speed and reverse rotation.

Extrusion type: a template with a hole and a pressure roller are used to extrude the prepared material; particles are formed by friction resistance.

Fig. 10.45 MUZL610 pellet machine

Punching type: The punching plug is used with a reciprocating linear motion to press the material into the cavity to create pellets.

Representative models in China include the MUZL610 (Fig. 10.45) pelleting machine developed by the Muyang Group. The equipment consists of a feeder, a dual-shaft differential conditioner, and a single ring die pelletizer, with a production capacity of 3000–13,000 kg/h.

Chapter 11
Laws and Regulations on Forage in China

Fuyu Yang, Xusheng Guo, and Kuikui Ni

11.1 The Seed Law of the People's Republic of China

The Seed Law of the People's Republic of China (the Seed Law) was promulgated and implemented in 2000. At that time, the seed industry of China was in the process of transition from a planned system to a market economy and in the development stage of separating government with private enterprises. The Seed Law played an important role in developing diverse market entities and invigorating the seed market. It can be said that among the agricultural and forestry industries, the seed industry has achieved legal governance in an earlier time.

The Seed Law was revised and approved by the 17th meeting of the Standing Committee of the 12th National People's Congress of the People's Republic of China on November 4, 2015. The revised Seed Law has been implemented since January 1, 2016.

The Seed Law is composed of 10 Chapters and 94 Articles. The main contents include germplasm conservation, variety selection, validation and registration, new variety protection, seed production and management, seed supervision and management, seed import and export and cooperation with foreign countries, supportive measures and legal responsibilities.

The purpose of the Seed Law is to protect and rationally utilize germplasm resources, regulate breed selection, seed production, management and use, safeguard the legitimate rights and interests of breeders, seed producers, operators and users, improve the quality of seeds, promote seed industrialization, and promote planting and forestry.

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The idea of the revision of the Seed Law: first, focus on building a modern seed industry system framework; establishing a modern seed industry system is an important strategic measure to ensure national food security, seed industry safety, ecological security, protect farmers' rights and interests, and promote agricultural modernization. The Seed Law was revised based on the strategic and basic core industry status of the seed industry, and striving to build a modern seed industry legal system with industry as the leading factor, enterprise as the main body, focusing on the "integration of industry, university and research", "combination of cultivation, reproduction and promotion", independent innovation capability, intellectual property protection capability, enterprise market competitiveness, seed supply security capability and market supervision capability.

Second, the decisive role of the market in allocating resources and the strict supervision of the government should be combined. Adhering to market-oriented reform, the resource allocation of seed industry should be mainly determined by the market. Except for public welfare research, others should all follow the principle of surviving the fittest through market competition. At the same time, government regulatory boundaries should be delineated, regulatory responsibilities clarified and a strict management model under market orientation established. The government's supervision must conform to the laws of the market economy and the law of the development of seed industry. It can neither involve in all matters, nor can it do nothing. The key points of supervision are planning, market access, market order, quality standards, and safeguarding farmers' rights and interests. In the supervision process, we will supervise the whole process in advance and follow all relevant lows.

The third is to grasp the degree of 'transformation and upgrading' and proceed step by step. The design of the seed industry system should not only reflect the development direction, but also cannot surpass the development stage. The reform path should follow the idea of "being gradual" and "running step by step" without rush to success. It should be compatible with the development level, scientific research level, government supervision ability and acceptance of reform participants at the present stage. We should learn from the international advanced seed industry management experience but do not blindly copy.

The new Seed Law transforms the principles and policies of the Party Central Committee and the State Council on the development of China's seed industry and the proven practices into legal norms. It covers germplasm conservation, seed industry science and technology innovation, protection of new plant variety rights, major crop variety approval and non-major crop variety registration, seed production and operation license and quality supervision, seed industry safety review, genetically modified variety supervision, seed law enforcement system., seed industry development support protection and legal responsibility. If the pre-revision Seed Law is the top-level design of the seed industry in the stage of transition from the planned economy to the market economy, then we can say that the new Seed Law is the top-level design of the development system for modern seed industry, thus its significance is great and far-reaching.

11.2 The Grassland Law of the People's Republic of China

The Grassland Law of the People's Republic of China (the Grassland Law) is a law enacted for the purpose of protecting, constructing and rationally utilizing grasslands, improving the ecological environment, maintaining biodiversity, developing modern animal husbandry and promoting sustainable economic and social development.

The Grassland Law was adopted at the eleventh meeting of the Standing Committee of the Sixth National People's Congress on June 18, 1985 and effective as of October 1, 1985. The current version is amended for the second time at the third meeting of the Standing Committee of the 12th National People's Congress on June 29, 2013.

The Grassland Law is composed of 9 Chapters and 75 Articles. Its main contents include grassland ownership, planning, construction, utilization, protection, supervision and inspection, and legal responsibilities.

The newly revised Grassland Law stipulates that the state adopts the principles of scientific planning, comprehensive protection, key construction, and rational use of grasslands to promote the sustainable use of grasslands and the coordinated development of ecology, economy and society. Governments at all levels should strengthen management of grassland protection, construction and utilization and shall incorporate the protection, construction and utilization of grassland into the national economic and social development plan. Any unit or individual shall have the obligation to abide by the laws and regulations of the grassland and protect the grassland, and they shall enjoy the rights of supervising, reporting and suing in violation of grassland laws and regulations and destruction of the grasslands.

The Grassland Law clearly defines the concept of grassland that the grassland referred to in this Law refers to natural grassland and artificial grassland. At the same time, it stipulates that natural grassland includes grassland, grass hills and grass slopes, and artificial grassland includes improved grassland and grassland returned from farmland and excluding urban garden grassland."

The Grassland Law also stipulates that the ownership and use of grassland shall be protected by law, and no unit or individual may infringe upon it. However, the fifth section of the original Grassland Law points out that in case of special circumstances, it is necessary to temporarily adjust the use of grasslands in accordance with the principle of voluntariness and mutual benefit. While the new Grassland Law clearly stipulates that during the grassland contract management period, the grassland used by the contractor shall not be adjusted. If it is necessary to properly adjust, it must be agreed by at least two-thirds of the villagers or herders who are the members of the collective economic organization, or by at least two-thirds of the villager or herder representatives, and reported and approved by the grassland administrative departments of the people's governments at the township and county levels. If the collectively owned grassland or the grassland owned by the state that is legally determined to be used by the collective economic organization is contracted by a unit or individual other than the collective economic organization, it must be agreed by more than two-thirds of the members of the village or herd meeting who are members of the collective economic organization or by more than two-thirds of the villager or herder representatives, and approved by the people's government at the township level. The revised Grassland Law is more specific compared with the original Grassland Law. What's more, grassland overgrazing is considered to be an important cause of grassland desertification and degradation. In order to change the situation of grassland overgrazing, the new Grassland Law clearly stipulates that grassland contractors should make rational use of grassland and must not exceed the amount of livestock ratified by the grassland administrative department. Contractors who violate the regulations will be punished accordingly.

In order to prevent the harm to the grassland ecological environment caused by the blind introduction of exotic grass species, the Grassland Law clearly stipulates the verification of new grass varieties, i.e., the new grass varieties must be examined and approved by the National Grass Variety Approval Committee, and can only be promoted after announced by the grassland administrative department of the State Council.

Grassland fence construction and livestock captivity are effective measures to restore grassland vegetation and improve the ecological environment. The Article 35 of the Grassland Law stipulates regulations on livestock captivity in agricultural areas, semi-agricultural and semi-pastoral areas and conditional pastoral areas. It is an arduous task to implement livestock captivity in pastoral areas, semi-agricultural and semi-pastoral areas, and to change traditional grassland livestock production methods. The state should provide corresponding subsidies to farmers and herdsmen for implementing livestock captivity. Therefore, the new Grassland Law also clarifies that in the grassland grazing ban and rotational pastoral areas, the state grants food and financial subsidies for the implementation of drylot feeding, and the specific measures are prescribed by the State Council or the relevant departments authorized by the State Council. Until now, the area of grassland fences in the country has exceeded 15 million hectares. Since the implementation of the Western Development Strategy in the country, the national investment in grassland protection has been further increased. The construction of grassland fences, combined with artificial grassland, forage material bases, livestock sheds and other constructions in the main pastoral areas lay a foundation for the implementation of natural grassland grazing prohibition and regional grazing, and drylot feeding, effectively alleviating the grazing pressure on natural grassland. Therefore, the ecological environment of some pastoral areas has been significantly improved.

In order to reduce the destruction of grassland by non-productive activities, the Grassland Law has issued regulations related to prohibitions on the driving of motor vehicles other than rescue and disaster relief in the grasslands. Because the herdsmen's use of motor vehicles during the relocation of pastures may not be avoided, the new Grassland Law should make more flexible provisions: "in addition to the rescue vehicles and the relocation of herders, motor vehicles are prohibited from leaving the roads and driving on the grasslands, destroying the grassland vegetation. If it is necessary to leave the road and driving on the grassland for activities such as geological exploration and scientific investigation, it shall submit the driving route plan to the grassland administrative department of the people's government at the county level and execute after confirmation.“

Insufficient investment in grassland construction and protection, and imperfect mechanisms are the important reasons for the low production level of grassland animal husbandry in China. According to statistics, from 1949 to 1996, the state invested a total of 4.6 billion Yuan in the grassland in 12 provinces and autonomous regions, and the average annual investment in grassland per Mu was only 3 to 4 cents, and a considerable part of it was used by the administrative sectors at all levels. Therefore, in order to establish a stable and effective investment guarantee mechanism for grassland protection, the new Grassland Law stipulates that the governments at all levels shall arrange funds in the national economic and social development plans at the same level according to the local grassland protection, construction and utilization plans for grassland improvement and artificial grass planting, and no unit or individual may intercept or misappropriate; the financial and auditing departments at or above the county level shall strengthen supervision and management.

On the basis of summarizing the practical experience of the implementation of the original Grassland Law for more than 20 years, the new Grassland Law proposes to further improve the legal system of grassland protection, construction and utilization, aiming to mobilize the enthusiasm of farmers and herdsmen in protection and rational use of grassland through policies and regulations, to improve grassland ecological environment and realize the sustainable use of grassland and the healthy and stable development of animal husbandry.

11.3 Measures for the Management of Grasses

The Measures for the Management of Grasses (the Measures) was announced by the No. 56 Order of the Ministry of Agriculture on January 12, 2006, and revised by the No. 5 Order of the Ministry of Agriculture on December 31, 2013, No.3 Order of the Ministry of Agriculture on April 25, 2014, and the No.1 Order of the Ministry of Agriculture on April 29, 2015.

The Measures formulated in accordance with the Seed Law and the Grassland Law were reviewed and approved at the 2nd executive meeting of the Ministry of Agriculture on January 5. The Measures is composed of 8 Chapters and 53 Articles. The main contents include the basic principles of grass seed management, grass germplasm resources protection, grass variety selection and validation, grass seed production, grass species management, grass seed quality, and grass seed import and export management. After the implementation of the new Measures, the Interim Measures for the Management of Forage Seeds (Trial) issued by the Ministry of Agriculture, Animal Husbandry and Fisheries on October 25, 1984 was abolished at accordingly.

China has rich grass resources and there are more than 6,700 species. By the end of 2005, there were more than 300 varieties of grass and forage crops approved by the National Grass Variety Approval Committee. In recent years, grassland ecological protection in China has been continuously strengthened. The development of grassland and grassland animal husbandry has been strong, and the urban and rural greening industry has flourished, putting forward higher requirements for grass seed production and management. After China's accession to the WTO, the international trade of grass species has become more frequent, and new challenges have been raised in the quality inspection and quarantine of grass seeds. However, at present, the grass breeding system in China is not perfect, the production level of grass seeds is relatively low, the management of grass seed production and management enterprises is not standardized, the quality and competitiveness of grass seeds are not high, which is far from meeting the needs of ecological construction, grass industry development, urban and rural greening and international trade. In some places, there even exists the phenomenon of selling fake and shoddy grass seeds to farmers, which damages the legitimate rights and interests of farmers and herdsmen.

The promulgation of the Measures will play an important role in strengthening the protection of grass germplasm resources, standardizing the production and management of grass seeds, inspection and quarantine and import and export management, improving the management level of grass seeds and enhancing the international competitiveness of grassland enterprises in China.

11.4 Regulations on the Certification of Grass Varieties

According to the No. 1605 announcement of the Ministry of Agriculture on July 7, 2011, in order to strengthen the management and review of grass variety certification and scientific, impartial and timely reviewing the grass varieties, the Regulations on the Certification of Grass Varieties (the Regulations) was developed based on Article 29 of the Grassland Law, Articles 15 and 76 of the Seed Law and the relevant regulations of the Measures for the Management of Grass Seeds issued by the Ministry of Agriculture.

The Regulations is composed of 6 Chapters and 22 Articles. Its main contents include the national grass seed certification committee, application and acceptance, approval and announcement, supervision and management.

Article 29 of the Grassland Law stipulates that new grass varieties must be examined and approved by the National Grass Variety Examination and Approval Committee and announced by the Grassland Administration Department of the State Council. The relevant provisions of the Land Management Measures and the Grass Variety Examination and Management Regulations issued by the Ministry of Agriculture further clarify the requirements for new grass varieties to be approved by the National Grass Variety Approval Committee before listing.

Articles 15 and 92 of the Seed Law stipulate that the number of major crops that need to be approved for promotion is reduced to five, namely rice (Oryzasativa), wheat (Triticumaestivum), corn (Zeamays), cotton (Gossypiumspp) and soybean

(Glycinemax). Article 22 stipulates that the state implements a pre-property registration system for some non-major crops. The Ministry of Agriculture is responsible for developing and adjusting the range of non-major crops that should be registered in accordance with the principles of biodiversity conservation, consumer safety and species safety. Non-main crop varieties not included in the registration can be promoted without registration.

11.5 Management Measures for Production Permit of Feed Additives and Additives Premix Feed

The Management Measures for Production Permit of Feed Additives and Additives Premix Feed (the Measures) was passed at the Executive Meeting of the Ministry of Agriculture on 9 December 1999 and implemented since 14 December 1999. It was formulated in accordance with the 9th Article of the Regulation on Management of Feed and feed Additives. It clearly points out that feed additives include nutritional feed additives and general feed additives; the additive premix feed is the homogeneous mixture made up of two or more than two feed additives with the carrier or diluent prepared in a certain proportion. Its dosage in not more than 10% in formulated feed. It also stipulates that the varieties for producing and using feed additives should be listed in the Catalogue of Feed Additives Allowed for Use published by the Ministry of Agriculture.

The Measures has a total of 5 Chapters and 21 Articles. It was modified and published twice according to the No. 26 Notice: Decision on Revision of the 'Management Measures for Production Permit of Feed Additives and Additives Premix Feed' issued by the Ministry of Agriculture and the No. 38 Notice: Decision on Revision of Regulations and Normative Documents for Agricultural Administrative Licensing on 7 April 2003 and 1 July 2004, respectively. Its main contents include the basic conditions, procedures and certificate management of enterprises. The implementation of the production license system has strengthened the safety management of feed quality and played an important role in ensuring the quality and safety of feed products in China.

11.6 General Plan for National Grassland Protection, Construction and Utilization

The General Plan for National Grassland Protection, Construction and Utilization (the Plan) was compiled by the Ministry of Agriculture in view of the weak links in the construction and protection of grasslands in recent years, in order to realize the rational and sustainable utilization of grassland resources, improve the ecological environment, safeguard the national ecological security and promote the development of grassland animal husbandry. It guides the overall planning of grassland protection and construction in China in the future and is of great significance to grassland construction in China.

The Plan is composed of 6 parts: the strategic position and important role of grassland; achievements and main problems of grassland protection, construction and utilization; guiding ideology and objectives of grassland protection, construction and utilization; regional distribution of grassland protection and utilization; grassland protection, construction and utilization of key projects; safeguards.

The Plan is a macro-directive plan for the protection, construction and utilization of grasslands in China and an important basis for the protection, construction and utilization of grasslands. It is of guiding significance to the local governments at all levels in compiling the grassland protection, construction and utilization planning in the region according to the provisions of the Grassland Law of the People's Republic of China.

11.7 Opinions on Accelerating the Development of Modern Crop Seed Industry

China's seed industry has entered the market since 2000. It is relatively weak in variety innovation ability, enterprise competitiveness and seed supply and support ability, which is difficult to meet the needs of modern agricultural development. The CPC Central Committee and the State Council attached great importance to the development of modern agricultural crop seed industry. During the past year or so, they organized relevant personnel to conduct research in scientific research units, seed bases and key enterprises in major seed-producing provinces. On this basis, they drafted the Opinions on Accelerating the Development of Modern Crop Seed Industry (draft for comments). It was submitted to the State Council in early 2011 and passed at the Executive Meeting of the State Council on 22 February.

The Opinions on Accelerating the Development of Modern Crop Seed Industry (the Opinions) is a programmatic document guiding the development of crop seed industry in the new era. It put forward the thought of seed industry development in the future, i.e., guided by the scientific outlook on development, to promote system reform and mechanism innovation, improve laws and regulations, integrate crop seed industry resources, increase policy support, increase investment in crop seed industry, strengthen market supervision, and rapidly enhance the scientific and technological innovation ability, enterprise competitiveness, seed supply guarantee ability and market supervision of crop seed industry in China; to build a modern crop seed industry system with industry as the leading factor, enterprises as the main body, bases as the backing, integration of production-university-research, and breeding and promotion as an integral whole, so as to enhance the development level of crop seed industry in China in an all-round way.

The Opinions is a milestone in the history of crop seed industry in China, which marks the new stage of industrial upgrading in China's crop seed industry.

11.8 Development Plan of Modern Crop Seed Industry in China (2012–2020)

The Development Plan of Modern Crop Seed Industry in China (2012–2020) (the Plan) was officially issued by the General Office of the State Council on 26 December 2012, which is the first comprehensive planning for the development of modern seed industry since the founding of the Republic of China.

The Plan is composed of 6 parts: planning background, general requirements, key tasks, development layout, major projects and safeguard measures. It summarizes the main achievements and main problems of crop seed industry development in China and analyzes in depth the current situation of crop seed industry from domestic and international perspectives. It points out clearly that China is in the new stage of synchronous development of industrialization, information technology, urbanization and agricultural modernization, and it proposed a higher standard for seed industry development to guarantee food security and realize agricultural modernization.

11.9 Opinions of the General Office of the State Council on Deepening the Reform of Seed Industry System and Improving Innovation Ability

The Opinions of the General Office of the State Council on Deepening the Reform of Seed Industry System and Improving Innovation Ability (the Opinions) was published on 20 December 2013. It has new breakthroughs in defining the reform path, refining reform measures and enhancing policy operability. It further highlights the main position of technological innovation in enterprises and puts forward new measures for speeding up the reform of seed industry science and technology system, mobilizing the initiative of scientific researchers, promoting the flow of seed industry resources to enterprises and promoting the innovation ability of seed industry; it proposes clearer and more specific requirements on supporting seed business development, strengthening basic public welfare services, speeding up seed base construction, and strengthening seed market supervision.

The general requirement put forward in the Opinions is to fully play the decisive role of the market in the allocation of seed resources, adhere to the dominant position of enterprises in technological innovation, deepen reform in an all-round way, promote the flow of innovative elements such as breeding talents, technology and resources to seed enterprises in accordance with the law, improve the ability of independent innovation of enterprises, accelerate the construction of commercial breeding system with scientific design, professional division of labor, industrial linkage, and intensive operation. It proposes to protect the legitimate rights and interests of scientific researchers in invention and creation, fully arouse the enthusiasm of scientific researchers, promote the combination of production, teaching and research, and accelerate the transformation of scientific and technological achievements. New breakthroughs will be achieved in key crop breeding, core breeding techniques, new model of joint production-university-research and new mechanism of Multi-input to continuously enhance the ability of seed science and technology innovation, accelerate the development of modern seed industry, and provide scientific and technological support for the construction of modern agriculture with high yield, high quality, high efficiency and ecological security.

11.10 Medium and Long-Term Development Plan for Protection and Utilization of Crop Germplasm Resources in China (2015–2030)

In 2015, China proposed a 16-year (2015–2030) national Medium and Long-term Plan for the Protection and Utilization of Crop Germplasm Resources (2015–2030) (the Plan), and started the third National Census and collection of crop germplasm resources. It is planned to investigate and collect crop germplasm resources in 2200 agricultural counties in China in 5 years or so. Field investigation and rescue collection were conducted in 650 counties with abundant germplasm resources. 100 thousand crop germplasm resources will have been collected; 70 thousand germplasm resources will have been identified, evaluated and stored; effective collection and protection of valuable and wild resources achieved, the total amount of resources saved greatly improved, and the structure optimized.

The Plan is composed of 6 parts: planning background, general ideas, basic principles and development goals, main tasks, system construction and distribution, key action plans and guarantee measures. In key action plans, it focuses on formulating technical specifications for census and collection of different crop germplasm resources such as grain, horticulture, pasture and so on. Cooperation will be strengthened with countries rich in crop origin and diversity such as maize, wheat and potato in Southeast Asia, West Asia and Latin America, as well as large countries with forage germplasm resources protection such as the United States, Russia and Australia to carryout joint investigation and technical exchanges of germplasm resources, establish joint laboratories, share research results and interests, and increase the introduction and exchange of excellent resources. The planning centers on the major needs of the original innovation of agricultural science and technology and the development of modern seed industry, takes “extensive collection, proper preservation, in-depth evaluation, active innovation and sharing utilization” as the guiding principle, takes safety protection and efficient utilization as the core, emphasizes systematicness, foresight and innovation, makes overall planning, implements step by step, and concentrates on major scientific problems and key technical problems in the protection and utilization of germplasm resources. It concentrates efforts on tackling major scientific and key technical problems in the protection and utilization of germplasm resources, further increase the number and diversity of germplasm resources in China, explore and create excellent germplasm and genetic resources, and provide material and technical support for breeding new varieties of crops, developing modern seed industry and ensuring food security.

11.11 Opinions on Increasing Reform and Innovation and Speeding up Agricultural Modernization

On February 1, 2015, the No. 1 Document of the Central Committee of the People's Republic of China issued the Opinions on Increasing Reform and Innovation and Speeding up Agricultural Modernization (the Opinions). It points out that to promote the reform of rural financial system, we should make comprehensive use of fiscal, taxation, monetary credit, financial supervision and other policies and measures to promote the continued inclination of financial resources towards "agriculture, rural areas and farmers" and ensure that the total amount of agricultural credit continues to increase and the proportion of loans related to agriculture does not decrease. At the same time, we will support banking financial institutions in issuing special financial bonds for "agriculture, rural areas and farmers", and encourage eligible agricultural-related enterprises to issue bonds.

The full text of the Opinions is about 12,000 words, which is divided into 5 parts and 32 Articles, including focusing on the construction of modern agriculture, accelerating the transformation of agricultural development mode, focusing on the promotion of farmers' income, strengthening the policy of benefiting agriculture, focusing on the integration of urban and rural development, advancing the construction of new countryside, increasing the vitality of rural development, deepening the rural reform in an all-round way, focusing on the work of "agriculture, rural areas and farmers" and strengthening the construction of the rule of law in rural areas. It also suggest to speed up the development of grassland and animal husbandry, support the cultivation of silage maize and alfalfa as forage, carry out the experiment of grain conversion and the combination of crop and forage, and promote the coordinated development of the ternary cropping structure of grain, cash crops and forage. It also makes specific deployment for optimizing the industrial structure of products and focusing on promoting agricultural quality and efficiency; promoting green production, enhancing the ability of sustainable development of agriculture; expanding new industrial forms and the value chain of agricultural industry; strengthening the drive of scientific and technological innovation, leading modern agriculture to accelerate development; complementing the shortcomings of agriculture and rural areas, consolidating the basis for rural shared development; and increasing rural reform, activating the endogenous driving force of agriculture and rural areas.

11.12 Implementation Plan of Grain Conversion

The Implementation Plan of Grain Conversion ("Grain for Feed") is an agricultural reform carried out by the Ministry of Agriculture. It is mainly based on the cyclic development of planting and feeding, guides the cultivation of high-quality forage and promotes the optimization of agricultural production structure. It also suggest to popularize forage in areas suitable for planting high-quality forage, change the simple granary into "granary + milk pot + meat storehouse", and adjust the binary structure of grain and cash crops into the ternary structure of grain, economy and feed crops. In 2015, the Ministry of Agriculture cooperated with the Ministry of Finance to carry out pilot projects in 30 counties in 10 provinces and autonomous regions including Heilongjiang and Inner Mongolia. With the whole silage maize as the focus, the grass and livestock matching was promoted, the area of grain conversion reached 2.86 million Mu, and 9.95 million tons of high-quality forage was collected and stored, and the expected target was doubled, achieving a win–win effect in both cropping and breeding.

The key point of "grain for feed" is to adjust the planting structure of maize and develop large-scale silage maize suitable for beef cattle, sheep, dairy cattle and other herbivorous animal husbandry. It takes the development of large-scale aquaculture as the carrier, aiming at improving the benefit of planting and breeding, strengthening the key links such as "seed, management, harvesting, storage and utilization", and vigorously implements the development strategy of "seed-breeding, combination of planting and breeding, matching of grass and livestock, combination of grass and enterprise". The demonstration will lead to a new way to develop animal husbandry of characteristic circular development, ecological development, green development and chain-like development.

11.13 Key Points for Development of Animal Husbandry in 2018

In order to carry out the spirit of the Nineteenth National Congress of the CPC and implement the arrangement of the Central Rural Work Conference, the No.1 Document of the Central Committee and the National Agricultural Work Conference, the Ministry of Agriculture issued the Key Points for Development of Animal Husbandry (the Pionts) in 2018 on January 30, focusing on seven aspects of work: reconstructing the new type of relationship between crop and animal husbandry, speeding up the transformation and upgrading of animal husbandry, optimizing the supply structure of animal husbandry, strengthening the quality and safety of feed and fresh milk, continuously promoting the revitalization of dairy industry, strengthening the construction of grassland ecological protection, and completing the long-term basic work of animal husbandry development.

One of the Points is to implement the policy of “Grain for Feed”. Focusing on the boundary area between Inner Mongolia and other provinces and the main maize producing areas in the Huanghai Sea and Huaihai Sea, the policy coverage and implementation scale of grain-to-feed conversion should be expanded and more than 12 million Mu of grain-to-feed conversion should be completed. On the basis of promoting silage maize, high quality forage varieties such as alfalfa, oat and sweet sorghum should also be popularized according to local conditions. Socialized professional storage service organizations should be vigorously developed to improve the commercialized supply capacity of high quality forage. We should actively strive for supporting policies such as purchase of large-scale harvesting machinery and equipment, transportation of forage and financing of harvesting Enterprises to strengthen the research and development of forage utilization technology mode, increase publicity and guidance, and create a good policy atmosphere.

The other main point for the development of animal husbandry in 2018 is to vigorously develop modern grassland industry. We should strengthen the protection of forage germplasm resources and the breeding base for good seed breeding, and examine and popularize a number of excellent herbage varieties; strengthen the popularization and service of advanced and applicable technology in grassland industry, formulate the technical standards and regulations for forage cultivation, processing and storage, and constantly improve the level of industrial development; develop artificial grass planting to suit local conditions, integrating and popularizing grass high-yield cultivation techniques, and constructing a number of standardized grass high-yield cultivation demonstration bases; strengthen policy support, foster and strengthen grass products production and processing enterprises and professional cooperative organizations, create a well-known brand of grass products.

The general idea of the development of animal husbandry is to fully implement the spirit of the Nineteenth National Congress of the Communist Party of China, earnestly study and implement the socialist ideology with Chinese characteristics in the new era led by President Xi Jinping, take the new development concept as a guide, thoroughly implement the decision-making arrangements of the Central Rural Work Conference and the National Agricultural Work Conference, and focus on the implementation of the strategy of Rural Revitalization and the new tasks and requirements of building a beautiful China. Aiming at optimizing supply, strengthening security and protecting ecology, taking “increasing efficiency” as the key point to speed up the transformation of production mode, taking “increasing value” as the key point to speed up the shaping of new industrial forms, taking “improving beauty” as the key point to speed up the reconstruction of planting and breeding relations, taking “increasing green” as the key point to strengthen grassland ecological protection and construction, and continuously improve labor production ratio, utilization of resources and productivity of livestock and poultry to promote high-quality development of animal husbandry and take the lead in realizing modernization in agriculture.