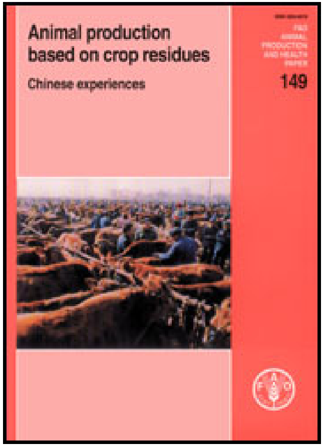
Animal Production Based on Crop Residues - Chinese Experiences



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opinion whatsoever on the part of the Food and Agriculture Organization of the United Nations concerning the legal status of any country, territory, city or area or of its authorities, or concerning the delimitation of its frontiers or boundaries.

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PREFACE

It is a fact that China has to feed its large population, equivalent to 22 percent of the whole world, with only 7 percent of global farmland. How to feed over 1 300 million people is the central issue. Domestic experts in different research fields have proposed various solutions. One suggestion is to establish an intensive grain feeding system, based on local production and imports, as in most developed countries. But how can this be achieved? Let us analyse it. Since Mr. Deng Xiaoping established the so-called "productive related interest distributing system" in 1978, unprecedented production activity has developed in a vast area of the Chinese countryside. For the following six years (1979-1984), the annual increase in grain output (up to 17 million tonne) greatly surpassed population growth at the time. It was a successful policy. However, it was impossible to maintain that high pace relying only on that strategy. The increment fell to less than 4.5 million tonne per year for the next 16 years, despite high government inputs (finance, staff, etc.). Per capita grain availability also fell. Looking towards the future, it is possible that some increase in grain production will take place, but it will certainly be difficult to keep up with population growth.

Another proposal has been to meet the grain demand of China through imports, because it was known that subsidies had been offered by governments of major grain exporting countries. Thus, the greater the imports, the larger the subsidy. However, in contrast to Japan, Rep. of Korea and Singapore, China is a country with a huge population, and if its grain consumption approaches the USA level, there would be an annual demand of 80-100 million tonne of grain, nearly half of total world exports. Grain prices would skyrocket. In this case, what of subsidies? Further, it would be a serious risk for world food security to have China relying mostly on imports. That is the theme of Lester Brown's book *"Who will feed China?*"

Various pasture experts had another proposal. They hoped that grasslands, representing 40 percent of China's surface, would make a substantial contribution to food supply. This optimistic idea sounded reasonable, but the grasslands are suffering from serious degradation, desertification and alkalization processes, which cause serious concern. Everyone would like the government to devote more attention to the pasture problem: strengthening protective measures, reducing overgrazing and augmenting financial support. Then, after generations of hard work, it would be possible to recover the primary ecological system of grasslands. Most pasture experts tend to agree on this approach.

Since the development of an "intensive grain feeding system" is restricted by the lack of grain, and the potential of grassland is also a distant oasis that cannot quench present thirst, then the exploitation of various kinds of non-traditional feed resources is the most obvious way to resolve the issue. Crop residues are the most abundant and widespread of the non-traditional feed resources. Consequently, attention was directed to crop residues as the key missing feed in China.

In the mid-1980s, The MOA started studies on how to improve the efficiency of crop residue use. Soon after, with the support of agricultural colleges, research organizations and agricultural technical services in different areas, some small-scale trials were conducted. In 1987, financial support was offered by FAO and United Nations Development Programme (UNDP), and pilot projects of cattle feeding based on crop residues were conducted in provinces such as Hebei and Henan, in cooperation with the Ministry of Agriculture (MOA). A group of well-known international experts (including E.R. Orskov, F. Dolberg, F. Sundstol and P. Finlayson) visited China, and many Chinese technical officials and experts were sent abroad to study and train. Thus, the techniques for crop residue treatment and animal feeding matured gradually. Based on the success of the pilot projects, 14 experts - led by Guo Tingshuang and Ji Yilun - jointly submitted a written proposal to the Central Government "to develop animal production based on crop residues". Some high-level officials accepted this proposal. As noted earlier, there are diverse positions on this issue, both for and against. Pursuing the philosophy of respecting science and seeking the truth, the Bureau of Animal Production and Health (BAPH) of MOA organized a large-scale debate on this theme in 1991. The proposal for *Animal production based on crop residues* (APCR) than received preliminary acceptance. In 1992, a State Councillor, Mr Chen Junsheng, went to Zhoukou Prefecture in Henan Province to make an on-site observation, accompanied by the author. His report strongly confirmed the importance of APCR for national agriculture. Former Premier Li Peng praised it highly, calling it "such an exciting report". Subsequently, the State Council convened three national conferences within two years on APCR planning. A project demonstrating cattle raising with crop residues began in 1992. From then on, China's cattle sector emerged from a dormancy that had lasted several decades, and began a new period of rapid development. Within only three years, national beef output doubled. Since then, beef production has always led livestock sector growth. More than 90 percent of the beef expansion came from agricultural provinces. The correctness of the APCR policy was corroborated in practice.

Soon after, the State Council decided to expand the APCR rearing approach to include buffaloes, sheep, goats and dairy cattle. Thus far, the APCR has become part of government policy and is currently practised by numerous farmers. By 2000, 13 APCR demonstration prefectures and 380 demonstration counties had been established in the country. For the last nine years, the direct economic benefit of the APCR project has been calculated to exceed ¥ 70 000 million. In addition, the APCR project generated numerous social, agronomic and environmental benefits.

It was then considered necessary to summarize the practical experiences of APCR projects, and put them on a scientific or technical level for their further expansion. Thus, responding to the initiative of FAO, experts were organized to prepare a book to be published and distributed worldwide. Recognizing our limitations, there could be some involuntary mistakes. We kindly ask the readers of this book to point them out to us, so that they can be corrected in future editions.

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May, 2001

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The book *Animal production based on crop residues - Chinese experiences* has finally been made available in English. Its publication has been possible thanks to thousands of technical staff who are working in the front line of animal production. They have been the ones who have popularized the new technology and who have accumulated the valuable experiences that are the source of this book. We express our deep appreciation to FAO for supporting the preparation of this book. In addition, the Bureau of Animal Production and Health, Department of International Cooperation (Ministry of Agriculture, PRC) and the China Agricultural University and their staff, contributed to the editing and offered technical and financial assistance. In the name of the group of authors, we thank them all.

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GLOSSARY OF ABBREVIATIONS AND UNITS

ADF	acid detergent fibre
ADL	acid detergent lignin
APCR	animal production based on crop residues
BAPH	Bureau of Animal Production and Health
BSS	bamboo shoot shell
CF	crude fibre

CP	crude protein
CSC	cottonseed cake
DM	dry matter
IVDMD	*in vitro* dry matter digestibility
MOA	Ministry of Agriculture
MNB	multinutrient block
OM	organic matter
NDF	neutral detergent fibre
RSM	rapeseed meal
SACDP	State Agricultural Comprehensive Development Programme
WSC	water-soluble carbohydrate
VFA	volatile fatty acid

The local measurement of area is the *mu* (1/15 ha; approx. 667 m^2)

The unit of currency is the yuan renminbi (symbol ¥) (US$ 1 ª ¥ 8.27)

Unless otherwise specified, all units are metric (SI) (1 tonne = 1 000 kg)

CHAPTER 1 - INTRODUCTION

Guo Tingshuang and
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Ministry of Agriculture

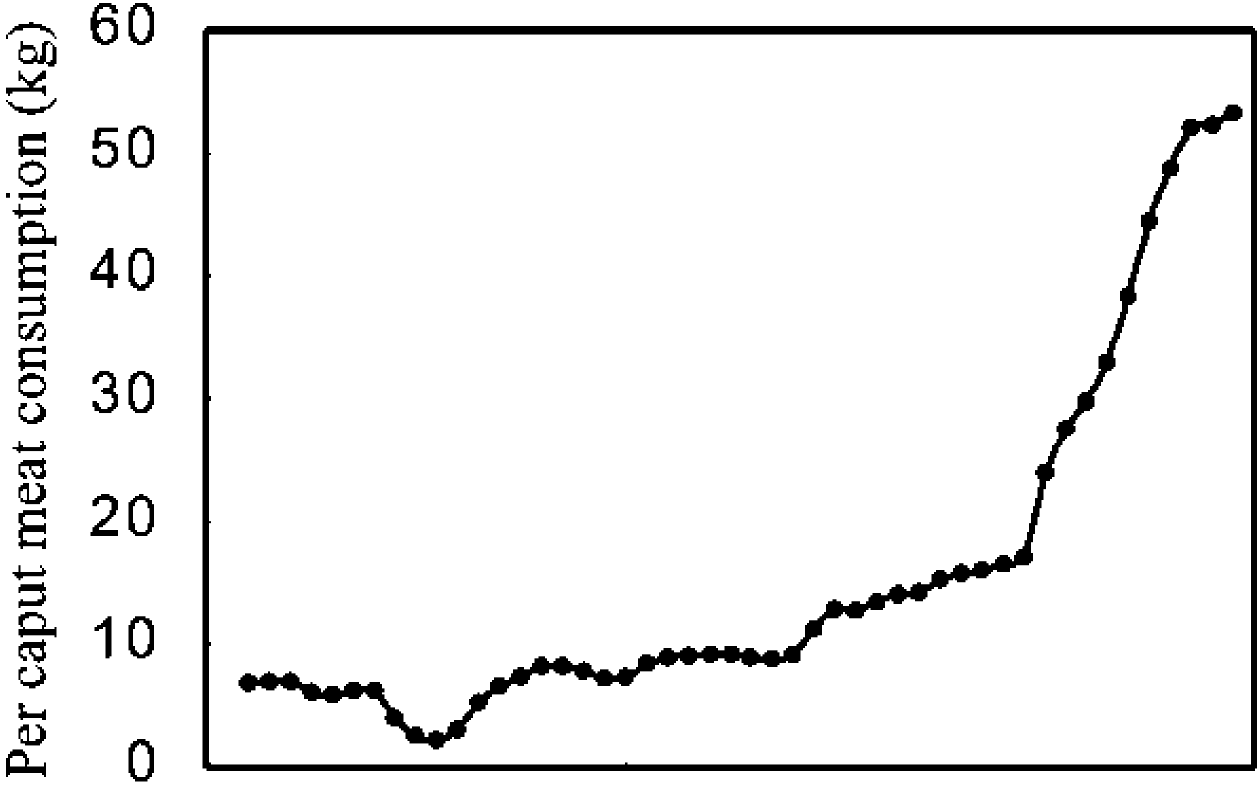
A grain-saving strategy to develop animal production in China

Since the "Reform and Opening-up" of 1978, animal production in China has grown steadily year by year. In 1999, total meat output reached 59.5 million tonne and egg output 21.3 million tonne, both ranked first in the world. For the ten years after 1978, China represented nearly half the total global annual increase in meat and egg production. Even though population increased continuously, per capita meat, egg and milk production rose with an ample margin. Between 1949 and 1979, annual per capita meat consumption amounted to less than 5 kg, but by the end of the 1990s it had increased by 39 kg of meat per capita (Figure 1-1).

Although the livestock sector has shown remarkable achievements in the past two decades, there are also hidden worries. One of the main concerns is the lack of feed grain. Cereal production is a weak link in the national economy.

During the last decade, grain output growth could not keep up with the increase in population, and at the same time arable area has been constantly reduced. Therefore, the future of grain supply may be very serious. One or two exceptional harvest years can not fundamentally change this situation. According to researchers, per capita grain-equivalent consumption in some metropolises such as Beijing, Shanghai, Tianjin, Shenyang, Guangzhou, etc. has already exceeded 400 kg. In Beijing, direct grain consumption was only 120 kg in 1989, but consumption of meat, eggs and milk required the equivalent of 400 kg extra, bring the total to more than 520 kg of grain-equivalent per capita. Grain production per capita in China was only 389 kg in 1999. If the consumption level of meat, eggs and milk in the whole of China had reached by 2000 that of Beijing in 1989, 182 million tonne of additional grain would have been necessary. During the past decade, net increase in grain yield was only 80 million tonne. Therefore, if the livestock sector were to depend mostly on grain, its development would inevitably be seriously restricted.

Figure 1-1. Development of per capita meat consumption in China



1950 1970 1990

Year

The dependency of the animal industry on grain relates to its structure. Over the past decades, due to state promotion, swine rearing developed rapidly and became the largest animal sector in the country. In 1978, pork represented more than 94 percent of total meat output. Since the "Reform and Opening-up," this situation has gradually changed. The proportion of poultry, beef and mutton increased yearly, while that of pork fell. Currently, pork still represents 67 percent of total consumption, but poultry, beef and mutton now contribute 20, 7.8 and 4 percent, respectively. Compared with world data (Table 1-1), China is the leader in pork production, with 50 percent, but only produces 10 percent of beef. Generally speaking, feed conversion efficiency in swine is less than for poultry. On this basis, suitably limiting swine rearing and promoting poultry production ought to be a rational strategy.

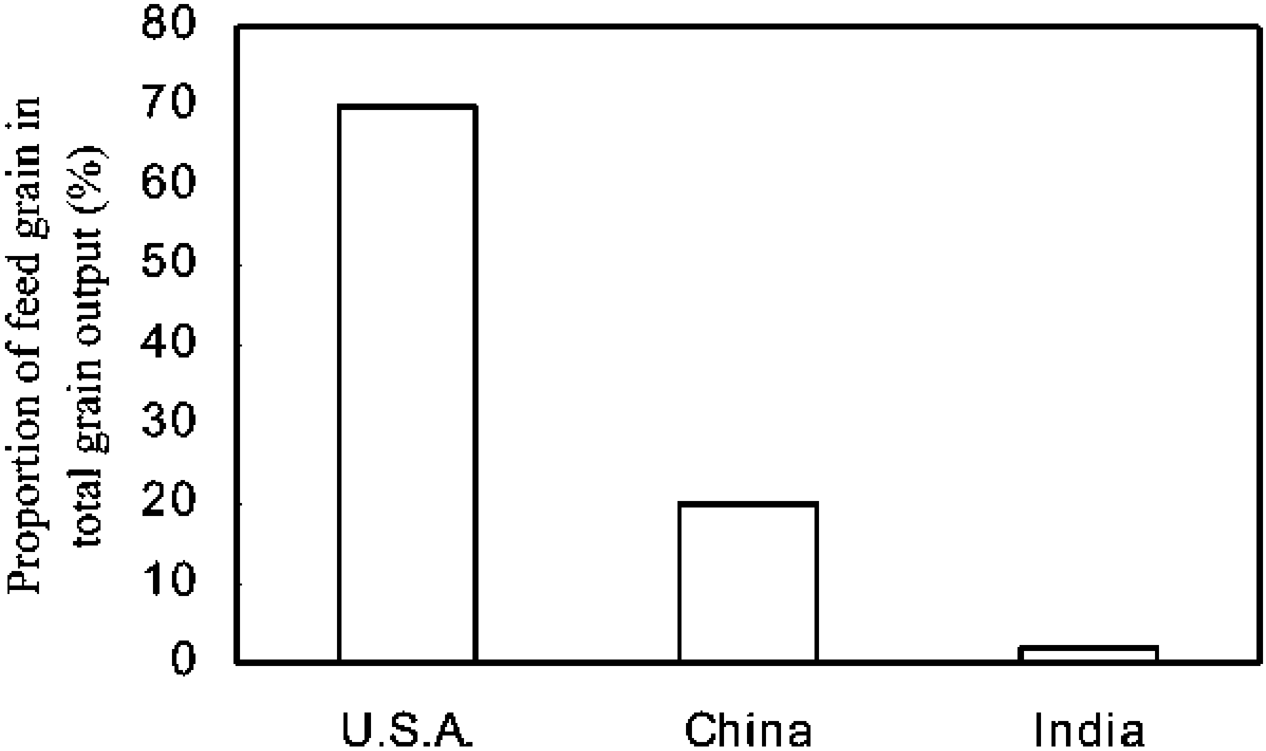
In the past 20 years, great effort was made to develop poultry production, with significant progress made. The proportion of poultry meat rose from 8.6 to 20 percent, and its growth is expected to continue. However, both swine and poultry require concentrates as their main feed and therefore they will be inevitably restricted by grain shortages. The rearing of herbivores without grain, but with small quantities of oil cake, should show considerable development. Adhering to a grain-saving strategy for the industry, the future of China's livestock development can be firmly based on stable feed resources, less susceptible to grain production fluctuations.

Table 1.1. Meat distribution in the world and in China in 1998 (in percent)

	Beef	Mutton	Pork	Poultry meat	Other
World	26.2	5.2	38.9	27.9	1.8
China	7.9	4.0	67.0	20.1	1.1

The well-known economist, Mr Yu Guangyuan, considered that the grain problem in China was essentially a feed issue. As indicated before, per capita grain output is 389 kg, more than enough to cover direct food grain needs (230 kg each), but not enough for feed. It is therefore clear that establishing a grain-saving strategy in the animal sector could help alleviate the problem. Certainly, the significance of this ought not to be underestimated. India, also a developing country with large population and limited farmland, faces a similar situation. Per capita grain yield is slightly more than one half of China's, but India does not need to import grain, because they have adopted a grain-saving approach to feeding livestock. From Figure 1-2 it can be observed that pursuing the USA way, in other words, devoting 70 percent of grain production to animal feeds, over half of the Chinese population would have no food grain. But following India's example, using only 2 percent of grain as feed, China's grain is not only sufficient, but there would be a huge surplus. Of course, it is not advocated to imitate India, but the experience can certainly be a valid reference to consider for the Chinese case.

Figure 1-2. Feed grain as a proportion of total grain output



Arguments for a strategy for herbivores in China

Chinese experts have had active debates for a while on how best to raise domestic herbivores. Whenever mentioning their development, people always think of the vast northern prairie. The verse

> "the blue sky, the boundless grassland,
> while wind blows, grass, cattle and sheep can be found"

is very well known. The northern prairie, with nearly 300 million ha, almost three times the total farming area of the country, has been the basis of traditional herbivore production. In the past several thousand years, Inner Mongolia, Xinjiang, Qinghai and Tibet have been the main regions for herbivore production. For several decades, exploitative use (mainly overgrazing and excessive land conversion of natural pasture to arable) has caused serious deterioration in the northern prairie. Consequently, forage output has declined by 30-50 percent since the 1950s. Meanwhile, animal numbers increased after the founding of People's Republic of China in

1949. The current carrying capacity of the northern prairie for existing animals is insufficient, so how can anyone talk about livestock development there? A fundamental ecological recovery of the northern prairie would require significant investments and the efforts of several generations. Certainly, one could not get the desired result in a short period. Therefore, the development of herbivore production can not be expected from grasslands.

The above argument has been disputed. Someone said that over the past several decades people have just extracted products from the prairie, with little input. The State provided under one yuan (US$ 1 = ¥ 8.27) per *mu* (1/15 ha) of grassland. With sufficient investment to favourably recover the prairie ecology, the huge potential of the grasslands could be exploited for livestock. In the future, the government would need to greatly increase investment in grasslands. However, as China is a developing country, it is unrealistic to expect large investments for this purpose. Recovering the prairies, constructing a whole system with water, grass, forest, machinery and roads, would need at least ¥ 300/*mu,* implying the sum of ¥ 1012 for the 3 300 million *mu* of utilizable grassland - an astronomical figure! The current State annual budget for livestock is only several hundred million *yuan.* If this funding level were devoted solely to grassland reconstruction, a thousand years would be needed. However, this simplistic analysis clearly demonstrates that large investment for prairie rehabilitation is not a viable option. The current urgent issue is to prevent further grassland deterioration. Grasslands must recover gradually, with reasonable inputs.

If natural grassland is not available, what about artificial pastures? There have been suggestions that China should follow New Zealand's approach, and rely on planted grass, with almost no concentrates. The prosperous livestock sector brought New Zealand to its developed status. South China, with over one thousand million *mu* of grassy hills and slopes, and favourable water and climatic resources, better than in the northern prairie, could be transformed into several New Zealands. This proposal has a certain validity, since the southern grassy hills and slopes clearly have an enormous potential. In certain locations, artificial grasslands could be established, but this approach, as a general strategy, is not advisable. This is because the available farmland must be used for food crops, rather than for forage, so as to feed the huge population. New Zealand uses 270 000 km^2 (twice Jiangsu Province) to feed 3.3 million people ad to export (Jiangsu Province has over 50 million). Going the New Zealand way, China's 9.6 million km^2 could only feed 120 million people. And how to feed the rest, over 1 000 million people?

If the grassland strategy for livestock development is not feasible, then what is the option? Extensive research and vast demonstrations have shown that rural areas have an extraordinary potential for herbivore production. In China, there is an annual production of 500 million tonne of grain and 600 million tonne of crop residues (Table 1-2), the latter equivalent to almost fifty times the hay from the northern prairie. Furthermore, the ample supplies of cottonseed cake, rapeseed cake and brans can be used as inexpensive concentrates. Relying on abundant roughage and concentrates, coupled with a benign climate and sufficient qualified staff, the rural areas are rapidly developing and becoming the main source for herbivore products in China. The comparison between Inner Mongolia and Henan Provinces clearly illustrates this. In 1982, Henan Province had 55 000 head of cattle, one sixth of Inner Mongolia. Four years later, Henan Province had surpassed Inner Mongolia, and in 1999 it produced 5 518 million head of cattle, over four times that of Inner Mongolia (Figure 1-3).

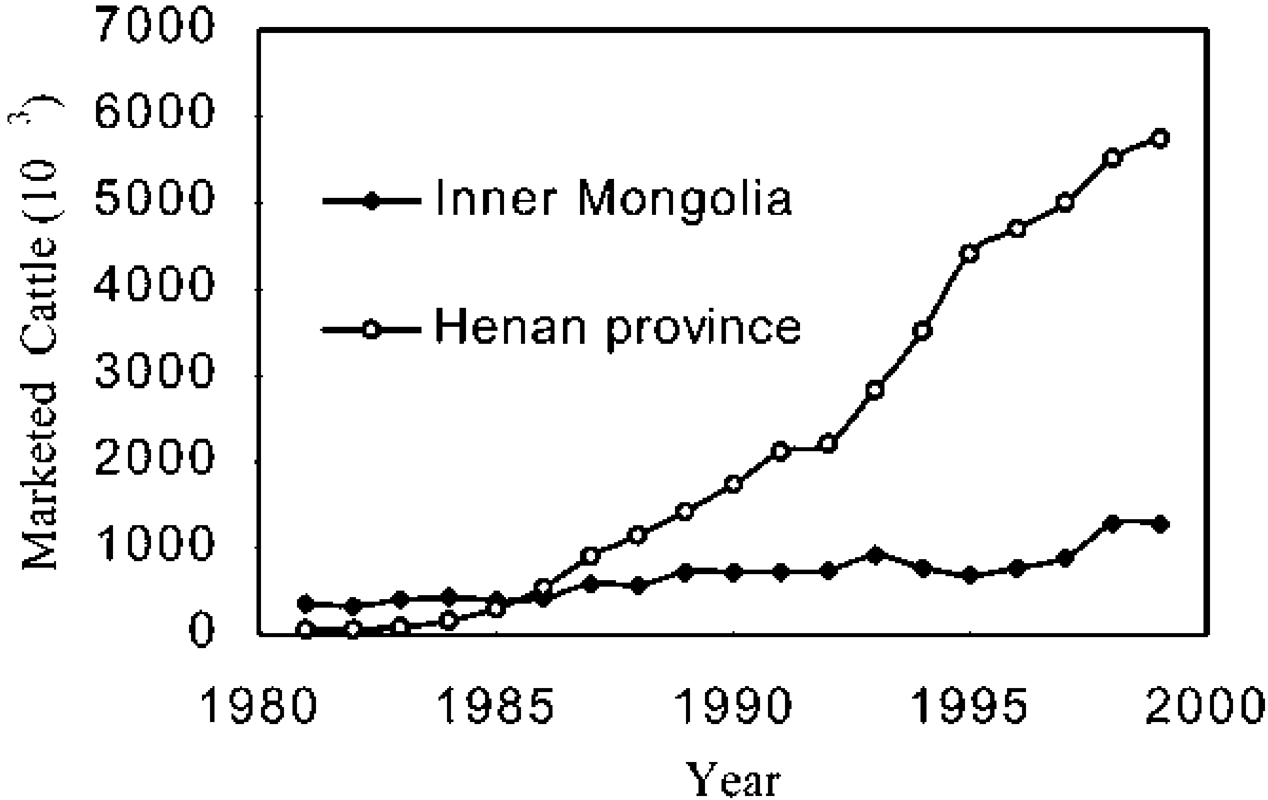
Table 1-2. Amounts of various crop residues in 1993 ('000 tonne)

Crop residue	Amount	Crop residue	Amount
Rice straw	187 913	Peanut vine	6 623
Wheat straw	109 292	Rape stalks	20 874
Maize stover	155 152	Sugar cane tops	14 405
Millet straw	6 390	Sesame stalks	299
Sorghum stubble	10 228	Sunflower stalks	803
Soybean straw	14 985	Cotton leaves	2 705
Coarse grain straw	19 588	Edible sesame stalks	1 600
Sweet potato vine	24 359	**Total**	575 215

SOURCE: Data from Non-conventional Feed Development and Application Task Team (Agricultural Science Academy of China, 1993).

NOTE: In 1993, grain output was 450 million tonne. Now it is 500 million tonne, so the amount of crop residues should be over 600 million tonne

Figure 1-3. Cattle production development in Henan and Inner Mongolia Provinces



Currently, the agricultural areas of the Central Plain provinces of Shandong, Henan, Anhui and Hebei have already become the leading beef and mutton producers in the country, more than Inner Mongolia, Xinjiang, Qinghai and Tibet Provinces, the largest pastoral zones. Apart from these four agricultural provinces, many other areas have similar conditions, and with a suitable approach, these also have the production potential of the Central Plain provinces, and could quickly become beef cattle zones or goat and sheep belts.

It is clear that agricultural areas have an immense potential for herbivore production. This approach can be termed animal production based on crop residues. The fact that livestock production based on crop residues is advocated does seem to ignore pasture production. Both are very important and mutually complementary. Currently, special emphasis is given to livestock in crop areas because it had been neglected in the past, with its enormous potential ignored.

The debate on herbivore development strategies has so far concluded that livestock based on crop residues is the most viable for China. The agricultural areas should be the main source for herbivore production.

Methods for improving the feeding value of crop residues

Crop residues are the main agricultural by-products in the countryside. Since ancient times, Chinese farmers have traditionally fed crop residues to herbivores. From the 600 million tonne of crop residues produced at present, about a third is used as feed. Most of this was untreated, and thus with low digestibility, low crude protein (CP) content and poor palatability, and so intake has been low. Untreated residues can barely satisfy maintenance requirements, and, as a result, animal performance is modest. For the past twenty years, scientists and technicians in China have studied and tested several methods for improving the feeding value of crop residues, and these are summarized here.

Physical methods

Chopping straw and stubble to 1 cm, or a little longer, before feeding is practised widely in the north. There is a saying among farmers "chopping hay to one inch, fattening can be done without concentrate." Scientific tests have shown that chopping does not improve straw digestibility, but it increases intake to a certain degree and reduces feed waste. It is a simple and effective method, with ample practical application. Grinding straw does not improve digestibility either, it just wastes energy in vain. However, ground straw easily mixes with other feed components. It is widely applied in feedlot fattening.

Apart from chopping and grinding, others have tried steaming, irradiation treatment, etc., as means to improve the feeding value of crop residues. There has been some progress, but it has not reached the practical application stage. There is also the so-called "salting" method, in which chopped straw is soaked in a dilute salt solution before feeding. Although this method has not been scientifically tested, many farmers in northeast and north China practise it, considering it effective.

Biological methods

The purpose is to allow microbes to degrade cellulose or lignin in straw as a means to improve its nutritive value. In the past half century, many local and foreign scientists have conducted research on this approach, but until now the ideal method has not been found. In the early 1990s, the "micro-storage" technology became popular. MOA found that this technology did not improve straw digestibility, but the treatment resulted in a product with a fragrance similar to wine, which improved palatability and intake. Thereby farmers welcomed it, and it was rapidly popularized.

Up to now, silage is still the most important microbial treatment method in practical application. In 1999, silage making surpassed the 100 million tonne level nationally, but its main limitation is that at best it can preserve the nutrients contained in green straw. Silage making is very widely used.

Chemical methods

Alkalization and ammoniation are the main chemical methods. In the 1920s, Beckman, a German scientist, successfully used sodium hydroxide to treat stalks, greatly improving digestibility. During the Second World War, northern European countries applied the Beckman method extensively. The main shortcomings of alkalization are its high cost and pollution, and ammoniation replaced it after the mid-1970s. Ammoniation has been widely applied in China for its low level of environment pollution, lower cost and ease of application.

In 1999, nationwide, ammoniation of residues exceeded 50 million tonne. Although ammoniation has practical advantages, it improves digestibility less than does alkalization. Recently, some scientists are studying combinations of the two treatments. Some progress has been made, but it is still not popular.

To summarize, although scientific and technical experts have conducted many studies and tests on how to improve feeding value of crop residues, the only popular treatment methods so far are ensiling and ammoniation.

Plate 1-1. Wheat straw, an abundant resource in north China

Plate 1-2. Rice straw, an abundant resource in south China

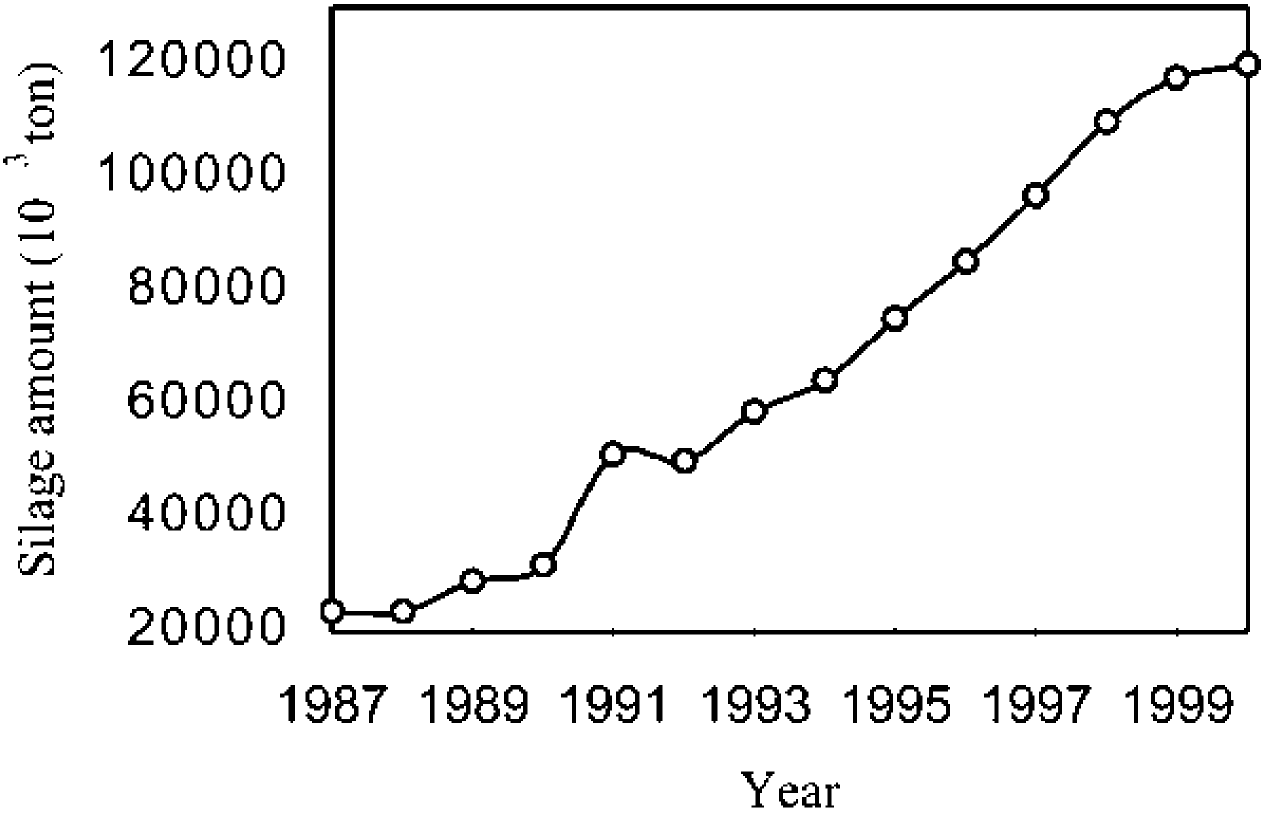
Plate 1-3. A traditional way of feeding straw to cattle in South China

Plate 1-4. Burning of residues still happens frequently

Extension of technology and herbivore development

Since the 1950s, MOA has promoted silage making. After harvesting the grain, sorghum spikes and maize ears, the stalks are successfully ensiled. While ensiling was manual, the amount was small, but with mechanization and use of plastic sheets, it rapidly increased (Figure 1-4). Nevertheless, the silage making season is a very busy time for farmers due to autumn harvesting, ploughing and seeding, and often they do not have time available in which to make silage, leaving crop residues untreated. Thus, silage making is restricted because most stalks are already dry and withered before the farmer can ensile them.

Figure 1-4. Silage making in China in recent years.



In the mid-1980s, MOA provided financial support for crop residue ammoniation research. Afterwards, some small-scale demonstrations and extension were conducted. In the last decades, agricultural universities, research institutions and technical extension departments from different counties have carried out much work on crop residue treatment, demonstration and extension.

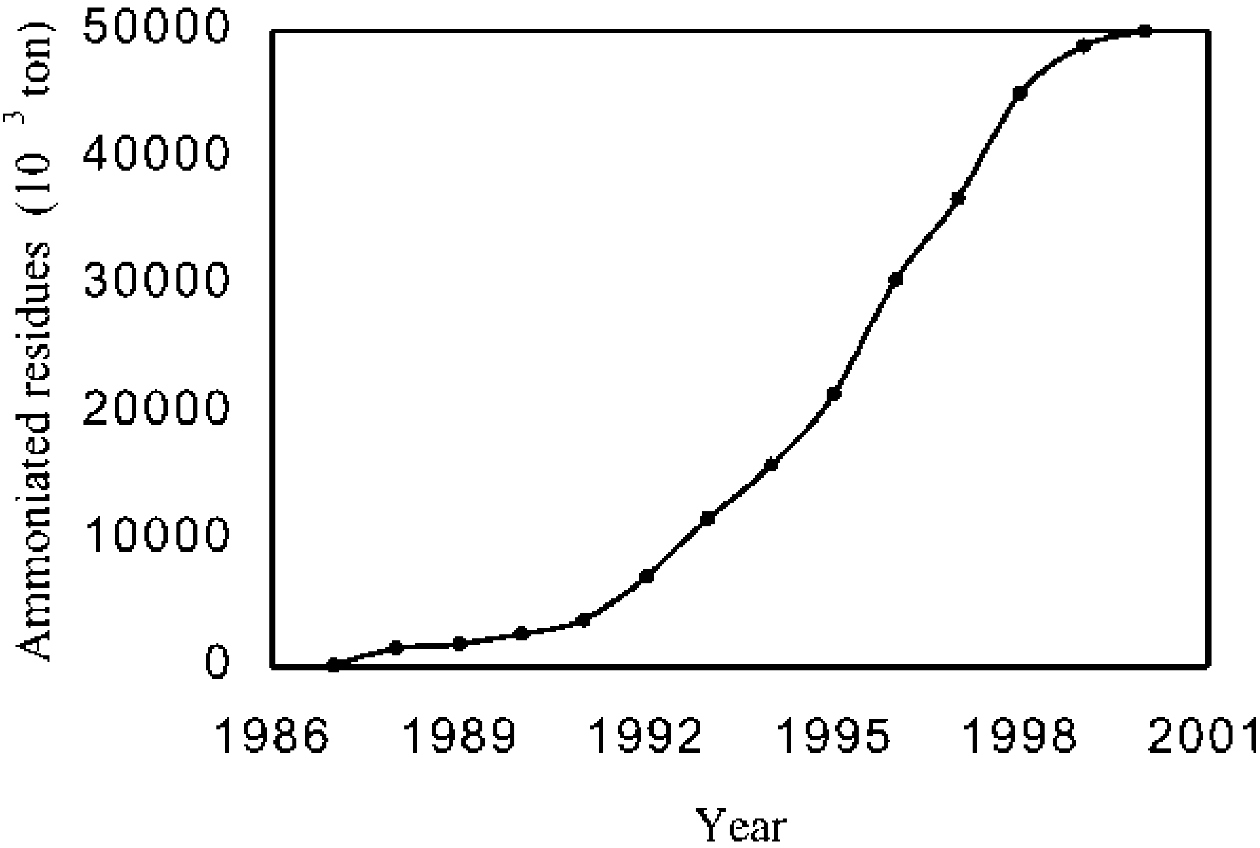
In 1987, FAO sent experts to China to provide technical guidance. From 1988 to 1992, FAO and UNDP provided funds and executed two projects (TCP/CPR/8858 and FAO/UNDP/88/057). During implementation, outstanding experts (such as E.R. Orskov, F. Sundstol, F. Dolberg and P. Finlayson) came to work in China. Many Chinese technical officers and experts were also sent abroad for studies and training. Thus, ammoniation technology and cattle raising based on crop residues matured. Extension efforts were also fostered.

According to MOA, ammoniated residues increased from 148 000 tonne in 1987 to 50 million tonne in 1999 (Figure 1-5).

There are currently over 8 million farmers already applying this technology.

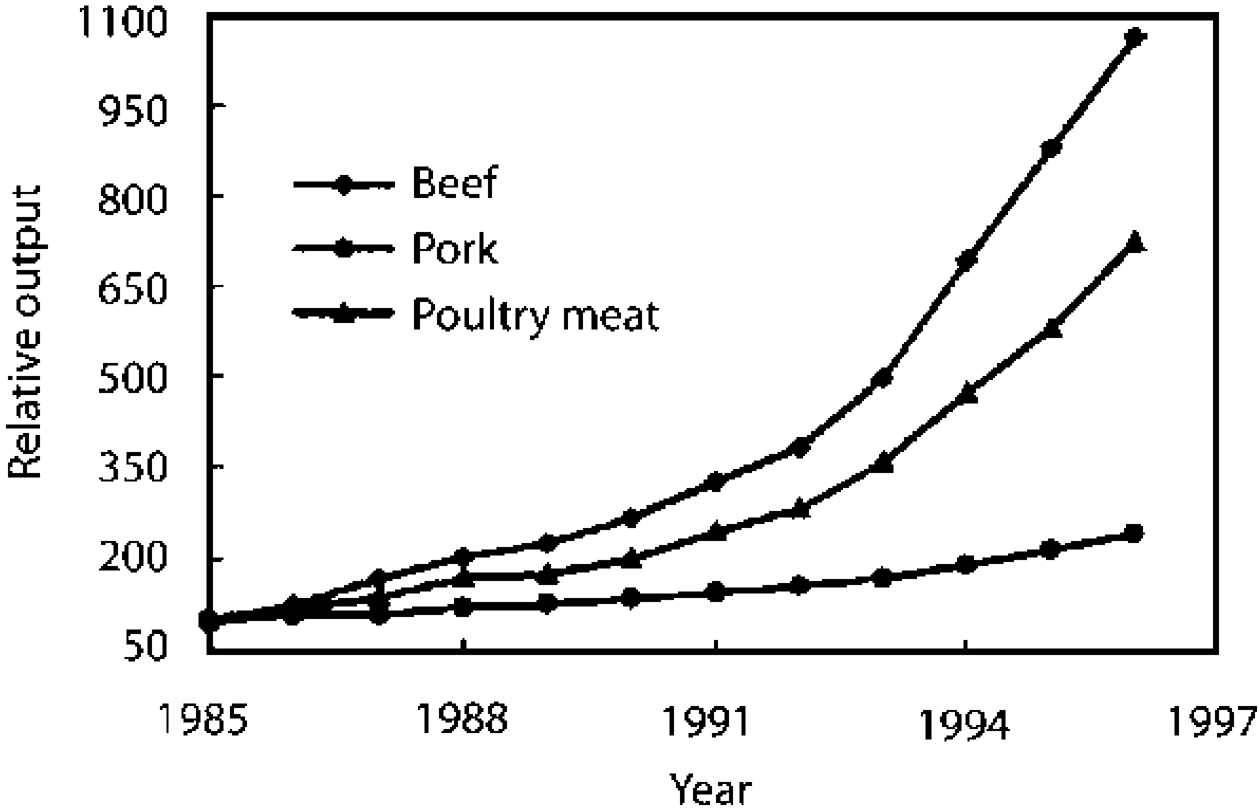
The extension of ammoniation technology greatly encouraged the development of APCR. Today, it is no longer a dream to raise many beef cattle in regions without grasslands. Beef production in agricultural areas has been very successful. In only six to seven years, some agricultural provinces became the leading beef producers of the country, with 90 percent of total output. Beef is the fastest growing meat sector (Figure 1-6). In 1999, China produced 5 054 million tonne of beef, over triple that prior to project start in 1991.

Figure 1-5. Ammoniation of crop residues in China in recent years



Utilizing crop residues as the feed base to develop cattle raising has been the main achievement of APCR. However, it has gone well beyond cattle. The following sections describe other important accomplishments.

Figure 1-6. Growth curves for production of various meats (1985 as 100%)



Sheep and goat raising

Since the "Reform and Opening-up," along with economic growth and livelihood improvement, mutton demand and price have increased. In contrast, sheep and goat production were in decline at one time. Research demonstrated that due to grassland deterioration and forage shortage, sheep and goat raising was constrained in agricultural areas. At the same time, grazing sheep and goats also conflicted with forestry, and mountain areas were closed for forest protection. This led to a lack of grazing land for sheep and goats, limiting production. Feed trials indicated that sheep and goats are similar to cattle in digesting crop residues. If the modality of feeding sheep and goats were changed from grazing to use of crop residues, silage and ammoniated stalks, properly supplemented with concentrates, a significant development in sheep and goat production could be expected. In 1993, based on our proposal, the State Council decided to include sheep and goat raising with crop residues in the State Agricultural Comprehensive Development Programme (SACDP). From that point, sheep and goat production began a period of fast development. In 1999, domestic mutton output reached 2 513 million tonne, over double the figure before project start in 1991, with 80 percent coming from the agricultural areas.

Buffalo production

There are over 20 million buffaloes in China, the second largest population in the world. Buffaloes are mainly used for traction, and in most regions of China. With agricultural mechanization, the role of buffaloes for draught weakens yearly. If an alternative use of buffalo for milk and meat is not found, recession in the buffalo population will be unavoidable. Furthermore, buffalo rearing in south China is based on grazing, and weight loss is serious due to insufficient grass. Besides, grazing land has been reduced due to forest protection in recent years. Without a change in raising modality, buffalo will be certainly difficult to develop.

Trials have shown that buffaloes digest crop residues very well, and considering that their milk and dairy products are much appreciated and demanded in Europe, development based on ammoniated stalks could have export opportunities. Buffalo meat is also well accepted, not only in Guangdong and Guangxi, but also in Hong Kong and Macao. The Yellow cattle are very small in south China, and there is a saying "a shoulder pole can carry two cattle." If cattle of this region are not improved, it will be hard to meet export standards for size. In contrast, buffaloes can easily meet these size requirements (for Hong Kong and Macao) without improvement. Both buffalo meat and milk are excellent, and buffaloes are also suitable for roughage-based feeding, so there is a bright prospect for them. The State has already established buffalo demonstration counties in Guangxi Autonomous Region. Dairy and meat buffalo production units will appear in south China in the coming years.

Dairy production

The possibility of developing dairy production in agricultural areas is also very large. Except in Heilongjiang Province, the country's dairy cows are mainly around large- or medium-sized cities. The shortage of forage in these areas has already become one of most important limiting factors restricting production. Large amounts of hay are bought annually for the more than 60 000 dairy cows of Beijing, from as far away as the northeastern regions, at a cost of almost ¥ 10 million. In recent years, tests carried by the Beijing Dairy Cow Centre substantiated that hay could be substituted, partly or totally, by ammoniated residues. If this change occurs in practise, not only would feed costs be sharply reduced, but also transportation shortages alleviated. There is therefore a solution to the dairy cow roughage supply problem in urban areas. Per capita milk consumption in China is less than 7 kg, far below 10 percent of the world's mean. The domestic market for dairy products is very large indeed. Applying APCR for dairy cattle can greatly increase milk production. China produced 8 069 million tonne of milk in

1999, 154 percent more than in 1991.

Deer rearing

With higher living standards, demand for a variety of delicacies has increased in recent years, and so deer production also has bright prospects. In New Zealand, deer are raised just like sheep. Deer graze pastures all year round, without special care. During the Qing Dynasty, royal deer gardens were set up in the northeastern provinces, so deer husbandry in China is more than a century old, with animals tamer than those in New Zealand. Implementing deer raising based on crop residues can benefit the deer sector. In recent years, deer farms have been established in the Guangdong Leizhou Peninsula. Despite differences in climate and feed compared to the northeast, deer do very well. Velvet antler quality is also quite good. This indicates that trying silage and ammoniated residues as the basic feed to develop deer is well justified.

Economic, social, agronomic and environmental benefits of developing animal production based on crop residues

The importance of APCR goes beyond the animal industry itself. Its development not only implies significant economic benefits, but also results in attractive social and environmental benefits. These are summarized below.

APCR can save large amounts of feed grain.

There were 117 million tonne of silage made and 50 million tonne of crop residues ammoniated in China in 1992. This represented grain feed savings of over 37.7 million tonne (using the "oat unit" for conversion). Currently, 200 million tonne of treated crop residues and 111 million tonne of untreated crop residues are being used as feed in the country, saving the equivalent of 22 million tonne of feed grain. The utilization of crop residues could be doubled within ten years, and, in this case, annual grain savings would increase to 120 million tonne, meeting 80 percent of grain demand. The significance of this can not really be underestimated.

APCR favours agriculture

In the past decade, increasing amounts of chemical fertilizer have been applied to land as one of main methods to raise grain yields. However, this practice raises costs, worsens soil condition and causes environment pollution. The utilization efficiency of chemical fertilizer in China is only 30 percent. Nearly 70 percent flows into rivers, lakes and sea. This has caused nutrient enrichment of water bodies and sporadic coastal "red tides".

In recent years, the Agricultural Department has strongly encouraged the direct return of crop residues to farmland to increase fertility, organic matter content and to raise the soil's capacity to conserve water and nutrients. However, direct application of crop residues to farmland is expensive and potentially harmful to germination of the following crop. In addition, this practice might not help to reduce crop diseases and pests. Because of these concerns and despite strong promotion, the direct return of residues to agricultural land remains very limited.

When crop residues pass through the animal digestive system and are returned to farmland as manure, the above worries cease. It has been already demonstrated that silage (anaerobic fermentation) and ammoniation reduce harmful microbes, pests and weed seeds. In addition, digestion of crop residues and application to land further reduces microbial pathogens and weeds. Tests over many years at the Beijing Plant Quarantine Institute showed that ammoniation treatment killed almost all the seeds of *Pseudosorghum* spp., as well as other weeds.

The benefits of returning manure to land have been known for long time. Wuji County, Hebei Province, a demonstration county for cattle production based on crop residues, became the top county in beef production in the province. With many cattle, annual returns of manure to farmland in Wuji County are of the order of 290 000 tonne, sparing 7 000 tonne of chemical fertilizer. This enables a reduction in grain production costs of US$ 54/ton. Soil organic matter content increased 0.15 percent within 5 years, and soil water and fertilizer retention were improved significantly.

Fuyang Prefecture (Anhui Province), with 10 counties, is an advanced prefecture for cattle raising with crop residues. Its beef production exceeds that of the whole of Inner Mongolia. As cattle numbers increase, so does the manure available for agriculture. Between 1985 and 1999, soil organic matter content went from 1.2 to 1.8 percent, and grain yield doubled. The net result was higher margins, with 30 percent lower costs.

In other APCR demonstration prefectures (such as Zhoukou, Shangqiu, Nanyang, Zhumadian and Dezhou), grain output increases were higher than provincial or national averages.

Reducing environmental pollution

Farmers have used crop residues as feed, fuel and building material (for cottage roofing) for generations. Over the last decade, most farmers have gradually adopted coal as fuel, but some use biogas (methane), liquefied natural gas (around large cities) or electricity (in southern mountain areas). The number of farmers who still burn residues for fuel are decreasing yearly. Furthermore, along with the improvements in living standards, thatched cottages are already scarce. The reduced use of crop residues for fuel and construction have caused surpluses to accumulate, becoming a public hazard. Farmers are often forced to burn them, which not only causes air pollution, but affects people's health, industrial production and traffic safety. According to reports, air pollution from burning crop residues leads to low quality textile production in

Shijiazhuang City every autumn at harvest time. Furthermore, burning of crop residues often leads to uncontrolled conflagrations. In Guanzhong Prefecture, more than 100 000 trees were burnt, and in the northeast, fires extended to villages. In recent years, due to the smoke from burning crop residues, aeroplanes have difficulties at take off and landing, and there have been car accidents. Such reports are increasing all the time. Feeding crop residues and returning the manure to the land resolves these problems. In fact, in those prefectures where APCR has been extensively adopted (such as Fuyang Prefecture), burning of crop residues rarely occurs.

Benefits in terms of meat availability

Beef and mutton are healthy meats due to their lower fat and higher protein content compared to pork. Since the implementation of APCR, beef and mutton as a proportion of total meat intake has already increased from 8.6 percent in

1991 to 12.7 percent in 1999. Pork has dropped from 78 to 67.3 percent. APCR has not only significantly increased beef and mutton outputs, improving meat availability for urban and rural residents, but also has made meat supply more balanced.

Helping farmers to leave poverty

In coastal areas, farmers work in township enterprises, exporting agricultural products, and even as urban employees to earn money. Inland farmers do not have these opportunities. Cattle and sheep raising is a reliable alternative to earn money since feed (crop residues) and supplements (cottonseed cakes, bran, etc.) are readily available. For rearing 1-2 cattle or 8-10 sheep, only part-time labour is needed. In three northern areas (north, northeast and northwest) and in the regions of the Yellow, Wei and Hai rivers, large-scale studies revealed that net income from planting 1 *mu* of wheat is on average only ¥ 100. Raising a sheep also earns ¥ 100, but income from one beef animal is ¥ 1 200, and from a dairy cow, ¥ 3-4 000, more than the average farmer's total income. This explains the farmers' saying:

> "Raising two cattle: no need to worry about incidental expenses
> Raising three cattle: one storey built every year."

Recognizing the strategic significance of APCR, senior leaders have paid great attention to it. As early as 1990, the central leadership received the recommendations on APCR from 14 specialists, and fully endorsed them. In 1992, State Councillor Chen Junsheng made a special inspection trip to Henan Province. His report emphasized the importance and feasibility of APCR development. The Premier fully accepted Mr Chen's report and praised it highly, writing that it was "an exciting report." During 1992-2000, the State Council asked MOA to successively convene six national conferences on

APCR, asking local governments to use crop residue resources fully for development of herbivore production in their agricultural areas. Furthermore, in 1992, the State Council transmitted the document of MOA on "Energetically exploiting crop residues resources, developing rural herbivore production" to various provinces. In 1996, the State Council again approved and issued the "1996-2000 National scheme for animal production based on crop residues and farmland projects," asking all provinces (municipalities and autonomous regions) to implement it. Meanwhile, the funds for APCR provided by central government increased from ¥ 10 million in 1992 to ¥ 55 million in 2000. In nine years, the central government has allocated ¥ 367 million, with local governments contributing ¥ 400 million as counterpart funds. In addition, the state provided some urea and plastic film, especially for crop residue ammoniation.

In 2000, there were 13 APCR demonstration prefectures and 380 demonstration counties in 30 provinces (including municipalities and autonomous regions). APCR is clearly a national effort.

The main successful extension experiences

Highly relevant theme for national conditions

China is a major agricultural country with a large population and with rather limited resources. Adopting strict measures for saving and comprehensively using resources is a basic national policy. Crop residues are huge by-product resources from agriculture. The implementation of the APCR project converted these by-products into valuable commodities, benefiting the nation and its people. For this reason, once the APCR proposal was brought up, it was accepted by the central government, and, once started, farmers welcomed it.

Practical work was essential for rapid success

In developing countries, it is hard to achieve success in extension without government support. Mr Guo Tingshuang, head of the APCR programme, not only sent memoranda to senior officials, but also went to the State Council many times to request approval of APCR in order to get central government support. In addition, he accompanied State Council leaders a visit to Zhou Kou Prefecture, when the practicality of APCR was confirmed. The project finally got support from Former Premier Li Peng and other authorities. During the nine years of the project, the State Council convened six National Conferences on APCR. The "National scheme for APCR 1996-2000 development" was issued by the central government. All provincial governments were asked to carry out the scheme. So far, the extension of APCR has not only been the task of livestock technicians; there are also 40 000 extension workers whose excellent work has been praised by MOA. With this wide scope and numerous active technicians, the APCR implies an unprecedented bright future in China.

Equal emphasis on all benefits

With an integrated view, the APCR project paid equal attention to all benefits: economic, social, agronomic and environmental. This brought the attention of central leaders, who welcome the project and its approach.

A complete project

Research combined with demonstrations, technology extension, funding, materials and policies, together constituted a complete system. That was also a key for success. In the past, extension workers paid only attention to technology by itself, ignoring financial, material and policy support. This way their goals were hard to accomplish. In the APCR project, staff not only looked at research results, but also provided timely funding and materials (urea, plastic film, machinery, etc.), besides striving for government policy support. As a consequence, the extension work progressed smoothly.

CHAPTER 2 - COMPOSITION, NUTRITIVE VALUE AND UPGRADING OF CROP RESIDUES

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Introduction

Crop residues usually consist of the aboveground part of cereal plants after grain removal. They are potentially rich sources of energy because up to 80 percent of their dry matter (DM) consists of polysaccharides. Due to the prevalence and intensity of agriculture in most regions of China, crop residues represent a high proportion of total feed for herbivores. It is estimated that 550 million tonne of these resources are available annually in China (Feng Yanglian, 1996). However, they are not all well utilized as energy sources at present, since their digestibility is often low. They partly resist rumen microbial action so their digestion is far from complete. Due to their rigid structure and poor palatability, intake of crop residues is low. These constraints are mostly related to their specific cell wall structure and chemical composition, but there are also deficiencies of nutrients essential to ruminal micro-organisms, such as nitrogen, sulphur, phosphorus and cobalt.

In this section, the current understanding of crop residue structure is reviewed, with particular attention to the chemical and physico-chemical characteristics that influence their digestibility in ruminants. Subsequently, treatments for improving feeding value are discussed.

Botanical structure and cell wall chemical composition

Botanical structure and digestion differences

As parts of plants, crop residues contain five different tissue types: (a) vascular bundles containing phloem and xylem cells; (b) parenchyma bundle sheaths surrounding the vascular tissue; (c) sclerenchyma patches connecting the vascular bundles to the epidermis; (d) mesophyll cells between the vascular bundles and epidermal layers; and (e) a single layer of epidermal cells covered by a protective cuticle on the outside. These tissues are digested to different degrees in the rumen. In general, the extent of tissue digestion by ruminal bacteria is as follows: mesophyll and phloem > epidermis and parenchyma sheath > sclerenchyma > lignified vascular tissue. These differences in tissue digestion explain the wide range in nutritive value of crop residues compared to conventional feeds (Minson, 1990).

The cells have two major components: contents and walls. The cell content fraction contains most of the organic acids, soluble carbohydrates, CP, fats and soluble ash. The cell wall fraction includes hemicellulose, cellulose, lignin, cutin and silica. In most crop residues, the cell wall fraction accounts for 60-80 percent of dry matter (DM) (Xiong Yiqiang, 1986).

Chemical composition of cell walls

Cell walls of crop residues consist mainly of polysaccharides, protein and lignin. These substances, with small amounts of other components, like acetyl groups and phenols, are organized in a complex three-dimensional structure. Other wall components include suberin, cutin, tannins, waxes and minerals.

Polysaccharides

Major polysaccharides in primary cell walls of most higher plants include cellulose, xyloglucan and pectic polysaccharides, while secondary cell walls contain mainly cellulose and xylans.

Cellulose is a highly ordered linear homopolymer of glucose linked by b-1,4-bonds. In all higher plants, cellulose in primary and secondary walls exists in the form of microfibrils. The crystallinity of cellulose microfibrils is highly variable depending on the source and age of the tissue. In primary walls, the crystallinity has been estimated to be 20-30 percent, while in secondary walls it is 40-70 percent. The crystallinity of the cellulose in wheat internode walls is 30-50 percent and does not change markedly with maturity. Cellulose in mesophyll cell walls from ryegrass leaves, although fibrillar in appearance, had a low crystallinity index (ª1) compared with >12 for cotton mesophyll cells and 4-5 for non-mesophyll cells. Cellulose molecules in primary walls are heterogeneous in their degree of polymerization (DP), between 2-6 000, but in secondary walls they are longer and more homogeneous (DP = 14 000). Cellulose from maize stalk and wheat straw has DP values of 6-7 000 (Lam *et al*., 1990).

Hemicelluloses are a wide group of polysaccharides that basically share only the property of being soluble in dilute alkali and being able to bind to cellulose by multiple hydrogen bonds and to bind to lignin by covalent bonds. In grasses, the main fraction of hemicellulose is xylans, with a backbone of 4-linked xylose residues and short side chains of arabinose, glucuronic acid and 4-O-methyl-glucuronic acid residues. Most of xylose residues in higher plants are acetylated, mainly on the C-2 hydroxyl groups, but also on C-3. Hemicellulose polysaccharide concentrations in grasses can range anywhere from 150 to 400 g/kg DM, whereas in legumes, the concentration is much lower, generally between 80-150 g/kg DM. For both grasses and legumes, xylose usually comprises half or more of total sugars of hemicellulosic fraction. Furthermore, rhamnose only exists in the hemicellulosic polysaccharides of legumes.

Pectic polysaccharides are present in the primary cell walls of all seed bearing plants and are located particularly in the middle lamella. They are the major components of the primary cell walls of dicotyledons (e.g. legumes) but account for relatively less of the primary walls in monocotyledons (grasses). Three pectic polysaccharides have been structurally characterized from the primary walls of both monocotyledons and dicotyledons: rhamnogalacturonan I, rhamnogalacturonan II, and homogalacturonan (O'Neill *et al*., 1990). Pectic polysaccharide concentration is quite low in grasses (monocotyledons), generally <10 to 40 g/kg DM, while fairly high in legumes (dicotyledons) ranging from 50 to 100 g/kg (Van Soest, 1994). The distribution of the different pectic polysaccharides within the cell walls is largely unknown.

Proteins

Proteins make up 2 to 10 percent of the primary cell wall of many dicotyledons and some monocotyledons, and may become cross-linked by the formation of isodityrosine or dityrosine. Cell wall proteins may also be involved in covalent bonding with polysaccharides. Glycoproteins seem to be invariably found in primary cell walls. Apparent covalent protein-lignin linkages have also been observed in wheat internodes. Of the several types of structural proteins known, the best-characterized are the family of hydroxyproline-rich proteins, or extensin. These glycoproteins with rod-like conformations are components of the wall matrix in dicotyledons and in grass walls (e.g. maize pericarp). Other wall proteins, e.g. glycine-rich proteins, have been found in walls of herbaceous dicotyledons (Lamport, 1977).

Lignin

Lignin represents between 5-20 percent of crop residue DM. Lignin is described as three-dimensional networks of phenylpropane units. It is generally recognized that the precursors of these building stones are coniferyl, sinapyl, and *p*-coumaryl alcohols, which are transformed into lignin by a complex dehydrogenative polymerization process. These three aromatic monomers in lignin are referred to as *p*-hydroxyphenyl, guaiacyl and syringyl residues, respectively. Depending upon the number and type of functional groups on the aromatic rings and propane side chains, lignin has variable solubilities. Wheat straw lignin has higher alkali solubility than wood lignin. When wheat straw lignin is methylated with diazomethane, the number of free phenolic hydroxyl groups in the guaiacyl monomeric units resembled that in pine lignin (Lapierre *et al*., 1988). Grass lignin is esterified by cinnamic acids, chiefly *p*-coumaric acid through hydroxyls on its monomers. In addition, ether-linked ferulic acids have been observed in lignin from maize stalks, wheat straw, rice straw and bagasse (Lam *et al*., 1990).

Lignin in plant cell walls is physically and chemically associated with wall polysaccharides and proteins. The association between lignin and polysaccharides includes glycosidic linkages, ether cross-linkages, ester cross-linkages and cinnamic acid bridges. On the association between lignin and proteins in straws, limited information is available. Only a covalent protein-lignin linkage was reported in wheat internodes (Iiyama *et al*., 1993). The strong linkage between lignin and polysaccharides or proteins would definitely prevent cell wall components from enzymatic hydrolysis by ruminal micro-organisms, and thus limit the digestion of cell walls.

Others

Other components - including cutin, suberin, tannins, waxes and minerals - are also found in the cell walls. Cutin and waxes are attached to the epidermal walls on plants surface. Cutin is a three-dimensional polyester composed of w-hydroxy and mid-chain hydroxy fatty acids. It is often esterified with phenolic acids, and maintains a close association with pectin in the epidermal cell walls. Cutin appears to be embedded in wax and pectin; these components serve as diffusional barriers that impede ruminal digestion of the intact tissue. Suberin is a functional component of cell walls. The polyesters that appear in suberized tissue can be esterified with phenolic monomers, oligomers or lignin. Silicon is an important inorganic element in plant cell walls and mainly present in the form of silica in the walls of epidermal cells and leaf hairs. The presence of silica in the cell wall of rice straw can limit the rumen digestibility of polysaccharides. Tannins are phenolic compounds synthesized by some plants as a defence. They may inhibit the activity of specific enzymes, such as cellulases. Since tannins are often insoluble, they can contaminate the crude lignin, resulting in higher analytical value. As a result of complexes with protein, tannins would depress its utilization, but may not affect cell wall carbohydrates.

Nutritive value of crop residues

Nutritive value is generally determined by feed composition, intake and utilization efficiency of digested matter. Thus, the value of a feed depends on chemical composition, digestibility, intake and efficiency.

Table 2-1 contains the nutrient content of some cereal crop residues in China. All of these residues, with the exception of peanut hay, have insufficient CP for efficient rumen fermentation (<9 percent of DM). Apart from sweet potato vines, all have a high crude fibre (CF) or cell wall content (in terms of neutral detergent fibre (NDF)) and low available energy (e.g. NEL). Such high fibre contents are believed to be negatively correlated with voluntary intake, rate of organic matter fermentation, microbial cell yield per unit organic matter fermented, and propionate: acetate ratio in fermentation end products. Crop residues also have a low mineral content, especially P, and are deficient in vitamins. Therefore, supplementation of crop residues before feeding is necessary, in addition to various treatments. In rice straw, another unwanted constituent is oxalic acid, which can cause rumen disorders. However, oxalic acid can be eliminated by alkali treatment, washing or ensiling.

Various crop residues have their own nutritional values and are used for different animal species. Sweet potato vines and peanut hay are relatively rich in protein, available energy and vitamins, and are mainly fed to pigs in most rural areas. According to a survey conducted by Zhou Meiqing (1994), partially feeding pigs with fibrous feeds, including peanut hay and/or sweet potato vines, fresh, dried or ensiled, is a popular practice in Sichuan province, where close to 100 million swine are marketed each year. In this feeding system, fibrous feeds can meet a large percentage of the nutrient requirements: 40 percent of digestible energy, 70 percent of proteins and 80 percent of minerals and vitamins. Wheat straw and rice straw have high contents of cell walls, and are basically used for feeding ruminants. Millet straw and soybean straw, in contrast, are fairly palatable for herbivores, and are mostly used as feed sources for horses, donkeys, mules and rabbits.

Table 2-1. Nutrient content of some crop residues

Crop residue	Analysis on DM basis								
		DM	NE_L	CP	EE	CF	CW	Ca	P
		(%)	(MJ/kg)	(%)	(%)	(%)	(%)	(%)	(%)
Wheat straw	(Ningxia)	91.6	3.27	3.1	1.3	44.7	73.0	0.28	0.03
Maize stovers	(Jiangsu)	91.8	5.23	6.5	2.7	26.2	70.4	0.43	0.25
Rice straw	(Fujian)	83.3	4.11	3.7	1.6	31.0	64.4	0.11	0.05
Sorghum stovers	(Liaoning)	95.2	4.69	3.9	1.3	35.6	74.8	0.35	0.21
Barley straw	(Xinjiang)	88.4	3.69	5.5	3.2	38.2	80.1	0.06	0.07

Soybean straw	(Jilin)	89.7	3.85	3.6	0.5	52.1	74.0	0.68	0.03
Oat straw	(Hebei)	93.0	4.52	7.0	2.4	28.4	72.3	0.18	0.01
Millet straw	(Heilongjiang)	90.7	4.61	5.0	1.3	35.9	74.8	0.37	0.03
Peanut hay	(Shandong)	90.0	5.70	12.0	2.7	24.6	88.8	0.13	0.01
Sweet potato vine	(Yunan)	91.7	5.53	8.4	2.6	19.8	36.6	1.47	0.48

SOURCES: Chinese Feeding Standard for Dairy Cattle (Anon., 2000); Xing, 1995; Xiong, 1986.
KEY TO ABBREVIATIONS: DM = dry matter; NE_L = net energy for lactation; CP = crude protein; EE =

ether extract; CF = crude fibre; CW = cell wall or NDF; Ca = calcium; P= phosphorus.

Table 2-2. *In situ* DM and NDF digestibility (%; 48 hour) of some crop residues

Crop residue	ISDMD	ISNDFD
Wheat straw	47.6[1]	42.2[1]
Rice straw	42.9[2]	40.9[1]
Maize stover	50.6[2]	46.9[1]
Peanut straw	77.2[1]	54.6[1]
Barley straw	44.8[2]	-

SOURCES: (1) Xing Tingxian, 1995; (2) Feng Yanglian, 1996.

KEY: ISDMD = *in situ* dry matter digestibility;
ISNDFD = *in situ* NDF digestibility.

Considerable information on DM digestibility of crop residues was obtained from universities and research institutes in China. From the data presented in Table 2-2, it is clear that *in situ* DM and NDF digestibilities of wheat straw and rice straw are lower than in other residues.

The relatively high lignin content in those residues is probably responsible, at least to some extent, for the limited cell wall digestibility.

Since the 1950s, many *in vivo* digestibility experiments and feeding trials have been conducted in China to determine nutritive values of crop residues. Some results have been summarized elsewhere (Feng Yanglian, 1996; Meng Qingxian, 1990; Xiong Yiqiang, 1986; Bian Sibei *et al*., 1999). It has been concluded that without treatment or nutrient supplementation, feeding most crop residues can just, or barely, meet maintenance energy requirements.

Factors affecting the nutritive value of crop residues

A variety of factors have been identified that may influence nutritive value of crop residues. From literature reports and our experience, factors can be divided into three categories: plant, animal and environmental.

Plant factors

The lignin fraction and associated phenolic compounds are factors most consistently associated with the rigid structure of plants and limited accessibility. The association of lignin with cell wall polysaccharides is also believed to be responsible for resistance of plant cell walls to microbial digestion in the rumen. Table 2-3 shows the main chemical composition and *in vitro* DM digestibility of three major crop residues widely used in China.

Table 2-3. Composition and *in vitro* DM digestibility of three major crop residues

Residue	DM (%)	Chemical composition (% of DM)							IVDMD (%)
		CP	NDF	NDS	ADF	CEL	HC	ADL	
Rice straw	90.6	4.7	67.2	32.8	46.3	33.8	20.9	5.2	42.2
Wheat straw	90.3	4.4	79.1	20.9	54.9	43.2	24.2	7.9	43.0
Maize stover	96.1	9.3	71.2	28.8	38.2	32.9	32.5	4.6	49.1

SOURCE: Xing Tingxian, 1995.
KEY: DM = dry matter; CP = crude protein; NDF = neutral detergent fibre; NDS = neutral detergent soluble; ADF = acid detergent fibre; CEL = cellulose;

HC = hemicellulose; ADL = acid detergent lignin;
IVDMD = *in vitro* dry matter digestibility.

Wheat straw has higher lignin, and therefore lower DM digestibility, compared with maize stover. Although rice straw has a medium lignin content, its DM digestibility is rather low, which may be caused by its relatively high silica concentration.

Other plant factors include species, stage of maturity at harvest, cultivar, and proportions of leaf, sheath and stem. All these are believed to influence the nutritive value of crop residues. As plants mature, nutrient digestibility generally declines, linked to a decrease in the digestibility of cell wall components. Xing Tingxian (1995) reported that, at an early growth stage, *in vitro* DM digestibility (IVDMD) of wheat straw is pretty high. As wheat matures, however, the IVDMD of straw progressively decreases. When the grain is completely mature at harvest, the straw has its lowest IVDMD value, resulting from decreased nitrogen content and increased lignification. Xing Tingxian (1995) has also reported a variation in chemical composition and digestibility of crop residues among cultivars. Table 2-4 clearly shows differences in chemical composition, especially in CP, among different rice cultivars, that result in large variations in IVDMD values as crop residues.

Table 2-4. Composition and *in vitro* DM digestibility of straw of various rice cultivars

Cultivar	DM (%)	Chemical composition (as % of DM)							IVDMD (%)
		CP	NDF	NDS	ADF	CEL	HC	ADL	
Z802	89.1	3.8	61.7	38.3	42.0	32.0	19.7	3.9	48.5
XZ4	88.6	5.0	61.9	38.1	41.0	32.1	20.9	4.6	55.4
V49	86.3	5.5	60.3	37.2	38.8	30.7	21.6	3.8	47.1
V35	89.5	3.7	64.8	35.2	46.3	34.8	18.5	3.7	39.3
Mean	88.4	4.5	62.2	37.2	42.0	32.4	20.2	4.0	47.6

SOURCE: Xing Tingxian, 1995.
KEY: DM = dry matter; CP = crude protein; NDF = neutral detergent fibre; NDS = neutral detergent soluble; ADF = acid detergent fibre; CEL = cellulose; HC = hemicellulose; ADL = acid detergent lignin; IVDMD = *in vitro* dry matter digestibility.

Another large variation in chemical composition and digestibility is found among straw fractions. Research data from Xing Tingxian (1995) showed that stems from wheat straw have a much lower organic matter (OM) digestibility, compared with leaf blades and sheathes (Table 2-5). This low digestibility can be attributed to their high content of NDF and lignin. In rice straw, the OM digestibility of stems is much higher than that of leaf sheathes and blades (Table 2-5). Similar results were also reported by Aman and Nordvist (1983).

Table 2-5. Composition and *in vitro* DM digestibility of wheat and rice straw fractions

Fraction	n	Chemical composition (% of DM)					IVOMD (%)
		NDF	ADF	CEL	HC	ADL	
	Wheat straw						
Whole plant(1)	16	79.1	54.9	43.2	24.2	7.9	43.0
Stem	16	87.1	55.1	46.4	32.1	8.6	24.8
Leaf sheath	16	82.4	56.0	49.1	26.4	7.0	44.5
Leaf blade	16	71.6	52.8	46.9	18.8	5.9	61.5
	Rice straw						
Whole plant(1)	16	67.2	46.3	33.8	20.9	5.2	35.7
Stem	16	61.1	43.6	35.4	21.3	4.5	51.8

Leaf sheath	16	71.9	48.4	34.6	23.5	5.5	25.4
Leaf blade	16	61.1	39.8	25.5	21.2	5.5	33.4

SOURCE: Xing Tingxian (1995).
KEY: n = number of replicates; NDF = neutral detergent fibre; ADF = acid detergent fibre; CEL = cellulose; HC = hemicellulose; ADL = acid detergent lignin; IVOMD = *in vitro* organic matter digestibility.
NOTE: (1) Without grain.

Animal factors

Little information is available about animal factors that influence the nutritive value of crop residues. Farmers in China have long known that different breeds and types of animals use crop residues with various efficiencies. Cattle, which retain fibrous matter in the rumen slightly longer than sheep or goats, presumably have an advantage with lower quality crop residues.

Cross-bred Brahman (*Bos indicus*) steers, when fed hay with 730 g/kg NDF, digested more NDF in the rumen and had longer ruminal retention time for lignin than did Hereford (*B. taurus*) steers (Kennedy, 1982). With increasing popularization of cross-breeding techniques in China, farmers noted that, on a high concentrate diet basis, hybrid beef steers have much better growth performance than do native breeds; in contrast, on a low-quality fibrous feed (e.g. crop residues), the contrary was observed. Although the exact mechanism of this difference in animal performance between hybrid and native breeds is unclear, an inherent difference in food intake and digestion capacity may be responsible.

Environmental factors

Some environmental factors, including location, climate, soil fertility and soil type, seem to influence the nutritive value of crop residues. Recent studies (Xing Tingxian, 1995) have indicated that there can be significant differences in chemical composition and digestibility of crop residues grown on different soil types (Table 2-6). Irrespective of crop cultivar, straw from wheat grown in the so-called tide soils (alluvial soils with diurnal variation in groundwater level) had considerably higher CP content and lower fibre (NDF, ADF and ADL) content than straw from drab soils (cinammon soils of forest origin). These are probably the cause of digestibility differences.

Table 2-6. Composition and *in vitro* DM digestibility of wheat straw by soil type

Parameter	**Soil type**	**Wheat cultivar**		
		No. 3039	**Bao feng**	**ZY No.1**
CP	Tide soil	6.4	4.8	4.6
	Drab soil	3.7	3.3	3.3
NDF	Tide soil	64.4	71.2	58.5
	Drab soil	69.7	74.8	75.9

ADF	Tide soil	48.6	57.3	45.7
	Drab soil	58.4	55.1	64.6
ADL	Tide soil	7.4	8.3	6.2
	Drab soil	7.4	8.5	9.6
IVDMD	Tide soil	48.6	49.4	54.9
	Drab soil	53.6	45.3	33.8

SOURCE: Xing Tingxian, 1995.
KEY: CP = crude protein; NDF = neutral detergent fibre; ADF = acid detergent fibre; ADL = acid detergent lignin; IVDMD = *in vitro* DM digestibility.

Improving feed value by processing or treatment

Ruminants despite their unique and highly efficient digestive system, are not able to extract sufficient energy to grow and produce milk from low quality or highly lignified residues. These must be properly processed or treated in some way to make them useful for production.

Traditional processing and feeding methods

Historically, many fibrous crop by-products have been used as energy sources for ruminants in China. More than 1 000 years ago, during the Song Dynasty, Chen Fu in his *Nong Shu Book* [Agriculture Encyclopaedia] described the following method of processing and feeding crop residues:

> "Mix finely chopped straw with wheat or millet bran and beans, slightly soak them with water, and then feed animals *ad libitum.*"

and there is a farmers' proverb:

> "chopping hay to one inch, fattening can be done

without concentrate".

These ancient processing and feeding methods include particle reduction and reconstitution of roughage, and are still included in university textbooks and scientific publications. Chopping and water soaking are popular practices for crop residue feeding throughout the country. Although they do not always result in consistent improvements in animal performance, they definitely result in reduced diet wastage and diet selection (Xiong, 1986).

A method called *Jiegan Nian Qing* (crushing freshly cut alfalfa with straw) has been widely used in the southern part of Shanxi Province. A thick layer (about 30 cm) of wheat or rice straw is spread on a flat threshing ground. A layer of freshly cut alfalfa (about 30 cm thick) is put on top, followed by another layer of straw. A heavy stone roller is passed over the layers, squeezing out the alfalfa juice, which is absorbed by the straw. The alfalfa treated in this way can be dried much faster, with minimum leaf loss, and at the same time, the alfalfa juice absorbed by the straw enhances the straw feed value. This method is very useful in those areas where alfalfa drying is difficult.

Physical treatment

Numerous physical processing techniques to enhance the utilization of crop residues by ruminants have been used, with varying degrees of success. In this section, the more common methods - including grinding and pelleting, irradiation and steam treatment -will be briefly reviewed as they relate to crop residue utilization in China.

Grinding and pelleting

The most studied physical treatments for enhancing crop residue use by ruminants are grinding and pelleting. Grinding, or fine chopping, decreases particle size, increases surface area and bulk density of both leaf and stem fractions, and hence raises rumen microbial accessibility or feed intake. The increase in intake due to grinding is generally higher with low quality than with high quality residues, and with small and young animals rather than with older and larger animals. The critical feed particle size to exit the rumen is smaller in sheep than in adult cattle and therefore a greater degree of grinding is necessary before they leave the rumen. Screen sizes for hammer mill grinding in China range from 2.5 mm to 25 mm. Considering differences in intake between animal species and the energy expenditure for grinding, Xiong (1986) recommended 6 mm for sheep and 12 mm for cattle as the appropriate screen sizes for hammer mills.

Ground crop residues are often pelleted or cubed before feeding. Benefits derived from pelleting include a further increase in density, decreased dustiness and easier handling. However, DM digestibility of pelleted straws is depressed relative to the long or chopped forms, primarily due to faster passage rate. Pelleting usually augments straw intake due to quicker passage, which can offset the negative effect from decreased digestibility. Therefore, the net benefit of feeding pelleted crop residues in practice is increased energy intake and animal performance. In dairy cows, fine grinding and pelleting of forages can dramatically reduce rumination and rumen digestion times. Consequently, saliva production is reduced and the rumen fermentation pattern is altered, together with reduction in acetate/propionate ratio. This is believed to be the reason for the milk fat reduction with ground and pelleted forages.

Few studies have been conducted to assess the feeding value of ground and pelleted crop residues in China. Fu *et al*. (1991) studied the response of lamb growth performance to ground and pelleted maize stover. Compared with coarse grinding of maize stover (through a 25-mm screen), processing with fine grinding (through an 8-mm screen) followed by pelleting increased feed intake by half (1 098 g vs 728 g DM) and daily gain by 129 percent (148 g vs 65 g), and reduced the feed/gain ratio by 34.1 percent (7.4 vs 11.3).

Kneading

As milk fat can be lowered with finely ground or pelleted straws, the development of another physical processing method was necessary. Recently, a novel method for processing crop residue using a kneading machine has been reported (Gao Zhenjiang *et al*., 1994). When fibrous crop residues enter the machine, they are kneaded into threadlike fibres or hairs with no apparent stem internode structure. Kneading extensively destroys the rigid structure and thus significantly increases voluntary intake. Unlike other physical processing, such as grinding or pelleting, rubbing of crop residues produces long threadlike fibres (usually 8-12 cm long), and therefore should not affect milk fat content. Compared to chopping, kneading requires higher energy expenditure.

Several studies have been conducted to compare kneading with traditional chopping. Sun Zhongyin *et al*. (1991) reported that dairy cows fed with scrubbed soybean residue had higher dietary DM intake and milk production than with untreated residue. A similar result with kneaded maize stover fed to dairy cows was reported by Zhao Xiyou and Sun Qinglin (1992). Kneading treatment is becoming popular in China.

Irradiation

Irradiation treatment of lignocellulosic materials to improve the utilization of cell wall polysaccharides dates back to the work of Lawton *et al*. (1951). They found that when basswood was irradiated with high velocity electrons, rumen bacteria fermentation was increased. Electron irradiation of straw can also increase polysaccharide digestibility by ruminal micro-organisms. Based on volatile fatty acid (VFA) production during fermentation, the optimum dose appears to be at 2.5 ¥ 108 rad. *In vitro* DM disappearance increased with irradiation dosage up to 108 rad (Pritchard *et al*., 1962).

Several studies on irradiation of crop residues for increasing their nutritive value have been conducted in China. Meng Qingxiang and Xiong Yiqiang (1990) treated wheat straw with a combination of g-rays from a cobalt-60 source and NH_3 (3 percent of DM) or NH_3 (1 percent) plus CaOH (5 percent of DM) at different moisture levels. They found that irradiation doses (2 ¥ 105, 2 ¥ 106 or 2 ¥ 107 rad) had a significant interaction with the moisture level (20, 40 or 60 percent for ammoniation, and 40, 50 or 60 percent for NH_3 + CaOH). On either chemical treatment, as irradiation and moisture level increased, *in situ* DM disappearance (ISDMD) increased and NDF content diminished dramatically. These results suggest that responses to irradiation at a lower dosage can be compensated by higher moisture levels. In another study, Gu Chuipeng *et al*. (1988b) found lower contents of fibrous fractions (NDF, ADF and lignin) and elevated ISDMD with irradiation of rice straw. When straw was irradiated at dosage of 0, 5 ¥ 106, 107, 5 ¥ 107 and 108 rad, the ISDMD were 54.0, 54.7, 57.5, 71.0 and 75.5 percent, respectively. Treatment of rice straw with a combination of electron irradiation and NaOH also resulted in a considerable higher glucose release (Lu Zhaoxin and Xiong Changren, 1991).

Although irradiation is very effective in improving the nutritional value of fibrous crop residues, it remains unfeasible at the farm level.

High pressure steaming

High pressure steaming (also called "Heat spurt" by the inventor) to improve the nutritive value of low quality feeds was closely studied at the Inner Mongolian Academy of Animal Sciences (He Jian *et al*., 1989). Ground wheat straw or other crop residues are placed in a closed steel tank and saturated with high pressure steam. When the expected temperature (or pressure) and time are reached, a tank valve is suddenly opened allowing materials to enter a pressure-release tank through a specially designed tube. This high pressure steaming and explosion result in a brown straw with looser structure. High pressure steaming markedly decreases straw CF (Table 2-7) and therefore increases the *in vitro* DM digestibility (Table 2-8). Results from an *in situ* study (He Jian *et al*., 1989) showed that NDF digestibility (48 hour incubation) of the treated wheat straw was increased by 68 percent (38 to 69) in rumen-fistulated sheep and by 233 percent (19 to 62) with caecum-fistulated pigs. Rumen VFA concentration was also increased 9.9 percent (55.3 vs 50.6 mM/litre) in sheep fed diets based on the high pressure steamed wheat straw, compared to untreated straw. In lamb feeding trials (Hou Guizhi *et al*., 1997), animals were fed equal amounts of mixed concentrate and wheat straw per day per animal (230 g dry weight). Lambs fed high pressure steamed straw ate more of it (433-595 g DM) and gained faster (44.8-50.3 g) than lambs with untreated straw (intake of 413-535 g DM and gains of 18.6-18.8 g).

Compared with chemical treatment, high-pressure steam does not require reagents and thus minimizes potential environmental pollution. In relation to other physical treatments, high-pressure steam is more effective in improving crop residue nutritive value. However, it implies high investment for equipment and a steam generator, and it has not been developed for wider utilization throughout the country.

Table 2-7. Composition (% of DM) of wheat straw after high-pressure steaming

	DM	CP	CF	Ash
Before steaming	91.7	2.57	43.5	4.4
After steaming	94.8	2.84	37.8	9.1

SOURCE: He Jian *et al*,. 1989; Lu Dexun *et al*,. 1990.
KEY: DM = dry matter, CP = crude protein, CF = crude fibre.

Table 2-8. *In vitro* digestibility (%) of fibrous feeds after high-pressure steaming

	WS	CS	RS(1)	RS(2)	SD
Before steaming	38.7	52.1	40.1	40.3	24.9
After steaming	55.5	75.5	59.6	52.7	43.3

SOURCE: He Jian *et al*. (1989).
KEY: WS = wheat straw; CS = corn [maize] stover; RS(1) & RS(2) = rice straw samples; SD = sawdust.

Chemical treatment

Since the beginning of the 19th century, attempts have been made to improve the digestibility and nutritive value of crop residues. A major breakthrough was chemical treatment to remove encrusting substances (cellulose, hemicellulose and lignin). Many chemicals have been screened in laboratory experiments for their potential to enhance digestibility. However, only three are being routinely used in animal research: sodium hydroxide (NaOH), ammonia (NH_3), and calcium hydroxide (CaOH).

The modes of action of chemical treatment on crop residues, especially with alkalis, have been described by Klopfenstein (1981):

(1) hemicellulose solubilization,
(2) increases in cellulose and hemicellulose digestion, and
(3) increases in digestion rate for cellulose and hemicellulose.

The data on ammoniation of maize stover and rice straw from many studies (Mao Huaming and Feng Yanglian, 1991; Meng Qingxiang, 1988; Xing Tingxian, 1995; Ji Yilun *et al.,* 1988; Gu Chuipeng *et al*., 1988a; Liu Jianxin *et al*., 1992) support these modes of action for the chemical treatment.

Sodium hydroxide treatment

Sodium hydroxide treatment of crop residues has been investigated and used in some areas of the country since the late 1970s. The procedure basically followed the "dry method," where NaOH is applied at 3-5 percent and the moisture content is 20-30 percent of DM. Alkali treatment may saponify the ester bonds between lignin and carbohydrates or the phenolic acid-carbohydrate complexes in plant cell wall. Through these effects, structural carbohydrates in both lignified and unlignified plant tissues become more digestible, with consequent increases in rate and digestibility.

The treatment with NaOH results in increases in crop residue palatability and digestibility, and in animal performance (Xiong Yiqiang, 1986). Steers fed rations based on NaOH-treated wheat straw gained 20 percent faster than did the control group when concentrate was half of total ration (Sun Qinghai, 1985). Ye Risong *et al.* (1999) reported that dairy cows fed NaOH-treated rice straw diets ingested 1.9 kg (86.4 percent) more straw and produced 1.4 kg (7.9 percent) more milk per day than those on untreated-straw diets.

Although NaOH treatment works effectively in improving the nutritive value of crop residues, NaOH is expensive, corrosive and its use may result in significant excretion of sodium ions in animal excreta. Long-term accumulation of sodium may lead to soil fertility problems and environmental pollution. Thus, application of NaOH treatment of crop residues is not popular with the farmers at present.

Ammoniation

Since the middle of 1980s, ammoniation of crop residues has drawn a great deal of attention in China due to several advantages: effectiveness in improving digestibility, addition of non-protein nitrogen to treated residues, and absence of sodium accumulation in soils. Ammoniation is dealt with in Chapter 3.

Most data have shown a decreased NDF content, but little change in ADF and ADL contents of crop residues due to ammoniation (Meng Qingxiang, 1988; Wu Keqian, 1996; Xing Tingxian, 1995). The results suggest that ammoniation can break the linkage between hemicellulose and lignin and make the hemicellulose fraction partially soluble to NDF solution. The soluble hemicellulose would be highly digestible by ruminal micro-organisms. After being ammoniated, treated crop residues have an increased N content relative to untreated residues (Table 2-9).

Many *in vitro* and *in vivo* digestion trials have been conducted to evaluate the effect of ammoniation on digestibility of different crop residues. Ten studies with ammoniated crop residues indicated an average increase in digestibility of 24.3 percent (12.4-44.6) or 11.2 (6.4-17.8) percentage units. Animals ingested ammoniated residues faster than the untreated (Table 2-10).

Improvements in the feeding value of crop residues due to ammoniation have been observed in many feeding trials. Some of the results are summarized in Table 2-11.

Table 2-9. Effect of ammoniation on composition (% of DM) of crop residues

CP		NDF		ADF		ADL		Source
UNT	AMM	UNT	AMM	UNT	AMM	UNT	AMM	
Wheat straw								
3.5	9.1	89.1	78.9	53.7	54.2	14.3	14.1	Meng, 1988

2.8	6.6	78.1	69.2	51.3	51.3	19.7	14.5	Wu, 1996
-	-	84.2	76.4	50.3	49.9	15.1	14.6	Cao *et al*., 2000
3.3	9.6	-	-	-	-	18.7	17.1	Zhang *et al*., 1982
4.2	4.5	77.7	75.9	51.3	49.4	10.1	9.9	Xing, 1995
Rice straw								
-	-	69.7	65.9	51.2	47.2	12.0	10.4	Cao *et al*., 2000
6.1	13.5	75.0	71.4	49.9	48.7	8.7	8.3	Gu *et al*., 1988a
5.6	10.1	-	-	-	-	11.3	9.8	Zhang *et al*., 1982
3.7	7.3	67.2	65.0	48.6	45.1	5.1	5.2	Xing, 1995
Maize stover								
6.9	11.0	-	-	-	-	-	-	Zhang *et al*.,

								1982
10.7	27.2	69.4	63.9	38.7	36.2	4.7	4.6	Xing, 1995

KEY: UNT = untreated; AMM = ammoniated; CP = crude protein; NDF = neutral detergent fibre; ADF = acid detergent fibre; ADL = acid detergent lignin.

Computer simulation results on beef production under different practical conditions were always in favour of ammoniated wheat straw over untreated straw when comparison was made on the basis of maximum benefit per unit of body weight gain (Meng Qingxiang *et al*., 1990b).

Table 2-10. Effect of ammoniation on ingestion rate of crop residues

Residue	Treatment	Animal	Intake rate(1)	Source
	Ammoniated	Native steer	25.7	Zhang *et al*

	Ammoniated	Native steer	25.7	Zhang *et al*, 1982
Wheat straw	Untreated	Native steer	42.1	
	Ammoniated	Crossbred cattle	59.0	Du *et al*., 1992
	Untreated	Crossbred cattle	94.0	
Rice straw	Ammoniated	Dairy heifer	25.7	Lu *et al*,. 1984
	Untreated	Dairy heifer	44.0	
	Ammoniated	Native steer	20.2	Zhang *et al*,. 1982
Maize stover	Untreated	Native steer	23.5	
	Ammoniated	Crossbred cattle	49.4	Du *et al*., 1992
	Untreated	Crossbred	68.4	

		cattle		
Soy straw	Ammoniated	Goat	42.0	Chen and Li, 1998
	Untreated	Goat	45.0	

NOTE:(1) Intake rate is expressed as time (minutes) spent in ingestion of one kg of roughage.

Table 2-11. Effect on herbivore growth of ammoniation of crop residues

Residue	**Animal species**	**DM intake (kg/day)**		**BW gain (g/day)**		**Gain/Feed (%)**	
		UNT	**AMM**	**UNT**	**AMM**	**UNT**	**AMM**
	Native steers (1)	4.42	5.17	266	630	6.0	11.0
	Native steers (2)	7.43	7.96	574	722	7.7	9.1

Wheat straw	Native steers (3)	3.68	5.35	270	570	7.3	10.7
	Crossbred bulls (4)	10.29	11.16	860	1120	8.4	10.1
	Lambs (5)	0.50	0.73	-67	19	-13.5	2.6
	Dairy heifers (6)	6.58	7.45	324	613	4.9	7.9
	Native steers (1)	5.04	5.99	935	1226	18.6	20.5
Rice straw	Dairy heifers (7)	6.72	7.72	494	728	7.4	9.4
	Goats (8)	1.71	1.75	85	112	5.0	6.4
	Steers (1)	6.03	6.77	607	830	10.1	12.3
Maize stover	Dairy heifers (1)	8.51	9.38	830	950	9.7	10.1

Horses (1)	5.07	5.94	116	186	2.3	3.1

SOURCES: (1) Zhang Tianzeng *et al*,. 1 982; (2) Wu Keqian, 1996; (3) Meng Qingxiang, 1990a; (4) Cao Yufeng *et al*,. 2000; (5) Yuan Zhizhao *et al*,. 1986; (6) Jiang Zhijie *et al*,. 1986; (7) Lu Donglin *et al*., 1984; (8) Chen Ruirong and Li Yongfu, 1998.
KEY: BW = body weight; UNT = untreated; AMM = ammoniated.

The maximum benefit is expressed as minimum concentrate consumption per unit gain, or minimum feed cost per unit gain. Based on the beef market situation at that time, a two-stage feeding optimized system was proposed (Meng Qingxiang *et al*., 1990b). During the first period (from birth to 250 kg) with minimum concentrate consumption per unit gain, cattle should be fed a largish amount of ammoniated crop residues to maintain a relatively low rate of daily gain (300-500 g). During the finishing period (250 to 450 kg) with minimum feed cost per unit gain, cattle were to be fed on low crop residue and high concentrate diets to allow faster gain rates (> 1 000 g/day). The computer simulation results from this two-stage feeding system compare well to actual feeding results from Beijing, Shandong, Shanxi and Henan (Table 2-12).

Table 2-12. Beef cattle growth from computer simulation and actual feeding studies

tem	n(1)	Concentrate level (%)	Daily gain (g)	Concentrate per unit gain (kg/kg)	Feed cost per unit gain (¥/kg)
Growth period					
Simulation	-	38.8	718	3.59	2.62
Actual feeding	24	40.0	846	3.44	2.71

Finishing period					
Simulation	-	70.6	1168	4.04	2.55
Actual feeding	40	72.0	1069	4.71	2.61

Source: Meng Qingxiang et al., 1990b. Note: (1) Number of cattle used in the study

In another study, Meng and Xiong (1993) found that lambs fed ammoniated wheat straw had increased dietary intake, body weight gain and better concentrate conversion efficiency compared with animals fed untreated wheat straw. The magnitude of the improvement gradually declined with increasing proportion of mixed concentrates in the diet. Regression showed that feeding ammoniated straw diets to lambs could benefit either by increased daily gain at similar concentrate level, or by less concentrate feed consumption at the same rate of gain. Based on the results, it was calculated that each tonne of ammoniated wheat straw replacing untreated straw could produce 105.2 kg (37-159.2 kg) more of liveweight gain at concentrate levels from 22 to 72 percent. When lambs gained at equal rates, each tonne of ammoniated wheat straw could save about 285.4 kg (71.9-593.1 kg) of mixed concentrates or grains at the above range of concentrate levels. This conclusion agrees well with experience from commercial animal production: each tonne of ammoniated crop residues when replacing untreated residues could save 250-300 kg of grain in cattle or sheep (Guo Tingshuang, 1996).

Many studies have also demonstrated that feeding ammoniated crop residues greatly improved lactating performance of dairy cows. Table 2-13 summarizes the results of 4 trials and shows that ammoniation of crop residues increased actual yield on average by 1.7 kg (20.1 vs 18.4 kg) without changes in milk composition, including fat percentage.

Table 2-13. Effect of ammoniation on lactation performance of dairy cows

Residue	Treatment	n(1)	Milk (kg/d)	FCM kg/d	Milk fat (%)	Source
Wheat straw	Ammoniated	6	21.4	21.0	3.78	Song *et al*., 1998
	Untreated	6	18.4	18.0	3.68	
	Ammoniated	6	22.3	20.6	3.48	Wang *et al*,. 1996
	Untreated	6	22.0	20.1	3.42	
Maize stover	Ammoniated	8	20.1	18.8	3.57	Ma and Zhu, 1997
	Untreated	8	17.5	16.4	3.59	
	Ammoniated	6	16.4	16.3	3.98	Zhang *et al*.,

					1995
Untreated	6	15.7	15.4	3.88	

NOTE: (1) Number of cows in each study.
KEY: FCM = fat-corrected milk yield

Other treatments

Since limestone is available cheaply in China, the use of Ca(OH)2 to treat crop residues attracted a great deal of interest from the 1950s. Calcium hydroxide is generally less effective in treating crop residues than other alkaline sources, such as NaOH or NH_3. Combining $Ca(OH)_2$ with urea or other alkalis seems to solve this problem. Combining $Ca(OH)_2$ with urea, Mao Huaming and Feng Yanglian (1991) showed that rice and wheat straw treatment increased the CP content by 3.5 times (8.3 vs 3.1 percent) and *in situ* DM digestibility by 69.8 percent (65.9 vs 38.8). In a feeding trial (Feng Yanglian, 1996), dairy heifers fed such treated rice straw showed significant increases in dietary DM intake (from 6.56 to 6.89 kg), weight gains (from 829 to 898 g/day), feed conversion (7.9:1 to 7.6:1) as compared with those fed the untreated straw.

Cao Yufeng *et al*. (2000) reported significant improvements in the nutritive value of wheat and rice straws as a result of combination treatment with urea, calcium hydroxide and common salt. Table 2-14 shows the changes in NDF, ADF, ADL, cellulose and hemicellulose content and *in vitro* DM digestibility before and after treatment. Combined treatment reduced the content of NDF, ADF and hemicellulose, but did not change the content of cellulose and lignin over the untreated straw. The *in vitro* DM digestibility of treated straws was enhanced relative to untreated straws. Growth performance data with cross-bred beef cattle fed the combined, ammoniated or untreated rice straw diets are presented in Table 2-15. Cattle fed the combined diets had somewhat more dietary DM intake, better daily gain, improved feed conversion and considerably reduced feed cost per kg of weight gain than cattle on either untreated or ammoniated straw diet.

Table 2-14. Effect of combined treatment on composition (as % of DM) and digestibility (%) of wheat and rice straw

	NDF	ADF	CEL	HC	ADL	IVDMD
	Wheat Straw					
Untreated	84.2	50.3	33.6	33.9	15.1	36.2
Urea + $Ca(OH)_2$ + salt	74.5	47.4	32.5	27.0	14.2	43.7
	Rice straw					
Untreated	69.7	51.2	34.6	18.6	12.0	40.9
Urea + $Ca(OH)_2$ + salt	61.4	45.4	30.5	16.0	9.9	51.2

SOURCE: Cao Yufeng *et al*., 2000.

KEY: NDF = neutral detergent fibre; ADF = acid detergent fibre; CEL = cellulose; HC = hemicellulose; IVDMD = *in vitro* dry matter digestibility.

Table 2-15. Effect of combined treatment of rice straw on growth of cross-bred beef cattle

Treatment	DM intake (kg/d)	Average daily gain (kg)	Feed/Gain ratio	Cost/Gain (¥/kg)
Untreated	9.1	0.86	12.0	5.85
Ammoniated	9.9	1.12	10.0	4.81
Urea + $Ca(OH)_2$ + salt	10.3	1.28	9.0	4.17

SOURCE: Cao Yufeng *et al*., 2000.

Other combination methods for treatment of crop residues with sodium hydroxide and urea (Shi Chuanlin, 1998), ammoniation and enzyme (Chen Sanyou *et al*., 1998), and ammoniation and ensilage (Wang Xiaochun *et al*., 1996) have also been reported elsewhere. In each case, the nutritive value was improved, but these methods have not so far been taken into practice.

Biological approach

Regular ensilage

This popular method is described in Chapter 4.

Microbial ensilage

Ensilage of whole fresh maize plants is only practised for large-scale feedlots and dairy farms. For small-scale family farms, ensiling dry crop residues after reconstitution of moisture is usually the best way for preserving feeds, since farmers do not have suitable equipment to quickly harvest their cereal plants. Another reason is that they have to sow promptly the next crop in most regions with a double-cropping system. Ensiling dry crop residues involves actions such as chopping, reconstitution of moisture, pressing and mixing with certain additives, including micro-organisms such as lactic acid producing bacteria, cellulolytic bacteria, for proper fermentation and nutrient preservation.

A large number of dry crop residues have been successfully ensiled with addition of microbial products in China in recent years. This method is commonly called "microbial ensilage," or *Weizhu* in Chinese. Some bacterial products with specialized functions and warranted quality have been developed and approved for practical use by the government. Wu Keqian (1996) and Meng Qingxiang *et al*. (1999) ensiled wheat straw with addition of a specific microbial product containing bacteria that function as lactic acid and propionic acid producers and cellulose degraders, and fed it to cross-bred steers. The results showed that microbial ensiling resulted in reduction of NDF, ADF, cellulose and hemicellulose, and an increase in *in situ* DM digestibility (Table 2-16). In some feeding studies, it was shown that microbial ensilage of crop residues such as wheat straw, rice straw, maize stover or soybean straw caused increased daily gains, feed intake and feed conversion, and decreased feed cost per unit gain in growing ruminants (Table 2-17). Several studies (Zhang Yang and Meng Dongli, 1995; Chen Xiling *et al*., 1995; Ma Yusheng and Zhu Guosheng, 1997) also indicated that lactating cows fed diets based on microbial ensiled straw had increased milk and fat-corrected yield, and slightly higher milk fat percentages, compared with diets based on untreated straw.

Table 2-16. Composition of wheat straw before and after microbial ensiling

	DM	Composition (% of DM)	ISDMD	Source

	(%)	NDF	ADF	CEL	HC	ADL	(%)	
Untreated	87	78	51	32	27	20	42	Wu, 1996
Microbial	33	70	50	33	20	16	46	
Untreated	-	83	60	45	23	15	37	Meng *et al*,. 1999
Microbial	-	79	57	43	21	14	41	

KEY: NDF = neutral detergent fibre; ADF = acid detergent fibre; CEL = cellulose; HC = hemi-cellulose; ISDMD = *in situ* dry matter digestibility.

Table 2-17. Effect of microbial ensiliage of crop residues on animal growth

Residue Species	Concentrate (g/day)	Treatment	ADG (g)	Intake (kg DM)	Feed/Gain	Cost (¥/kg)
Soybean	150	Untreated	0.09	1.72	20.2	

straw						
(goats) (1)	150	Microbial	0.12	1.88	15.9	
Wheat straw	1 800	Untreated	0.62	5.88	9.4	6.40
(steers) (2)	1 800	Microbial	0.77	6.50	8.5	5.51
Wheat straw	3 300	Untreated	0.57	7.43	12.9	8.33
(steers) (3)	3 300	Microbial	0.89	8.22	9.2	5.66

SOURCES:(1) Chen Ruirong and Li Yongfu, 1998; (2) Meng Qingxiang *et al*,. 1999; (3) Wu Keqian, 1996.

KEY: ADG = average daily gain.

Another significant effect of microbial ensilage of dry crop residues is probably to hydrate and weaken plant structures so that less energy is expended on rumination. Ensiled crop residues usually have good palatability for ruminants, and thus high intake. In comparison with ammoniated straw, microbial ensiled residues give higher intake, faster rate of passage and therefore better performance. Other advantage of microbial ensilage is its low input cost for acquiring microbial products and accessories, e.g. plastic sheets, and therefore microbial ensilage is considered a better method to enhance the feeding value of dry crop residues. However, microbial ensilage generally results in lower digestibility than ammoniation (Wu Keqian, 1996). Another disadvantage of microbial ensilage includes substantial loss (usually 5-10 percent of DM) of organic material that would otherwise be rapidly fermented in the rumen. As a result, it is still argued academically whether the anaerobic ensilage of such ready digestible materials within crop residues is economically beneficial to the animal. Further in-depth research is required to select bacteria strains that selectively degrade cell wall fractions, especially lignocelluloses.

Treatment with White Rot fungi

Because White Rot fungi can effectively attack lignin and cellulose, their use to treat lignocellulosic material to increase digestibility has been studied quite extensively in other countries, but little in China. Xiao Xunjun (1998) and Peng Jun (1998) at China Agricultural University treated wheat straw with strains of *Cyathus stercoreus*, *Bjerkandera adusta*, *Dichomitus squalens*, *Pleurotus* spp. and *Pleurotus ostreatus* for 30 days, and showed that treatment decreased NDF from 71.4 (control) to 67.4, 59.2, 62.7, 65.0 and 67.9 percent, and ADF from 53.1 to 50.3, 45.1, 46.0, 50.0 and 51.3 percent, respectively. After fermentation by the five fungus strains, a considerable loss was found in lignin, from 23 to 44 percent, and in DM, from 11 to 17 percent. There was no apparent loss in cellulose and hemicellulose (Xiao Xunjun, 1998). When wheat straw was incubated *in vitro* with mixed rumen micro-organisms for 24 hours, DM digestibility was increased 11 and 8 percent for the treatment with *Bjerkandera adusta* and *Phleurtus* spp., respectively, compared with the untreated control. Straw digestibility with the other three strains did not change. When activity of polysaccharide-degrading enzymes (FPase, avicelase, CMCase, xylanase) and ligninase (Mn-dependent peroxidase) was measured, Peng Jun (1998) found that enzyme activity varied considerably with different fungus strains. It was also noted that most White Rot fungi grew slowly on common crop residues and could not effectively compete against other microbes. These observations suggest that effective breakdown of crop residue cell walls by White Rot fungi in practice will require selection or creation of better strains, and also further refinement of the current treatment techniques.

Use of mushroom-substrate residues

Crop residues have been used as a substrate to grow mushrooms. This practice is a very profitable business in some areas of the country. The substrate residue after mushroom harvest can be used to feed animals. The most commonly used crop residues are cottonseed hulls, wheat straw, rice straw and maize stover. The residues usually have higher CP and lower CF contents compared with the original substrate. Yang Xunyi *et al*. (1986) reported that after the 2nd, 3rd and 4th harvest of mushrooms, the CP content of the residual substrate increased by 32.5, 44.2 and 60.9 percent, while its CF content reduced by 42.4, 48.1 and 50.4 percent, respectively. When the substrate residue was included in growing pig diets at level of 5 percent (replacing half of the wheat bran), there was no significant difference in average daily gain and feed conversion (Liu Jianchang *et al*., 1998). However, growth performance of pigs decreased with increased substrate residue inclusion (Zhou Zongwang, 1991). The only benefit from inclusion of the substrate residues at a low rate in pig diet is the decreased consumption of concentrate or feed cost per unit of body weight gain (Lu Zuozhou *et al*., 1995b).

Undoubtedly, the use of crop residues for mushroom production is a very good approach in China's agro-ecosystem. Research data have also indicated that some species or strains of mushrooms have strong enzymatic activities digesting cellulose and lignin. Regarding the feeding value of this residue, however, more work remains to be done before any overall recommendations can be given.

Enzymatic treatment

The use of enzymes to attack the lignocellulose structure of crop residues for enhancing their feeding value has been attractive. Crude enzyme products, with cellulolytic and hemicellulolytic capability, are usually added to fibrous feeds in attempts to improve their digestibility. Wang An (1998) observed that treatment of maize stover with an enzyme product, prepared from *Trichoderma viride*, reduced the contents of some cell wall components and enhanced the ruminal digestibility in sheep (Table 2-18). Huang Jianhua (1998) and Huang Jianhua *et al*. (1998) treated maize stover and spent grain from malting (60:40) with an enzyme mixture containing cellulase, proteinase and amylase, and measured the effects on the performance of finishing pigs and laying hens. Inclusion of 10 percent of the treated maize stover and spent grain mixture in the diet did not affect gain rate of pigs or egg production of hens, but reduced by ¥ 0.25 the feed cost per kg of liveweight gain with the pigs (Huang Jianhua, 1998) and by ¥ 0.49 per kg of egg production with the laying hens (Huang Jianhua *et al*., 1998).

Table 2-18. Effect of cellulase addition to maize stover on fibre fraction content and *in situ* digestibility in sheep

Item	Control	With cellulase
Chemical composition (%)		

Chemical composition (%)		
NDF	58.2	56.2
ADF	37.3	35.3
ADL	4.9	4.5
CEL	32.3	29.8
HEM	20.9	20.9
Digestibility (%)		
DM	39.8	45.8
NDF	27.4	31.3
ADF	29.4	31.7
ADL	16.0	17.8
CEL	31.5	33.7
HEM	23.6	30.5

SOURCE: Wang An, 1998.
KEY: NDF = neutral detergent fibre; ADF = acid

detergent fibre; ADL = acid detergent lignin; CEL = cellulose; HEM = hemicellulose; DM = dry matter.

Commercial cellulase products were also added to diets to increase the supply of readily available carbohydrate. When the enzyme products were included at 0.1-0.2 percent of the diet of pigs, cattle and geese, animal performance was considerably improved (Table 2-19). Chen Xiafu *et al*. (1986) also reported the use of crude enzyme products prepared from *Trichoderma viride* as feed additives for growing rabbits. In eight growth trials, rabbits fed on a diet with addition of the cellulolytic enzymes gained 17.5-39.3 percent faster than the control. The difference was consistent and highly significant (< 0.05).

Table 2-19. Effects of cellulase addition on animal performance

	Enzyme		**Treatment**		

Animal	level (%)	Item		Control	Enzyme	Source
Growing pig	0.1	Dietary DMI	(g)	935	1010	Wang, 1998
	0.1	Daily gain	(g)	325	348	Wang, 1998
	0.1	Feed/Gain		2.88	2.90	Wang, 1998
Beef cattle	0.1	Daily gain	(g)	794	942	Chen *et al*,. 1998
Dairy cow	0.1	Grain DMI	(kg)	8.71	9.52	Lu and Wang, 1990
	0.1	Milk yield	(kg)	17.0	17.6	Lu and Wang, 1990
	0.1	Milk yield	(kg)	19.2	21.1	Wang

	0.1	Milk yield	(kg)	19.2	21.1	Wang, 1998
	0.2	Milk yield	(kg/day)	26.4	28.6	Su *et al*., 1997
	0.2	Milk fat	(%)	3.43	3.41	Su *et al*,. 1997
Goose	0.2	Gain	(g)	25.8	41.3	Zhao, 1999

KEY: DMI = dry matter intake.

Although there is a tendency toward increased use of cellulolytic enzymes in animal feeds, at present the cost of suitable enzymes is too high for commercial use. Obviously, advances in biotechnology and increased production of effective enzymes would be expected to lower the cost of enzymatic treatment.

CHAPTER 3 - AMMONIATION OF CROP RESIDUES

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Introduction

As early as 1933, a German scientist started research on straw treatment with ammonia. In 1938, scientists in the former Soviet Union treated wheat straw with anhydrous ammonia to increase digestibility. In the 1950s, a Danish patent was issued on ammonia treatment technology. From the 1970s, Bangladesh, Canada, Denmark, Egypt, India, Japan, Niger, Norway, Tunisia, United Kingdom and USA started research on straw ammoniation. Some countries have popularized ammoniation at national level. Straw ammoniation technologies were introduced to Norway in 1975 with government financial support, and in 1988 total straw treatment had reached 130 thousand tonne, 17.3 percent of total straw output. For environmental protection, Denmark recently prohibited straw burning.

Chinese farmers have known that human urine can be used to treat straw for cattle feed. It is pity that no research has been done on this. From the 1980s, China started to adjust its animal production structure with a new policy of a grain saving strategy. Fundamental research and experiments were started. MOA began to popularize straw ammoniation in 1987. In 1989, straw ammoniation became one of ten key extension techniques of MOA, and by 1993 it had been popularized throughout the country, with 11.7 million tonne of straw treated, the largest in the world. FAO and UNDP had several successful projects on straw utilization for feeding animals. At FAO's suggestion, international conferences on *Increasing Animal Production with Local Resources* were organized in China on three occasions. These conferences provided the opportunity to exchange experiences among different countries.

The principle and effects of straw ammoniation

The main component of straw is fibre, including cellulose and hemicellulose that can be digested by ruminants. Some cellulose and hemicellulose are bound to lignin and resistant to microbial attack. The role of ammoniation is to destroy this link, so these fractions are available to the animal. Ammoniation usually increases digestibility by 20 percent and CP content up to 1-2 times. It can also improve palatability and consumption rate. The total nutritional value can be doubled, reaching 0.4-0.5 feed units for each kilogram of ammoniated straw. In addition, ammoniation reduces mould development, destroys weed seeds (e.g. wild oat, false sorghum, etc.), parasite eggs and bacteria.

Ammonia sources for straw ammoniation

The sources of ammonia to treat straw include anhydrous ammonia, urea, ammonium bicarbonate and aqueous ammonia.

Anhydrous ammonia

Anhydrous ammonia means "ammonia without water." Its formula is NH_3, and its N content is 28.3 percent. The normal dosage is 3 percent by weight of the straw DM. It is the most economical source of ammonia.

The boiling point of anhydrous ammonia is -33.3°C, its vapour density is 0.59 (that of air is 1) and its liquid density 0.62 (that of water is 1). Gas pressure is 1.1 kg/cm^2 at -17.8°C and 13.9 kg/cm^2 38°C. At normal temperature and pressure, anhydrous ammonia is a gas. Expensive pressure containers are required not only to keep it as a liquid, but also to transport and store it. Anhydrous ammonia is a potentially dangerous and toxic material, and stringent safety precautions need to be observed when using it. Its natural ignition temperature is 651°C. If the ammonia content in the air reaches 20 percent, an explosion from self-ignition could occur. Attention should be paid to possible ammonia explosions, even though it seldom happens.

Urea

The N content of urea is 46.7 percent. Its formula is $CO(NH_2)_2$. It is decomposed into ammonia and CO_2 by ureases at ambient temperature. The chemical reaction is:

$$CO(NH_2)_2 + H_2O \xrightarrow{\text{Urease enzymes. Ambient temperature}} 2NH_3/ + CO_2$$

Urea dosage needed to treat straw may vary a lot. The recommended dosage is 4-5 percent urea on DM basis, taking into consideration the effect of ammoniation and costs. Urea can be transported conveniently at normal temperature and pressure. It is harmless to humans. Treating straw with urea does not need complex equipment and the sealing conditions are not as strict as with anhydrous ammonia. It is known that farmers in Bangladesh ammoniate straw in bamboo baskets lined and covered with leaves of a kind of banana. From the *Yellow Cattle Magazine*, it is known that, in Anhui province, technicians use urea as a source of ammonia to treat straw without cover and get good results, which is beneficial for extension of straw ammoniation to rural areas. At present, urea is a widely used source of ammonia in China. Urea is not as effective as anhydrous ammonia for straw treatment, but it is better than ammonium bicarbonate.

Ammonium bicarbonate

The nitrogen content of ammonium bicarbonate is 15-17 percent; its formula is NH_4HCO_3. It can be decomposed into NH_3, CO_2 and H_2O at a suitable temperature (above 60°C). The chemical reaction is:

$$NH_4HCO_3 \xrightarrow{\text{Heating}} NH_3 / + CO_2 + H_2O$$

The dosage of ammonium bicarbonate, estimated by its N content, is 14-19 percent of straw DM. But, according to the experiments carried out in Zhejiang and Shanxi Agricultural Universities, using 8-12 percent of ammonium bicarbonate can give the same result as with 14-19 percent.

Ammonium bicarbonate is a major product of the fertilizer industry and it is readily available at low price. It has a retail price of ¥ 300/ton (compared to more than ¥ 1000 for urea) and it is easy to use. Since ammonium bicarbonate is an intermediate product of urea breakdown, theoretically, in the right concentration, its effect should be similar to urea. Reports from Zhejiang Agricultural University indicate that in the humid south, straw ammoniated with urea showed more mould spots than with ammonium bicarbonate. It does not decompose completely at low temperature, thus in cold climates the effectiveness of treatment with ammonium bicarbonate is not good. When treating with ammonium bicarbonate in an oven, one day is enough, since the temperature reaches 90 °C and it decomposes completely.

Aqueous ammonia

Aqueous ammonia is a solution of ammonia in water. The concentration is quite variable, but the usual value is 20 percent. At this concentration, the normal dosage is 12 percent by weight of straw DM. It is only adapted to areas near to fertilizer factories because its low N content makes transport expensive.

Other sources

Besides the above sources of ammonia, human and animal urine also can be used to treat straw. However, collection difficulties limit practical applications.

Methods for ammonia treatment of straw

At present, the methods for popular ammonia treatment of straw in China include stack, silo or bunker, and oven methods. Each uses a different ammonia source.

Stack method

The procedure for the stack method is as follows. First, an area is selected with an elevated, dry and even surface. This area is covered with non-toxic polyethylene sheet and the baled or loose straw (chopped or whole) is stacked on it. It is better to bale straw or to chop it into pieces. Especially for hard and thick maize stover, chopping before treatment facilitates feeding, saves plastic and reduces the danger of puncturing the plastic. The moisture content of straw should be adjusted to 20 percent or more during stacking (anhydrous ammonia requires a low-moisture straw compared with urea and ammonium bicarbonate). The high moisture has a positive effect on straw treatment. However, after treatment, it is difficult to ventilate the straw and it can be easily attacked by mould. A wooden bar, which will be pulled out when ammonia injection starts, is placed before stacking so that ammonia can be injected easily and conveniently. The stack is sealed with non-toxic polyethylene sheet and injected with 3 percent anhydrous ammonia by weight of straw DM. At the end, the hole left when the pipe is removed is sealed with good quality tape.

Operators working with ammonia must be trained and should strictly follow relevant regulations to ensure personal safety. Treatment time varies inversely with temperature. For example, more than four weeks are needed at a temperature of 5-15°C, but only one week at >30°C.

Straw treatment with anhydrous ammonia is simple and efficient, but particularly suited for large-scale use. The method also had been widely applied in developed countries. It requires some expensive equipment. For instance, the cost of an EQ144 ammonia truck tank carrying 5.1 tonne is ¥ 16 000; a 200-kg ammonia bottle costs ¥ 2 500; a 400-kg bottle costs ¥ 4 500; and an 8.82 kW four-wheel tractor costs ¥ 8 000. Furthermore, anhydrous ammonia is not well suited for private farmers because of its dangers.

In order to explore the best supply system of ammonia for farmers, ammoniation stations have been built in Hebei Xingtai region, Boxiang county; Baoding region, Dingxing county; and Henan Zhoukou region, Fugou county. These stations have accumulated experiences during the past few years to share with other regions.

Selection of plastic film

The basic requirements for plastic film are that it is non-toxic, durable and suitable for sealing. The plastic often used is polyethylene. Thickness, width and colour are determined by practical situations. Thick film (about 0.12 mm) is used for maize stover; thin film (less than 0.12 mm) for wheat straw. Width of film is determined by the size of stack and market availability. If used in the open air, black colour should be preferred, because it is durable and absorbs solar energy, which heats the stack and shortens treatment time. If used indoors, film colour has no obvious influence on treatment. The amount of film required can be calculated by the size of stack.

Size of bottom sheet:	Length = Length of stack + (0.5-0.7) m (overlap)
	Width = Width of stack + (0.5-0.7) m
Size of covering sheet:	Length = Length of stack + height x 2 + (0.5-0.7) m
	Width = Width of stack + height x 2 + (0.5-0.7) m

The ammoniation station in Fugou County made a covering sheet that was especially suitable for a 500-kg wheat straw stack. Covering the stack greatly improves treatment efficiency.

Measurement of the stack density

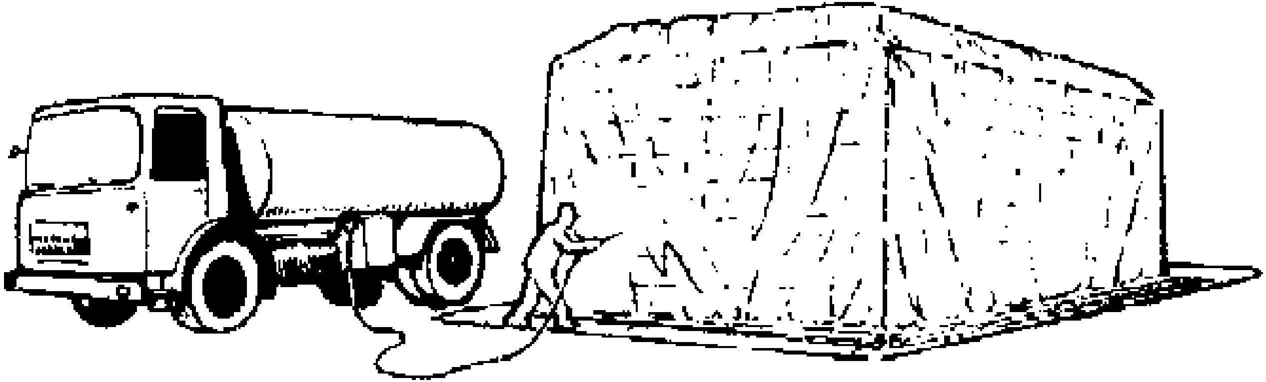
Weighing the stack is a basic task for straw treatment. It is well known that it is important to inject the correct amount of ammonia: too little ammonia is ineffective; too much ammonia increases the cost and has no further effect on treatment. The exact weight of straw must be known so that the correct amount of ammonia can be applied. But weighing is difficult under field conditions. A simple method is to first measure the average density of stack for various straws, then to multiply it by its volume. Stack density depends upon plant species, moisture content and particle size. Of course, density also varies with time. In order to get reliable data, it is necessary to measure many stacks (at least 8 for each straw type).

Density is expressed in kg/m^3. In old stacks, volume is measured first, then it is weighed. New stacks are weighed before stacking and volume measured after. It is very easy to calculate the volume of rectangular and cylinder stacks. The volume of stack with irregular shape may only be estimated. In 1989, 9 stacks of air-dried straw were measured in Boxiang county during the FAO project. The average density was 55 and 79 kg/m^3 for new and old wheat straw, and 79 and 99 kg/m^3 for new and old maize stover, both whole, respectively.

Ammonia dosage measurement

The precision of ammonia injection depends on not only the correct weight of straw but also the correct amount of ammonia. Currently there are two main methods for ammonia injection used in China. One is to inject ammonia into the stack directly from an ammonia truck tank filled in the factory (Figure 3-1), the other is to inject it from a bottle (Figure 3-2).

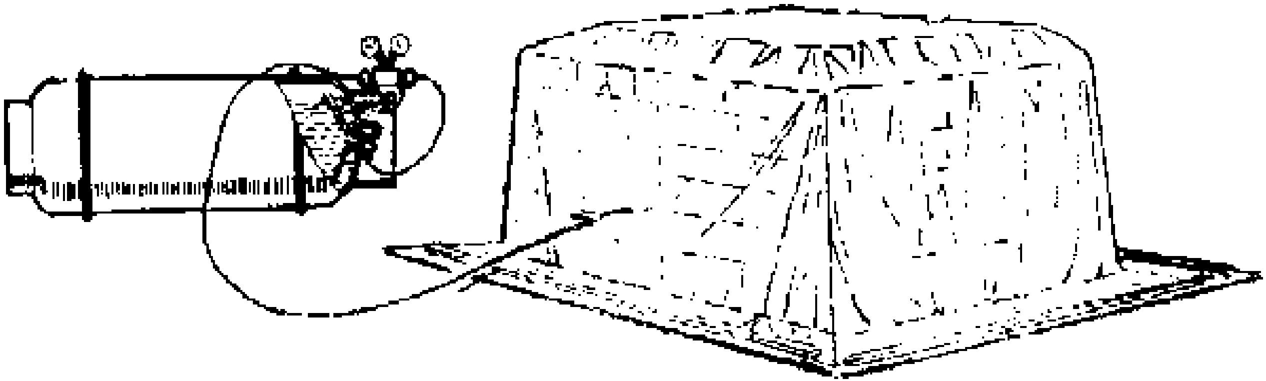
Figure 3-1. Transfer of anhydrous ammonia from tank truck to stack of crop residues



At present, domestically produced ammonia flow meters are not available in China, and the price of imported ammonia flow meters is very high.. The Non-conventional Feeds Institute of China Agricultural University has developed an ammonia flow meter. With a flow of 3-5 kg/min, the error is less than 3 percent. The price of the meter and its accessories is ¥ 500 and it is ready to go to the market.

In most situations, the amount of ammonia to be injected is estimated by the injecting time. This method is not very precise because both the pressure and the flow rate of the ammonia vary with temperature. Sometimes ammonia dosage is estimated by the weight of the ammonia bottle. This method is more precise for ammonia injection. In brief, there are still many problems to be solved in terms of measuring ammonia dosage.

Figure 3-2. Transfer of anhydrous ammonia from ammonia bottle to stack of crop residue



Proposal for "one stack - one bottle"

In order to solve the measurement problems of ammonia dosage, F. Sundstol, FAO expert, proposed "one stack, one bottle." This approach could overcome the measurement difficulties, since a whole bottle would be used for a standard stack. At the same time, small bottles should be easily transported by small tractors with trailer, or by bicycle, an obvious advantage for rural areas with bad roads. In addition, farmers can buy ammonia bottles and store them for later use. For the small ammonia bottle system it is very important to select the appropriate size. If the ammonia dosage is 3 percent of the straw, the net weight of ammonia should be 15, 30 and 60 kg for 500, 1 000 and 2 000 kg stacks, respectively. A large stack should have a weight multiple of the small stack, so that entire bottles can be used.

The "one stack, one bottle" system has been tried in Henan, Hebei and other regions. It has been found that there are still some problems to resolve before it is generalized. Firstly, the small ammonia bottle is thin and long, inconvenient for transport by bicycle. Secondly, the popularization of the "small ammonia bottle" implies more people involved in their transport, with increased accident risk. It is also imperative to strengthen training for safety operation.

Plate 3-1. Ammoniating operation with anhydrous ammonia, stack method

Plate 3-2. Ammoniating pit in farm yard

Plate 3-3. FAO expert checks the operation of transferring anhydrous ammonia from tank truck to bottle

Plate 3-4. Trainees in ammoniation workshop watch the operation of ammonia transfer

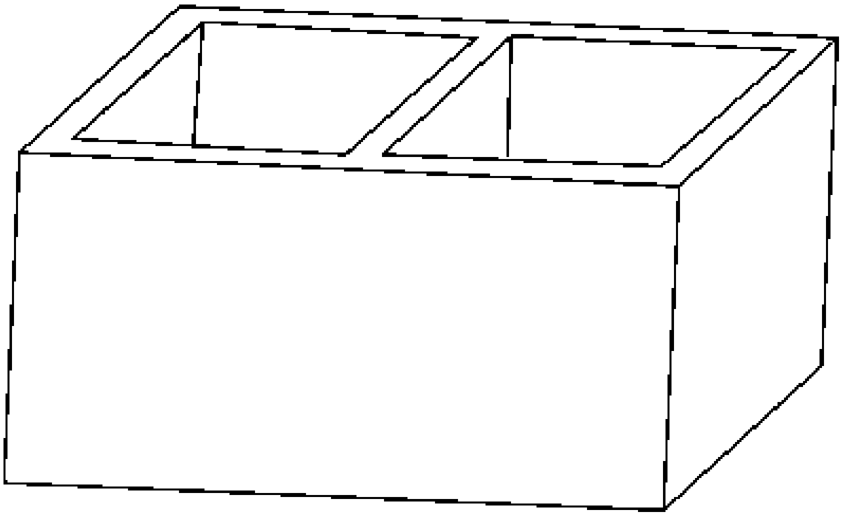
Silo or bunker method

Ammoniating straw with urea in silos or bunkers has been widely used in China. This method has many advantages: silos or bunkers may be used for either ammoniating or ensiling year round; bunkers are easy to manage and avoid rodent damage to plastic films. Silos or bunkers constructed with cement are the best, since they save on plastic (only one sheet is needed, to cover) and minimize repairs. Once a silo or bunker is constructed, it can be used for several years. In addition, the bunker facilitates the estimation of straw weight.

Animal type and quantity determine bunker size. It should be known how much straw (air dried) can be placed per m^3 of bunker; how much ammoniated straw an animal requires per year; whether the bunker may also be used for ensiling; and how many treatments are required per year. Average weight of air-dried and chopped crop residue (wheat, rice and maize), measured in different regions, is about 150 kg per m^3. Straw intake varies with animal type, size and concentrate level. Generally speaking, daily straw intake is 2 to 3 percent of liveweight. For example, daily net straw intake is 4-6 kg for a 200 kg steer, equivalent to 1.5-2 tonne per year. If the silo is used for straw, 1 m^3 will hold about 650 kg (25 percent DM). With these data, the size of a silo or bunker can be designed according to practical needs (number of ammoniations per year, numbers of animals).

There are many types of bunkers. They can be built on the surface, underground, or half-and-half. It is recommended to build rectangular bunkers that, by adding internal walls, can be divided into double or twin bunkers for sequential treatment (Figure 3-3). If a double bunker is used for silage, a second fermentation can be started in the second compartment while straw is being used from the other half. Double bunkers are very common in Henan Zhoukou region. For instance, a bunker with a volume of 2 m^3 requires 500 bricks, a bag of cement and a wagon of sand. Its total cost is ¥ 100. The cost of a double-bunker holding 4 m^3 is ¥ 200, affordable to farmers. One bunker of 2 m^3 can hold 300 kg of wheat straw. The two bunkers can be used in turns. One bunker of ammoniated straw is enough for two cattle for a month. If a bunker is used for silage, one bunker can hold more than 1 000 kg. The silo or bunker method has been well received by farmers.

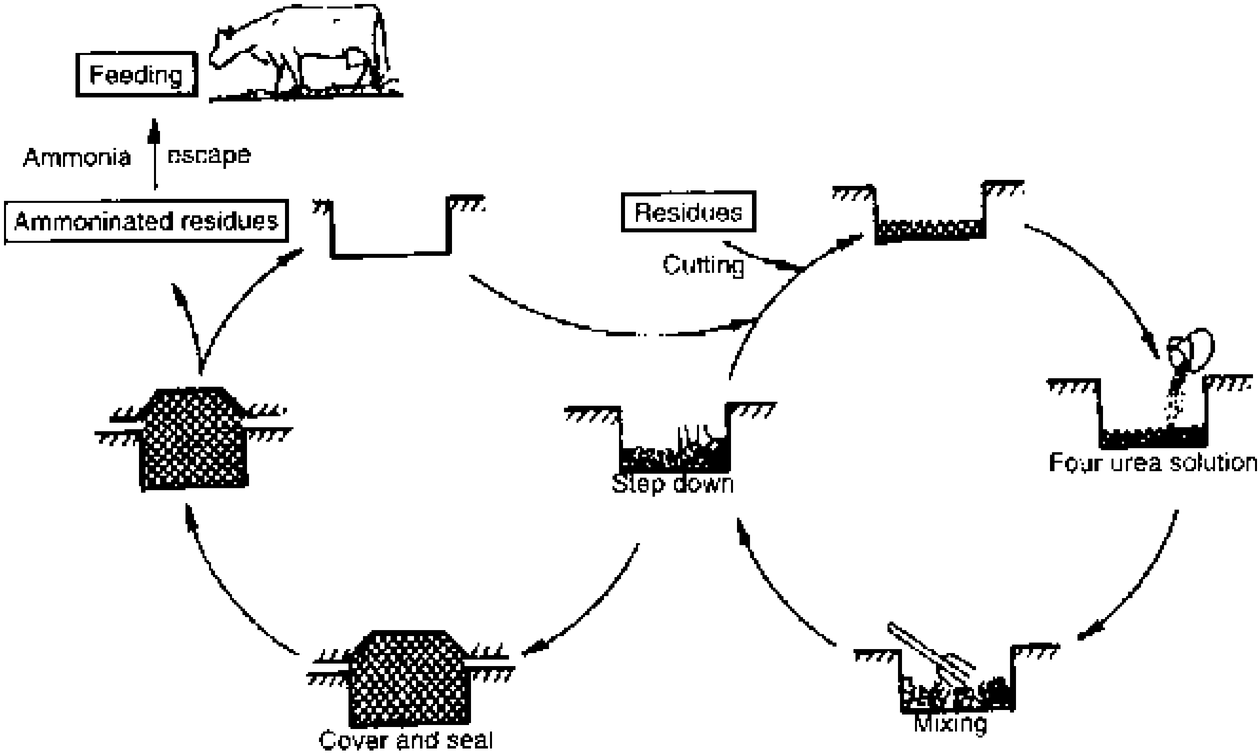
Figure 3-3. A twin bunker



Operation

First, straw is chopped to about 2 cm long. The general principle is that thick and hard residues, such as maize stover, should be cut shorter, while soft materials may be a little bit longer. Then urea (or ammonium bicarbonate) is added to water and stirred to completely dissolve it. Normally, 100 kg of dried straw needs 5 kg urea and 40-60 kg water. Next, the urea solution is sprayed repeatedly over the straw. Before loading the silo, straw can be spread in an open area to facilitate uniformity in spray application. While straw is added to the silo, each layer should be compacted till the bunker is full, and then it is covered with plastic film, held firmly in place by a layer of fine soil (Figure 3-4). Treatment time with urea is a little longer than with anhydrous ammonia.

Figure 3-4. Flow chart of the ammoniation of crop residues with urea



When treating straw with urea, the speed of urea decomposition into ammonia should be taken into consideration. It depends on ambient temperature and amount of ureases present in the straw. Decomposition rate increases with temperature, so this method is well adapted to warm regions (or warm seasons). In general, it is suggested to add some substance rich in ureases, such as soybean cake powder, to accelerate urea breakdown. Maize stover contains much more ureases than other cereal straws, so ureases are not required. In China, maize stover is one of the three main crop residues, along with rice and wheat straw. The nutritive value of maize stover is higher than other straws, either before or after ammoniation. However, it was seldom used as feed because it is thick and hard, and not easy to be store and transport. Nowadays it should be preferentially used as feed because processing and treatment methods (chopping, kneading, heat-extrusion, baling and ammonia treatment) are available to overcome these problems.

Oven method

Straw can be quickly treated quickly with ammonia in an oven.

The Non-conventional Feed Institute of China Agricultural University has developed a metal, self-assembly oven for ammonia treatment. The oven is composed of a chamber, a heating system, an air circulating system and a straw trailer. The chamber must be insulated, sealed and resistant to corrosion by acid or alkali. The heating device may be an electric heater or a coal-fired steam heater, depending on local conditions. Shanxi Wanrong County used steam to heat the oven, with good results. The straw trailer should be convenient for loading, unloading, transport and heating. A metal mesh trailer with steel wheels is the preferred option.

Operation

Ammonium bicarbonate (8-12 percent of straw DM) is first dissolved in water. Straw (baled or loose; chopped or whole) is placed on the trailer. The solution is uniformly sprayed over the straw, adjusting moisture content to about 45 percent. Once the trailer is full, it is moved into the chamber, the door is closed and heating started. If heating is by electricity, the heating tube needs to be set to control the chamber's temperature at about 95 °C. After heating for 14-15 hours, it is turned off. The chamber should remain sealed for 5-6 hours more, and then the straw trailer is moved outside for ventilation. Once ammonia residues are gone, the straw can be fed.

The oven can shorten treatment time considerably since it only takes 24 hours to treat straw. In addition, oven treatment is not weather dependent, so ammoniation can be done all year round. However, the cost is relatively high, limiting its application. In recent years in Jilin Province, straw has been treated in a coal-heated chamber usually used for flue-curing tobacco. The investment for the oven was avoided and fuel expenses reduced, so treatment cost was greatly decreased.

Other options

Besides the above three widely used methods, there are still some other methods for straw treatment. For instance, ammoniation within plastic bags was readily accepted by farmers due to low initial cost. However, repeated purchases of plastic bags increased costs and restricted wider application. In some places, straw is treated in locally available containers (such as vats). This latter method may be worth advocating.

Factors influencing effectiveness of ammoniation

There are a number of factors that influence the effectiveness of straw ammoniation, including dosage, moisture content, temperature and treatment time.

Ammonia dosage

Experiments relating ammonia dosage to digestibility were conducted by Sundstol *et al*. (1978). Results showed a significant improvement in *in vitro* digestibility by increasing ammonia dosage from 1 to 2.5 percent of straw DM, and a slight improvement from 2.5 to 4 percent. There were no further effects beyond 4 percent. In recent years, many similar experiments have been carried out with similar results. The economic optimum ammonia dosage probably lies between 2.5 and 3.5 percent of DM.

When treating straw with anhydrous ammonia, urea, ammonia bicarbonate or aqueous ammonia, the dosage should be estimated by their nitrogen content: 82.3, 46.7, 15 and 20 percent, respectively. As the conversion ratio of nitrogen to ammonia is 1.21, the dosage of other sources can be calculated by the following equation:

$$\text{Dosage (kg)} = \frac{\text{economic optimum for dosage of ammonia}}{\text{nitrogen content of ammonia source} \times 1.21}$$

Optimum dosages (per 100 kg of straw) are: 2.5-3.5 kg for anhydrous ammonia; 4.5-6.2 kg for urea; 13.8-19.3 kg (8-12 kg in practice) for ammonium bicarbonate; and 10.3-14.5 kg for aqueous ammonia (20% N).

Normally, treating 100 kg air-dry straw requires either 3 kg of anhydrous ammonia, 4-5 kg of urea, 8-12 kg of ammonium bicarbonate or 11-12 kg of aqueous ammonia (20% N).

Moisture content of straw

Moisture content of straw is another important factor determining the effectiveness of treatment. Ammonia combines with water to form ammonium hydroxide $(NH_4)OH$.

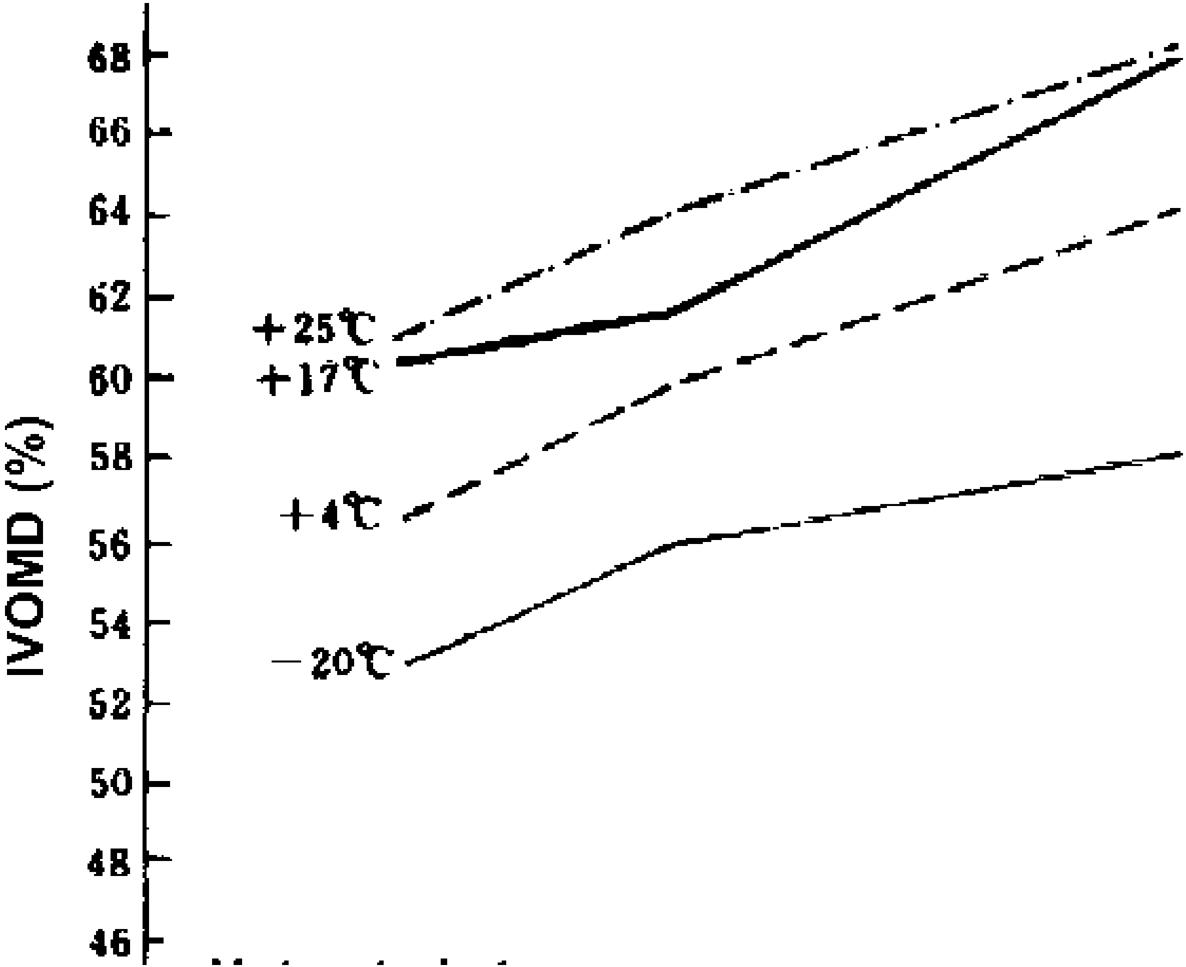
Regarding the optimum moisture content of straw, experts from China and abroad have different opinions. Sundstol *et al*. (1979) found that increasing moisture content of straw from 12 to 50 percent had a positive effect on *in vitro* organic matter digestibility (IVOMD) (Figure 3-5), regardless of temperature. With extremely low moisture (3.3 percent), ammonia treatment had no positive effect on enzyme solubility and straw IVOMD. Sundstol and Ekeern (1982) found that a 6-week treatment with 2 percent anhydrous ammonia of straw with 2.5, 5.0, 7.5 and 10.0 percent moisture, produced corresponding IVOMDs of 52.1, 58.5, 59.1 and 66.0 percent, respectively. Treating straw with 15-20 percent moisture with aqueous ammonia (25 percent) was better than with anhydrous ammonia. Aqueous ammonia improved the moisture content of straw. For example, using 2 percent aqueous ammonia to treat straw is equivalent to adding 6 percent water to straw. Experiments proved that the straw IVOMD could be gradually improved by increasing moisture from 2.5 to 50 percent.

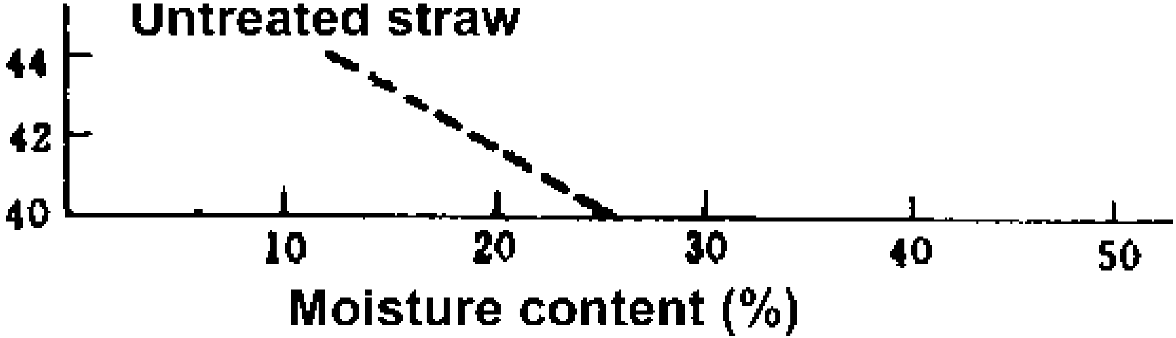
Experiments conducted by Professor Ji Yilun of Shanxi Agricultural University indicated that the optimal moisture content of straw was about 45 percent when treated with urea or ammonia bicarbonate. High moisture contents would result in handling problems and greater risk of damage during storage (e.g. mould development).

The positive effect of higher moisture has also been found in practice. Straw from both the top and the bottom of the stack has high digestibility and good intake due to its moisture content. Straw treated by the Animal Bureau of Zhoukou Region in Henan Province during the FAO project in 1989, with the proportions 100 kg straw: 100 kg water: 5 kg urea, gave good results despite the high moisture content.

On the whole, higher moisture content of straw may improve digestibility. Moisture content can reach 50 percent or more, if straw can be transported and stored without becoming mouldy.

Figure 3-5. Effects of varying moisture contents and treatment temperatures on straw IVOMD when treated with 3.4% ammonia in DM for 8 weeks


IVOMD (%)
68
66
64
62
60
58
56
54
52
50
48
46
+25℃
+17℃
+4℃
−20℃



Temperature and treatment time

High temperature reduces treatment time, since, in general, chemical reactions occur faster. High temperature had a positive effect on both N content and IVOMD of ammonia-treated straw. At a temperature around 45°C, treatment for 3-7 days greatly improved digestibility, whereas the reaction was extremely slow near -20°C. The season effect on ammonia treatment of oat straw in stacks had been studied by Alibes *et al.* (1983) in Spain, who divided 6 tonne into two parts for treatment in summer (38°C) and in winter (7°C). The results indicated that the CP content, DM digestibility, OM digestibility as well as straw intake were higher for summer treatment by 83, 12, 12.3 and 19.3 percent, respectively. Sundstol *et al*. (1978) treated oat straw containing 12.5 percent moisture and 3.4 percent CP with 3.4 percent NH_3 in DM at temperatures of -20°C, 4°C, 17°C and 24°C for 8 weeks. The CP contents after treatment were 6.5, 7.3, 8.3 and 8.5 percent, respectively. Sundstol *et al*. (1978) believed that ammonia treatment may significantly increased N content at temperatures over 25°C, but in longer treatment times (e.g. 3 weeks) increasing temperature from 40°C to 120°C had no positive effect on IVOMD. The length of treatment time for different temperatures had been given by Sundstol *et al.* (1978):

Temperature (°C)	**Treatment time**
< 5	>8 weeks
5-15	4-8 weeks

15-30	1-4 weeks
> 30	< 1 week
> 90	< 1 day

A closed stack may be stored for a long time without becoming mouldy, and stacks should not be opened before it is necessary to use the treated feed. After opening a stack of ammonia-treated straw, it should be aerated for a time before feeding. In cold climates, increasing treatment time has positive effects on ammoniation, but CP content decreases slowly after opening. Beijing Dairy Institute treated rice straw with 3 percent hydrous ammonia and the CP content of treated straw reached 7.8 percent, but 3 months later was below 7 percent.

Quality of material being treated

In general, straw quality after ammoniation depends a lot on pre-treatment quality. Greater improvement is obtained from low quality materials.

Pressure

High pressure is beneficial for ammonia treatment. Experiments conducted by Lie (1975) indicated that increasing the pressure from 1 to 5 kg/cm^2 had a positive effect on IVOMD. Sundstol and Owen (1984) had carried out experiments with similar results. It is known that if ammoniated straw is wafered or pressed into pellets, N-content and IVOMD can be further improved.

Quality evaluation of ammoniated straw

There are three methods to evaluate quality of ammoniated straw: sensory evaluation, chemical analysis and biological tests. The physical changes in straw can be visually observed as an easy, but imprecise, way to evaluate treated straw quality. By chemical analysis, the components of straw such as CF and CP can be measured, but by itself it can not give an estimate of overall nutritive value and animal intake. The scientific method of evaluation of straw quality is through biological tests. For example, digestibility *in sacco* (in the rumen), cellulase digestibility test, and especially digestibility *in vivo*, can estimate not only the digestibility but also the speed of digestion.

Sensory evaluation

Properly ammoniated straw is soft, brownish yellow or light brown, and with a light fragrance after excess ammonia has evaporated. If straw appears white or grey and is sticky or clumps, it means that it has been attacked by mould. This damaged straw should not be used as feed. Of course, this situation seldom occurs if treatment is correct. Mould normally results from high moisture content, defective sealing or delayed ventilation after opening. If, after ammoniation, straw colour is nearly the same as before treatment, it means that ammoniation did not go very well, but it can still be used as feed.

Chemical analysis

Chemical analysis is being widely used in China at present. This method evaluates the extent of straw quality improvement by analysing the main parameters (as digestibility of DM and CP) before and after ammoniation. Lu Xilei (1991), from the Beijing Dairy Institute, ammoniated straw by ensiling with anhydrous ammonia at 3 percent DM on the farm. Comparisons of the main parameters between ammoniated straw and Chinese wild-rye hay are shown in Table 3-1. After treatment CP content improved by 5.44, 3.98 and 5.02 percent for wheat straw, rice straw and maize stover, respectively. The corresponding figures for digestibility were 10.3, 24.0 and 20.0 percent, respectively. Digestibilities of ammoniated wheat straw and maize stover were nearly the same or higher than Chinese wild-rye hay.

Table 3-1. Nutritional comparison between ammoniated straw and Chinese wild-rye hay

Feed	Nutritive factor (%)			
	DM	CP	CF	DM digestibility
Chinese wild-rye hay	90	5.9	32.0	52.0
Winter wheat straw	90	2.2	41.0	39.7
Ammoniated winter wheat straw	70	7.6	39.0	50.0
Rice straw	93	3.9	33.1	24.0
Ammoniated rice straw	90	7.8	32.5	48.0
Maize stover	90	3.7	30.5	42.0
Ammoniated maize stover	90	8.7	30.5	60.0

SOURCE: Lu Xilei, 1991.

Biological tests

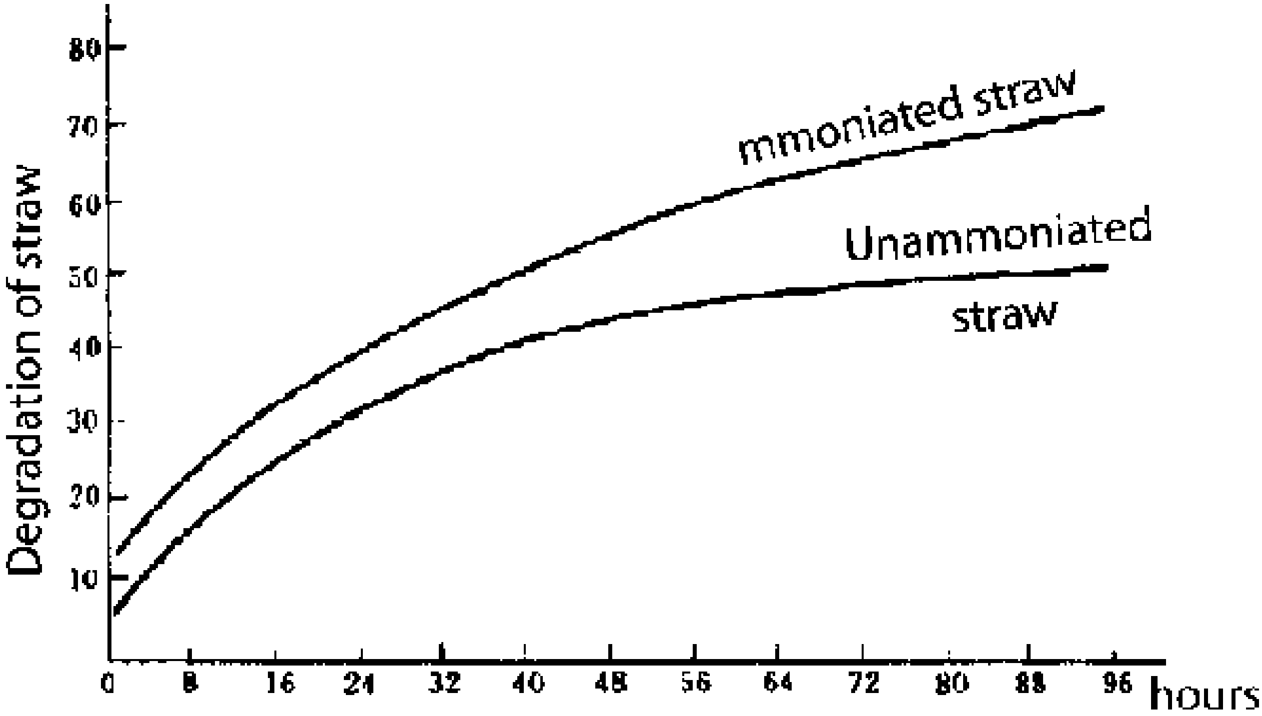
Biological tests, especially the nylon bag *in sacco* method for digestion rate, has been widely applied not only in science and research institutes but also in some production units. For example, in Henan Zhoukou region, the straw degradation rate was measured by the nylon bag technique in sheep during the FAO project (1989-1990). The results, presented in Table 3-2 and Figure 3-6, showed that the maximum rate of degradation (P-value) for ammoniated barley reached 77.1 from 52.1 percent in untreated straw. In the last five years, the Institute of Animal Production and Health in Hebei Province has measured digestibility rates for 9 feedstuffs (89 samples) by the nylon bag technique in sheep. These feeds include beans, cakes, pomace, dregs, animal by-products, leaf and straw. The nylon bag technique provides a foundation for systematic development of the feed resource.

Table 3-2. Nylon bag (*in sacco*) dry matter degradation of wheat straw (%)

Sample	Incubation time (hours)						a	b	c	RSD(1)
	0	8	24	48	72	96				
Ammoniated	16.4	23.7	40.0	55.6	64.8	70.1	13.1	64.4	0.04	1.70
Untreated	12.2	17.0	32.7	44.1	48.1	50.8	4.9	47.3	0.02	0.99

Note: (1) RSD = residual standard deviation

Figure 3-6. Digestibility curve



Straw degradation rate can be calculated by the equation:

$$p = a + b\ (1-e^{-ct})$$

where:

p = the amount degraded at time (t)
a = soluble material which is immediately digestible,
b = the fraction which will be digested in the given time,
c = the rate constant for digestion of b,
a + b = the asymptote or the potential extent of digestion,
e = natural log
t = degradation time

The above parameters give an indication of feed quality. Considering the popularity of ammoniation, it is imperative to establish a standard suitable for estimating treated straw quality.

Animal experiments with ammoniated straw

Feeding experiments with beef cattle

A UNDP-funded project, *Beef cattle production system based on ammoniated straw,* was effected between 1991-1992 in Huaiyang and Shangshiu counties of Henan Province; Boxiang county in Hebei Province, and some other regions. At the same time, beef cattle feeding experiments were conducted.

Experiments in Huaiyang county

Experiments were conducted in more than 100 counties with 259 animals. Cattle had *ad libitum* access to ammoniated straw and received a concentrate supplement according to body weight. Each animal needed 0.5 to 2.25 kg of concentrate feed (3/4 cotton seed cake + 1/4 maize grain). Results of feeding experiments are presented in Table 3-3, and the economic benefits in Table 3-4.

Results showed that average daily gain between 150 and 450 kg was 0.5 kg. The ratio of concentrate to weight gain was in the range of 0.83 to 3.5. This ratio was less than 2 for cattle under 350 kg. It took 498 days to go from 150 to 450 kg. Experiments with calves were also conducted. The results demonstrated that it took less than 2.5 years from birth to market weight (450 kg) under the current management regime. It took less than 2 years to bring cattle to 400 kg.

Table 3-3. Feeding experiments with ammoniated straw in Huaiyang county

Body weight (kg)	Concentrate (kg/day)	Straw intake (kg/day)	Weight gain (g/day)	Concentrate per kg gained
151-200	0.5	5.2	605	0.83
201-250	0.7	6.0	574	1.22
251-300	0.9	6.6	593	1.52
301-350	1.3	7.1	654	1.99

351-400	1.8	7.4	514	3.50
401-450	2.3	7.9	707	3.18

Table 3-4. Economic analysis from studies in Huaiyang county

Body weight (kg)	Weight gain (g/day)	Inputs (¥/day)	Output (¥/day)	Benefit (¥/day)
151-200	605	0.78	2.30	1.52
201-250	574	0.94	2.18	1.24
251-300	593	1.08	2.25	1.17
301-350	654	1.30	2.48	1.18
351-400	514	1.53	1.95	0.42
401-450	707	1.77	2.69	0.92

NOTES: Feed prices: cotton seed cake, ¥ 0.4/kg; maize, ¥ 0.5/kg; urea, ¥ 1.0/kg; wheat straw, ¥

0.04/kg. De preciation of feeding equipment and health care were ¥ 0.1/head/day. Cattle price was ¥ 3.8/kg. Worker labour costs were covered by manure sales.

Experiments in Shangshui County

The experiments were carried out on 85 private farmers, with 344 cattle, during 1992. Cattle had free access to ammoniated straw mixed with concentrate according to body weight. Each beast consumed 1.5 to 2 kg concentrate (3/4 cotton seed cake + 1/4 ground maize) per day. The results of feeding experiments are shown in Table 3-5, and the economic benefits in Table 3-6.

Average daily gain was between 608 and 629 g from 150 to 450 kg when cattle consumed ammoniated straw supplemented with 1.5-2 kg concentrate per day. The ratio of concentrate to weight gain was 2.39-3.29. It took 482 days from 150 to 450 kg, with a daily average input of ¥ 1.31, an output of ¥ 2.36 and net profit of ¥ 506.1 per animal.

Table 3-5. Feeding experiments with ammoniated straw in Shangshui county

Body weight (kg)	Concentrate (g/day)	Straw intake (kg/day)	Weight gain (g/day)	Concentrate per kg of gain
150-250	1.5	7.0	628	2.39
251-350	2.0	8.9	629	3.18
351-450	2.0	11.4	608	3.29

Table 3-6. Economic analysis of studies in Shangshui country

Body weight (kg)	Weight gain (g/day)	Inputs (¥/day)	Output (¥/day)	Benefit (¥/day)
150-250	628	1.05	2.39	1.34

251-350	629	1.38	2.39	1.01
351-450	608	1.50	2.31	0.81

NOTES: Feed prices: cottonseed cake, ¥ 0.4/kg; maize grain, ¥ 0.5/kg; urea, ¥ 1.0/kg; wheat straw, ¥ 0.04/kg. Depreciation of feeding e quipment and health care were ¥ 0.1/head/day. The price of live cattle was ¥ 3.8/kg.

Studies by Institute of Animal Production and Health in Hebei Province

Twelve 18-month-old cattle were divided into 4 groups receiving *ad libitum* four straw sources: wheat straw, maize stover, ammoniated wheat straw and ammoniated maize stover. In addition, each animal received 1.5 kg of cotton seed cake per day. The study lasted 80 days, starting 21 February 1992. The results are presented in Table 3-7.

The results confirmed that gains were better with ammoniated straw. Treatment of wheat straw improved growth 85.1 percent (from 348 to 644 g/day) and treatment of maize stover by 45 percent (from 513 to 744 g/day). It also reduced the concentrate needed per kg of gain (from 4.32 to 2.33 kg). In other words, 1.99 kg concentrate was saved and straw conversion rate increased by 46.1 percent. Corresponding figures for maize stover were 2.93 to 2.02 kg of concentrate needed per kg gain; 0.91 kg of concentrate saved; and conversion improvement of 31.1 percent. Intake of crop residue DM varied from 2.14 to 2.83 kg per 100 kg of weight. Intake order was: ammoniated maize stover > maize stover > ammoniated wheat straw > wheat straw.

Table 3-7. Results of feeding experiments in Hebei Province

		Group			
		Untreated	**Untreated**	**Ammoniated**	**Ammoniated**

		wheat straw	maize stover	wheat straw	maize straw
Number of cattle		3	3	3	3
Days of experiment		80	80	80	80
Average initial weight	(kg)	234.8	234.8	234.8	234.8
Total weight gained	(kg)	83.4	122.8	154.5	178.6
Average gain	(g/day)	348	513	644	744
Cottonseed intake	(kg/day)	1.5	1.5	1.5	1.5
Total feed intake	(% BW)	2.56	3.10	2.94	3.29
Straw intake	(% BW)	2.14	2.70	2.48	2.83
Concentrate:		4.32	2.93	2.33	2.02

Concentrate: gain ratio		4.02	2.06	2.66	2.02
Straw degradation rate	(%)	45.03	62.97	54.75	69.31

Experiments in Dingxing County

Experiments were carried out on demonstration farms. Thirty local yellow cattle of 200 to 300 kg BW and 1.5 to 2 years old were selected and divided into 3 groups. Cattle were mainly fed *ad libitum* with ammoniated wheat straw (treated with 5 percent urea). The groups were supplied with 2, 3 and 4 kg cottonseed cake, respectively, to study the effect of supplement level. The experiments started on 26 May 1992 and lasted 42 days. Results are presented in Table 3-8.

Results showed that daily gains increased with concentrate level, but in a diminishing response. From 2 to 3 kg, gains increased by 217 g/day, or 22.5 percent, but from 3 to 4 kg, only by 105 g/day, or 14.1 percent. The efficiency of concentrate use for growth also decreased with the level.

The results from the above studies show that on the basis of ammoniated straw diets, the concentrate required per kg of weight gain varied from 0.83 to 3.5 kg, starting at 150 kg. The concentrate used per kg of liveweight gain was less in cattle than in swine. Cattle market age can be reduced to 2.5 years. This low-level concentrate feeding system is well suited for Chinese conditions.

Table 3-8. Effects of cottonseed cake ration on daily gain

		Group		
		I	**II**	**III**
Number of cattle		10	10	10
Experimental period	(days)	42	42	42

Cottonseed cake intake	(kg/day)	2	3	4
Ammoniated straw intake	(kg/day)	7.25	7	4
Total initial group weight	(kg)	2 629	2532	2 847
Total final group weight	(kg)	28 85	2943	3 205
Total weight gain	(kg)	256	312	358
Average daily gain	(g/day)	609	826	931
Concentrate to gain ratio		3.28:1	4.04:1	4.70:1
Straw to gain ratio		11.89:1	9.44:1	7.93:1
Cost of gain	(¥/kg)	2.94	2.97	3.11
Total income	(¥)	922	1 121	1 287
Total expenses	(¥)	528	718	911
Net benefit per head	(¥)	39.4	40.4	37.6

Feeding dairy cows

The Rowett Research Institute of UK reported the use of ammoniated straw for dairy cows instead of dry hay, without effects on milk yield or quality. Most researchers have tried ammoniated straw feeding for beef cattle and growing cattle, but there have been very few studies on high yielding dairy cows (> 7 000 kg/lactation). In 1999, Lu Xilei from the Beijing Dairy Institute conducted systematic experiments feeding high production cows with ammoniated straw, with great success. Some results are presented here.

Feeding dairy cows with ammoniated rice straw (1990)

Ammoniated rice straw replaced 30 percent of Chinese wild-rye hay in the ration, without negative effects on yield and composition (Tables 3-9 & 3-10).

Table 3-9. Groups of dairy cattle for ammoniated rice straw study

Group	(1)	Number of	Milking	Milk	Body

Group	n(1)	Number of calvings	Milking days	Milk production (kg/day)	Body weight (kg)
Treated straw	30	2.7	167	24.1	573
Untreated straw	30	2.8	164	23.6	576
P		> 0.05	> 0.05	> 0.05	> 0.05

NOTE: (1) Number of dairy cows in each group

Table 3-10. Average milk production and composition when feeding rice straw

Group	n(1)	Days	Milk production (kg)	Fat (%)	Protein (%)	Lactose (%)
Treated	30	112	24.12	3.24	-	4.75

straw						
Untreated straw	30	112	23.39	3.51	3.19	4.80
P			> 0.05	> 0.05	> 0.05	> 0.05

NOTE: (1) Number of dairy cows in each group

Feeding dairy cows with ammoniated maize straw (1991)

Feeding experiments were carried out supplying half of the ration as either ammoniated maize stover (group A) or untreated maize stover (group B). The other half was Chinese wild-rye hay. A third group (C) received only Chinese wild-rye hay. The comparisons of milk yield and composition among the three groups are shown in Table 3-11. No negative effects on milk production and composition were found when ammoniated maize stover or untreated maize stover substituted half of the Chinese wild-rye hay, but obvious economic profits were obtained. In other words, ammoniated straw could replace part of Chinese wild-rye hay for high yielding cows (with 7 500 kg of milk per lactation), but whether it could be replaced completely still needs further experimentation. A Shuangqiao farmer obtained good results with total replacement of Chinese wild-rye hay by ammoniated straw.

Table 3-11. Comparison of milk production and composition among three groups

Group	n(1)	Milk yield (kg)	Fat (%)	Protein (%)	Lactose (%)
A	6	26.24	3.30	2.94	4.73
B	6	25.48	3.20	3.01	4.75
C	6	25.27	3.30	3.06	4.82
P		>0.05	>0.05	>0.05	>0.05

NOTE: (1) Number of dairy cows in each group

Feeding sheep

In Norway, Nedkvitne and Maurtvedt (1980) conducted an experiment with pregnant ewes, feeding them with straw and concentrates. One group was fed with 0.6-0.8 kg forage and another with 0.8-1.0 kg ammoniated straw. Mean values of the 3-year experiment are shown in Table 3-12.

Results showed that there was no obvious difference in the number of lambs born between the two groups. Weight increases during pregnancy for the ammoniated straw group were more rapid than in the untreated group, but weight losses were also greater, so weight balance was better with forage. There were no differences in lamb weight in autumn.

In recent years, some institutes in China have also used ammoniated straw in feeding experiments. For example, Zhen

Erying from Hebei Agricultural University used urea-treated rice straw to feed sheep, with satisfactory results.

Table 3-12. Results of feeding ammoniated straw to pregnant ewes

Parameter		**Forage group**	**Ammonia straw group**
Feedstuffs	(kg/day)		
Forage		0.6-0.8	-
Ammoniated straw		-	0.8-1.0
Silage		1.5-2.5	1.5-2.5
Concentrate		0.2-0.3	0.2-0.3
Lambs per lambing		54/31	45/34
Ewe weight on 12 December	(kg)	74	75
Weight gain during	(kg)	8.7	10.7

pregnancy			
Net weight gain after lambing	(kg)	2.7	1.0
Lamb birth weight	(kg)	5.1	5.1
Lamb weight gain in spring	(g/day)	344	344
Lamb weight in autumn	(kg)	49	49

SOURCE: Unpublished report (1991) on dairy cows fed on ammonia-treated residues. Shuangqiao State Farm, Beijing.

CHAPTER 4 - ENSILING CROP RESIDUES

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Silage is the material produced by controlled fermentation of crop residues or forages with high moisture content. The purpose is to preserve forages by natural fermentation by achieving anaerobic conditions and discouraging clostridial growth. The ideal characteristics of material for silage preservation are: an adequate level of fermentable substrate (8-10 percent of DM) in the form of water soluble carbohydrate (WSC); a relatively low buffering capacity; and a DM content above 200 g/kg. The ensiling material should also ideally have, after harvesting and chopping, a physical form that allows easy compaction in the silo. Materials such as maize stover and grass can be ensiled successfully, while crop residues such as rice and wheat straw, with low WSC content, do not fulfil these requirements, and therefore pre-treatments, such as fine chopping or use of additives, or both, may be necessary.

There are plenty of materials suitable for ensilage in China. Whole maize and stover are the most common materials. Sweet potato vines are also usually ensiled after harvesting the tubers. In the provinces along the Yangtze River valley, large amounts of Chinese milk vetch are cultivated as green manure to improve soil fertility. Traditionally, farmers ensile surplus vetch for later use.

Types of silos

Tower silo

In China, tower silos are constructed from brick, and are several metres in diameter and 10-20 m in height. The advantages of this type of silo include: long life, small space required, low storage losses, and possibility for mechanization. Both the filling operation and daily extraction can be mechanized. However, tower silos are expensive, and therefore not widely used in China, with the exception of some state-owned farms.

Cellar silo

The cellar type is the most common silo on individual farms. Round or square concrete silos are usually built inside houses for protection from the weather. Advantages are lower cost and easy management. Size can be adjusted according to scale of production. Cellar silos are suitable for rural conditions in China. A disadvantage is high effluent loss, especially with clay walls.

Trench silo

This type is generally built underground or semi-underground, with two solid walls of 1.5-2 m in height. Advantages are similar to the cellar silo, but the trench silo is more suitable for mechanization. The tractor can be driven on top from one side to the other for compaction purposes. After compaction, it is covered with a plastic sheet pressed down with soil, sandbags or straw bales to maintain anaerobic conditions.

On many dairy farms, trench silos are built on the surface of ground. This type of trench silo resembles a bunker silo, but has vertical walls of 0.4-0.5 m in thickness and 3-4 m in height. This design makes mechanization more convenient, and may also prevent bottom leakage.

Stack silo

This type of silo implies a pile of material on the ground surface. On flat and dry ground, plastic sheet is placed underneath and the material is laid in a stack. The top is covered with plastic and sealed all round with soil. Sandbags or old tyres, or any other suitable objects, are placed on top to prevent the top cover from being blown away by the wind. The advantages of the stack silo are low cost and flexibility of placement.

Plate 4-1. Ensiling, building a trench on the ground

Plate 4-2. Ensiling, building a trench below ground surface

Plate 4-3. Silage bales wrapped with plastic

Plate 4-4. Tower silos, Shanxi, China

Plastic silo

Animal scientists from Neijiang, Sichuan Province, successfully ensiled sweet potato vines in plastic bags in 1978. The plastic silo is similar to the stack silo but it is covered with plastic sheets of polyvinyl chloride (PVC) or polyethylene. Alternately, the silo can be made in bags with sealed tops. The stack silo is also inexpensive and can be placed anywhere. However, labour requirements are high due to manual filling and handling. A specific machine has recently been developed by the Grassland Institute, Chinese Academy of Agricultural Science, to fill plastic bags with forage.

Silage making

Control of moisture content in raw materials

Ensilage can only be successful, with minimum DM and nutrient losses, when the moisture content of the raw material is kept to a suitable level. Although silage may be made within a large range of moisture contents, DM should be over 20 percent to assure silage quality.

There are many disadvantages to ensiling crops with high moisture content. First, ensiling of wet materials results in the generation of a large volume of effluent, which not only poses disposal problems, but also carries off valuable, highly digestible nutrients in solution. The amount of effluent increases with silo height, due to pressure. Effluent is produced when moisture is above 75 percent. Secondly, the critical pH value for clostridial growth varies directly with the moisture content of the plant material, and unless soluble carbohydrate levels are exceptionally high, ensiling wet crops will encourage clostridial fermentation, resulting in high losses and reduced nutritive value. Thirdly, even if the water-soluble carbohydrate (WSC) levels are adequate to ensure lactic fermentation, very wet silages may still be nutritionally undesirable because voluntary DM intake of these is frequently low. Finally, drier plant materials are preferred because they are easier to handle and a higher quantity of DM can be carried per trailer load.

Moisture content of forage and grasses is above 80 percent when harvested at a suitable stage. Therefore the moisture content should be reduced by field wilting. It takes 4 to 6 hours to wilt in dry regions such as the north western provinces and Inner Mongolia, and 6 to 10 hours in north eastern and northern areas. Longer periods may be needed in southern provinces, depending on climate and weather, but it is not desirable to exceed 24 hours. When weather conditions are unfavourable, field wilting should be avoided to prevent nutrient loss due to rain leaching. In these cases, other methods should be considered.

In contrast, the moisture content of cereal straw is generally too low to allow tight packing, so cereal straw and stover should be finely chopped. Sometimes water should be added to bring moisture content to a suitable level.

Sweet potato vines are high in moisture content and wilting is necessary. Chopped vines are usually mixed with finely chopped straw or bran prior to ensiling to increase overall DM content.

The moisture content of plant materials may be measured with instruments, but it is usually estimated manually on farm. Samples of chopped and minced grass or leguminous forage are grasped tightly by hand for one minute or so to estimate moisture content. If juice can be extracted, moisture content is above 75 percent. If the material remains together but without juice, moisture content is between 70-75 percent. If the material has elasticity and spreads out slowly, moisture content is 55-65 percent. If the material spreads out quickly, moisture content is about 55 percent. If the material breaks, moisture content may be below 55 percent.

Chopping, compaction and sealing

Prior to ensiling, plant materials should be chopped. The fineness of chopping varies with moisture content and nature of the material. The following guidelines can be used, but, in principle, rough and hard materials should be finely chopped, while delicate and soft materials can be roughly chopped.

High moisture forage (Moisture >75%)	chop to 6.5-25 mm
Wilted materials (Moisture 60-70%)	chop to 6.5 mm
Whole maize plant	chop to 6.5-13 mm

What are the advantages of chopping? Firstly, chopping facilitates compaction and thus reaching the anaerobic stage. When most oxygen is removed, clostridial growth is discouraged and lactic acid fermentation encouraged. Secondly, chopping releases plant juices, stimulating the growth of lactic acid bacteria. Thirdly, chopping may increase silage intake by improving quality of fermentation and by accelerating rate of passage of feed particles through the rumen. However, very finely chopped silage reduces the rumination and may decrease milk fat content. Thus, 10-15 percent of the silage material should be above 25 mm in length in order to maintain an effective fibre function.

Factors influencing silage quality

Quality of silage fermentation is influenced by several factors, including moisture, WSC content of raw materials, degree of compaction and effectiveness of final sealing. Stage of maturity influences a forage's nutritive value and thus quality of silage. Leguminous forages at budding stage have optimal energy, protein and carotene contents, but DM yield and nutritive value decrease with maturity (Table 4-1). Grass at heading stage is highest in caloric value and protein content. When leguminous forages reach late flowering stage or grasses reach seed stage, the energy value has decreased by 70-75 percent, digestible CP by 67-83 percent, and carotene content by 75-84 percent.

Table 4-1. Yield of dry matter and nutrients in legumes and grasses by growth stage

Growth stage	Yield (ton/ha)			
	Fresh	DM	Feed	Digestible

	yield		unit	CP
Legumes				
Pre-bud	13.0	2.7	2.3	0.44
Mid-bud	16.5	4.2	3.8	0.58
Flowering	14.8	4.2	3.7	0.54
Full bloom	8.4	3.5	1.9	0.19
Green seed pod	7.1	2.8	1.2	0.13
Milky ripe and dough seed	6.8	2.8	0.5	0.10
Grasses				
Heading	17.2	5.0	4.6	0.49
Early bloom	17.3	5.2	3.8	0.40
Full bloom	9.1	3.8	2.3	0.19
Green seed pod	8.4	3.0	1.2	0.08
Milky ripe	8.0	3.0	1.1	0.06

Dough seed	7.8	2.6	0.7	0.05

Therefore, it is important to harvest forage crops at their optimal stages. Legumes should be harvested at budding stage, grasses at heading stage, and whole maize plant at late milky to early dough seed stage.

Grass is highest in protein at pre-heading, and highest energetically at dough seed stage. Many grasses can not head again after the first cutting, and the re-growth may be collected 4 to 5 weeks after the first harvest. The appropriate stages at which plants may be harvested are indicated in Table 4-2.

Table 4-2. Appropriate harvest stages for grasses and forage crops

Grass and forage	Stage of growth	Moisture

crops		(%)
Alfalfa	Late bud to 1/10 bloom	70-80
Red clover	Late bud to early bloom	75-82
Orchard grass	Pre-head to heading	
Awnless bromegrass	Pre-head to heading	75
Timothy	Pre-head to heading	
Sudan grass	About 90 cm in height	80
Mixed grasses	Pre-head to early heading	
Mixed legume and grass	Depending on grass	
Grain forage	Pre-head to early heading	
Whole-crop maize	Dough seed	65-70
Maize stover	Soonest after maize harvest	50-60
Whole-crop sorghum	Early to mid-dough seed	70
Sorghum stover	Soonest after sorghum	60-70

	harvest	
Oat	Pre-head to early heading	82
Oat	Milky ripe	78
Oat	Early dough seed	70
Barley	Late bud to early dough seed	82-70
Rye	Late bud to early dough seed	80-75

Because straw and stover are harvested after grain collection, their nutritional value is generally low. It has been recently shown that yield and grain quality do not change when harvest is shifted to an earlier stage (by 7-10 days). However, this shift may be beneficial in terms of improved nutritional value of straw and stover.

Silage additives

The purpose of using additives is to ensure silage quality by encouraging lactic acid fermentation, by inhibiting undesirable microbes or by improving its nutritional value. Common silage additives include bacterial cultures, acids, inhibitors of aerobic damage, and nutrients.

Bacterial cultures

A dominant lactic acid fermentation is the key to making good silage. Lactic acid bacteria are normally present on harvested crops together with clostridial bacteria in a ratio of about 10 to 1. Considerable nutrient loss usually occurs at initial stages of ensiling when oxygen is still present. Addition of lactic acid bacterial cultures during filling-up increases their population rapidly, encouraging lactic acid fermentation and pH reduction to a level that inhibits clostridial development. Different strains of lactic acid bacteria look similar under the microscope, but their biological activities are very different. Only those acid-tolerant strains that possess a homo-fermentative pathway, producing the maximum amount of lactic acid from hexose sugars readily available, and a growth temperature range extending to 50°C, should be used as a silage additive.

The environment under which lactic acid bacteria multiply favourably is also important. Lactic acid bacteria are anaerobic, and hence air should be removed and the silo should be kept airtight. These micro-organisms ferment soluble sugars to a mixture of acids, but predominantly lactic acid. Plant materials should contain at least 2 percent WSC, otherwise soluble sugars (e.g. molasses) should be added. Starch may also be added along with amylase in order to provide lactic acid bacteria with soluble sugars.

Cereal straws and stovers are high in lignocellulose. A mixture of inoculum or enzymes, or both, containing cellulase and xylanase is often used. Enzymes degrade lignocellulose, liberating soluble sugars for bacterial use. A number of commercial preparations are available from foreign companies, and some have been registered by government authorities and can be sold in China. During the Ninth Five-Year Plan, Chinese scientists successful produced a special additive for ensiling fresh cereal straws and stovers.

Mineral or organic acids

The original proposal to use acids as silage additives dates back to 1885. In the late 1920s, Virtanen from Finland, adopted this approach and recommended the rapid acidification of the crop with mineral acids (AIV process) to a pH of about 3.5, which was originally thought to inhibit microbial and plant enzyme activity. This AIV process was widely used in Scandinavia until quite recently. Due to the difficulties in handling corrosive acids, organic acids were later used as silage additives. When acids are added, plant materials sink quickly and are easy to consolidate. Acidity may arrest plant respiration and reduce heat production and nutrient loss. Rapid acidification may also inhibit clostridia.

However, addition of acids increases effluent and can be potentially toxic to animals. Furthermore, acids are corrosive to people, animals and machinery. Reduction of moisture content may minimize effluent, and addition of calcium carbonate can be used to adjust silage acidity. Appropriate concentrations of different acids as silage additives are recommended as follows:

- sulphuric and hydrochloric acids: 50-80 litre of dilute acid (concentrated acid diluted with water at 1:5 v/v) per tonne

- formic acid: about 3 kg/ton

- acetic acid: 5-20 kg/ton

- propionic acid: 1 litre/m^2 of surface to prevent mould development.

Inhibitors of aerobic deterioration

The most common inhibitors of aerobic deterioration are sodium nitrate, sodium nitrite, sodium formate and formaldehyde. These chemicals do not contribute to the improvement of fermentation, but are effective in preventing silage deterioration. Some plant parts, such as larch leaves, contain natural bactericides that may safely function as antiseptics. Formaldehyde is a well-known sterilizing agent and is commercially available as formalin, which contains 40 percent of the gas in aqueous solution. Scientists are interested in the additives because of their bacteriostatic properties, and because of their known properties of protecting plant proteins from rumen microbial degradation. Adding formaldehyde at 3-15 kg/ton may result in a well-preserved silage.

Nutrients

Nutrient additives are defined as substances which, when added to ensilage materials, contribute significantly to the nutritional value of the silage. Most of nutrient additives can also favour lactic acid fermentation. A number of materials are considered to be in this category.

Nitrogenous compounds

Certain crops, such as maize and most cereal straw, are nutritionally deficient in nitrogen, and when fed to ruminants as silage require supplementing with a protein supplement. An alternative approach is to improve the CP content of the silage by adding urea during ensiling. When applied to maize, urea produces silages with higher pH values and fermentation acid contents than in untreated silages. Urea addition has also a marked effect on nitrogenous components of the silages, resulting in higher CP, true protein, free amino acids and ammonia. Addition of urea to cereal straw and stover may also have an ammoniation effect, which is associated with higher CP and lower fibre content. However, attention should be paid to the rapid release of ammonia from urea in the rumen. High concentrations of ammonia in the rumen may cause ammonia poisoning. One solution is to add the urea or other nitrogenous compounds together with soluble sugar sources, such as molasses and starchy grains.

Urea may be added at 0.5 percent of fresh materials. When whole maize plant was added with urea at 0.5 percent, the CP of the resulting silage increased to 12.9 from 8.7 percent in the untreated silage. Urea may also be added prior to feeding the animals.

Carbohydrate-rich materials

Carbohydrate-rich materials are added to silage crops in order to increase the supply of available energy for the growth of lactic acid bacteria, and are of particular importance in crops such as legumes, which are deficient in soluble carbohydrate content. Materials that have been used for this purpose include molasses and cereals. Molasses is a by-product of the sugar industry, and has a DM content of 70-75 percent and a soluble carbohydrate content of about 65 percent of DM. In order to obtain maximum benefit, it should be used at 4 percent (w/w) for grass silage and 6 percent (w/w) for legume silage. Cereals have been used as additives in an attempt to improve both the fermentation quality and the nutritional value of silages. Cereals contain 50-55 percent of starch that can be hydrolysed to soluble sugars and then utilized by lactic acid bacteria. If amylase or amylase-rich materials, such as malt, are added with the cereal to ensiled crops, they will be more effective as fermentable carbohydrate sources.

Minerals

In addition to being nutritionally deficient in N, most straw and stover is a poor source of Ca and many micro-elements.

Limestone is sometimes added to silages as Ca supplement and to alleviate silage acidity. Calcium carbonate may be added at 0.45-0.50 percent to obtain maximum benefit. Common salt has a high osmotic pressure to which clostridia are sensitive, but lactic acid bacteria are not. Addition of salt may increase lactate content, decrease acetate and butyrate, resulting in silage with good quality and palatability.

Other minerals may be used in ensiled materials. Examples of mineral sources include copper sulphate (2.5 ppm), manganese sulphate (5 ppm), zinc sulphate (2 ppm), cobalt chloride (1 ppm) and potassium iodide (0.1 ppm).

Finally, it has to be pointed out that recommendations on the use of silage additives must be based not only on the results of scientific research, but also on sound economic return.

Evaluation of silage quality

The nutritive value and the quality of silage should be accurately evaluated. Working on behalf of the Bureau of Animal Production and Health (BAPH), MOA, researchers at Zhejiang University drafted methods of evaluating nutritive value and quality of silage, which have been tested in China since 1996. This handbook includes subjective methods (on-farm) and chemical methods (for use in laboratory).

Subjective methods of evaluation

The pH value and certain simple subjective criteria such as colour, smell and texture are used to evaluate the quality of silage on-farm. These criteria are briefly reviewed below.

pH value

The pH is the simplest and quickest way of evaluating silage quality, and may be determined on-farm using wide-range pH test papers such as bromophenol blue (range 2.8-4.4), bromocresol green (range 4.2-5.6) and methyl red (range 5.4-7.0). The classification of silage based on pH value is:

pH below 4.0	excellent
pH between 4.1 and 4.3	good
pH between 4.4 and 5.0	average
pH above 5.0	bad

Colour

Good silage usually preserves well the original colour of the standing plant. When green raw material produces silage with green or yellow colour, it can be considered of good quality. Temperature is one of the important factors affecting silage colour. The lower the temperature during ensilage, the less colour change. Above 30°C, grass silage becomes dark yellow. Above 45 to 60°C, the colour becomes closer to brown. Beyond 60°C, the colour darkens towards black due to caramelization of sugars in the forage.

However, silage quality can be misjudged by on a colour basis. For example, silage from red clover or Chinese milk vetch is often dark brown instead of light brown. Despite its excellent quality, it may be considered a failure due to colour. A more useful indicator is colour of the silage juices. It can generally be said that the lighter the colour of the juice, the greater the success.

Smell

Good silage usually has a mild, slightly acidic and fruity smell, resembling that of cut bread and of tobacco (due to the lactic acid). A rancid and nauseous smell denotes the presence of butyric acid and signifies a failed silage. A musty smell is a sign of deficient compaction and presence of oxygen. A distinctive unpleasant smell, of sow's urine and faecal matter, is always indicative of marked protein degradation during ensilage.

Texture

Plant structures (stems and leaves) should be completely recognizable in the silage. A destroyed structure is a sign of severe putrefaction. A viscous, slimy appearance reveals the activity of pectolytic (sporulating) micro-organisms.

Taste

This test is more suitable for specialists. It is of little value to the farmer, whose basis is the palatability to farm animals.

Integrative evaluation

It is obvious that silage quality can not be satisfactorily evaluated on any one of the above subjective indicators. The following methods of integrated evaluation (BAPH, 1996) have been on trial. Tables 4-3, 4-4 and 4-5 present indicators of integrated silage evaluation from maize stover, Chinese milk vetch or alfalfa, and sweet potato vines, respectively.

From overall evaluation scores (based on the parameters given below in Tables 4-3 to 4-5), silage quality can be classified as follows:

Class	Good	Satisfactory	Average	Bad
Scores	100-75	75-51	50-26	Below 25

Table 4-3. Integrated evaluation of silage from maize stover using scores

Score(1)	**pH(2)**	**Moisture**	**Smell**	**Colour**	**Texture**
	25	**20**	**25**	**20**	**10**
	3.4(25), 3.5(23),	70%(20), 71%(19),	Pleasant and	Light yellow	Loose and
Good	3.6(21),	72%(18),	sweet,		soft, non-

	3.7(20), 3.8(18)	73%(17), 74%(16), 75%(14)	acidic (18-25)	(14-20)	viscous (8-10)
Satisfactory	3.9(17), 4.0(14), 4.1(10)	76%(13), 77%(12), 78%(11), 79%(10), 80%(8)	Light acidic (9-17)	Brown yellow (8-13)	(Medium) (4-7)
Average	4.2(8), 4.3(7), 4.4(5), 4.5(4), 4.6(3), 4.7(1)	81%(7), 82%(6), 83%(5), 84%(3), 85%(1)	Irritative, alcohol, acidic (1-8)	(Medium) (1-7)	Slightly viscous (1-3)
Bad	Above	Above	Rancid and musty	Dark brown	Putrefactive & agglutinative

	4.8(0)	86%(0)	smell (0)	(0)	(0)

NOTES: (1) The figures in parentheses represent the scores.
(2) The pH value is determined using wide-range pH test paper.

Table 4-4. Integrated evaluation of silage from sweet potato vines using scores

Score[1]	**pH[2]**	**Moisture**	**Smell**	**Colour**	**Texture**
	25	**20**	**25**	**20**	**10**
Good	3.4(25), 3.5(23), 3.6(21), 3.7(20), 3.8(18)	70%(20), 71%(19), 72%(18), 73%(17), 74%(16),	Pleasant and sweet acidic (18-25)	Brown (14-20)	Loose and soft, non-viscous (8-

Satisfactory	3.9(17), 4.0(14), 4.1(10)	75%(14), 76%(13), 77%(12), 78%(11), 79%(10), 80%(8)	Light acidic (9-17)	(Medium) (8-13)	10) (Medium) (4-7)
Average	4.2(8), 4.3(7), 4.4(5), 4.5(4), 4.6(3), 4.7(1)	81%(7), 82%(6), 83%(5), 84%(3), 85%(1)	Irritative, alcohol, acidic (1-8)	(Medium) (1-7)	Slightly viscous (1-3)
Bad	Above 4.8(0)	Above 86%(0)	Rancid and musty smell (0)	Dark brown (0)	Viscous and agglutinative (0)

NOTES: (1) The figures in parentheses represent the scores.
(2) The pH value is determined using wide-range pH test paper.

Table 4-5. Integrated evaluation of silage from Chinese milk vetch or alfalfa

Score[(1)]	**pH[(2)]**	**Moisture**	**Smell**	**Colour**	**Texture**
	25	**20**	**25**	**20**	**10**
Good	3.6(25), 3.7(23), 3.8(21), 3.9(20), 4.0(18)	70%(20), 71%(19), 72%(18), 73%(17), 74%(16), 75%(14)	Pleasant and acidic (18-25)	Light yellow (14-20)	Loose and soft, non-viscous (8-10)
	4.1(17), 4.2(14),	76%(13), 77%(12),	Sour and	Golden	(Medium)

Satisfactory	4.3(10)	78%(11), 79%(10), 80%(8)	alcoholic (9-17)	yellow (8-13)	(4-7)
Average	4.4(8), 4.5(7), 4.6(6), 4.7(5), 4.8(3), 4.9(1)	81%(7), 82%(6), 83%(5), 84%(3), 85%(1)	Irritative acidic (1-8)	Light yellow brown (1-7)	Slightly viscous (1-3)
Bad	Above 5.0(0)	Above 86%(0)	Rancid and musty (0)	Dark brown (0)	Putrefactive & agglutinative (0)

NOTES: (1) The figures in parentheses represent the scores.

(2) The pH value is determined using wide-range pH test paper.

From the above review it can be seen that subjective criteria by themselves are insufficient to determine quality, and that an objective laboratory analysis is necessary.

Chemical methods of evaluation (laboratory methods)

Evaluation of silage in the laboratory is mainly based on chemical analysis. It includes pH determination and assay of organic acids (acetic, propionic, butyric and lactic), which are the main fermentation metabolites in silage. Fermentation characteristics may be estimated based on total acids or on proportions of individual acids. Free ammonia assay, and better still the ratio of ammonia nitrogen to total nitrogen, is the most valid criterion for protein degradation.

Before discussing the value of such analyses, it is necessary to emphasize the necessity for the sample to be truly representative. Samples must be taken with a probe from several places at different layers in the silos. The sampling points should be more than 30 cm from the edge of the silo to prevent misleading results. Samples should preferably be sent to the laboratory in sealed plastic bags or glass bottles to avoid aerobic deterioration (secondary fermentation). Ammonia nitrogen and pH should be determined as soon as possible.

Silage evaluation by pH

The pH of silage should be measured in the laboratory using a precise pH meter. For fresh grass silage (moisture above 75 percent) and maize silage at all DM contents, the pH is both the simplest and quickest method of evaluation. Research has shown that there is a very close relationship between pH value, fermentation quality and DM during ensiling. The criteria for evaluation of silage from pH values have been shown in the preceding section.

Silage evaluation by the ratio of ammonia-N to total N

The ratio of ammonia-N to total N (NH_3-N/TN) in silage provides information on the stage of protein degradation and it undeniably constitutes a test of the state of conservation of the ensiled proteins. The higher the ratio, the more protein has been degraded, and the worse the quality. In the system proposed, a maximum of 50 points is given for a ratio lower than 5 percent, and points are deducted for a ratio higher than 35 percent. Table 4-6 presents the point scale for the evaluation of silage from ammonia N.

Table 4-6. Scale for silage evaluation from the ratio of ammonia-N to total N

Silage quality	% NH_3-	Points	Silage quality	% NH_3-	Points

	N/TN			N/TN	
Very good	<5	50	Average	15.1-16.0	22
Good	5.1-6.0	48		16.1-17.0	19
	6.1-7.0	46		17.1-18.0	16
	7.1-8.0	44		18.1-19.0	13
	8.1-9.0	42		19.1-20.0	10
	9.1-10.0	40	Bad	20.1-22.0	8
Satisfactory	10.1-11.0	37		22.1-26.0	5
	11.1-12.0	34		26.1-30.0	2
	12.1-13.0	31	Very bad	30.1-35.0	0
	13.1-14.0	28		35.1-40.0	-5
	14.1-15.0	25		>40.1	-10

Silage evaluation using various organic acids

The presence of lactic acid and various volatile fatty acids, especially acetic, propionic and butyric acids, is a reflection of the fermentation that has occurred. It is appropriate therefore to take into account, when judging silage success, both the type of acids and the amount present. The higher the proportion of lactic acid, the better the quality. The evaluation system is basically that of Flieg from 1938 with a maximum of 100 points given. Full points are given for lactic acid (25) above 68 percent, for acetic acid (25) below 20 percent and for butyric acid (50) below 0.1 percent. Individual acids are scored independently, and the total is the sum of the three acids. Table 4-7 presents the key for silage evaluation according to Flieg (0 - 20 = failure; 21 - 40 = poor; 41 - 60 = satisfactory; 61 - 80 = good; 81 - 100 = very good.

Table 4-7. Key for the evaluation of silage according to organic acids

Percent	**Points**			**Percent**	**Points**		
	Lactic	**Acetic**	**Butyric**		**Lactic**	**Acetic**	**Butyric**
0.0-0.1	0	25	50	28.1-3	5	20	10

[illegible]	[illegible]	[illegible]	[illegible]	[illegible] 0.0	[illegible]	[illegible]	[illegible]
0.2-0.5	0	25	48	30.1-32.0	6	19	9
0.6-1.0	0	25	45	32.1-34.0	7	18	8
1.1-1.6	0	25	43	34.1-36.0	8	17	7
1.7-2.0	0	25	40	36.1-38.0	9	16	6
2.1-3.0	0	25	38	38.1-40.0	10	15	5
3.1-4.0	0	25	37	40.1-42.0	11	14	4
4.1-5.0	0	25	35	42.1-44.0	12	13	3
5.1-6.0	0	25	34	44.1-4	13	12	2

				6.0			
6.1-7.0	0	25	33	46.1-48.0	14	11	1
7.1-8.0	0	25	32	48.1-50.0	15	10	0
8.1-9.0	0	25	31	50.1-52.0	16	9	-1
9.1-10.0	0	25	30	52.1-54.0	17	8	-2
10.1-12.0	0	25	28	54.1-56.0	18	7	-3
12.1-14.0	0	25	25	56.1-58.0	19	6	-4
14.1-16.0	0	25	24	58.1-60.0	20	5	-15
16.1-18.0	0	25	22	60.1-62.0	21	0	-10

18.1-20.0	0	25	20	62.1-64.0	22	0	-10
20.1-22.0	1	24	18	64.1-66.0	23	0	-10
22.1-24.0	2	23	16	66.1-68.0	24	0	-10
24.1-26.0	3	22	14	68.1-70.0	25	0	-10
26.1-28.0	4	21	12	>70	25	0	-10

SOURCE: Flieg, 1938.

Integrative silage evaluation from ammonia-N and organic acids

In order to integrate the information from both protein and carbohydrate in the silage, an evaluation system based on the points from ammonia-N and organic acids is proposed. There is a maximum of 100 points in the scale, 50 points for proteins and 50 points for carbohydrates. Points for carbohydrates are obtained by dividing the data in Table 4-8 by 2.0. The following table is used for evaluation of silage quality from protein and carbohydrate:

Total points	0-20	20-40	40-60	60-80	80-100
Overall quality	Very bad	Bad	Average	Good	Very good

Feeding silage

Silage is suitable for feeding some 6-7 weeks after ensiling. The basic principle for silage use is to minimize the area exposed to air, with as little churning as possible. Silage should be taken from one side of the trench, and the exposed surface should be immediately covered to minimize re-entry of air and avoid secondary fermentations. Material taken out from the silo should be fed as soon as possible, since it rapidly deteriorates upon contact with air. Silage left in the trough must be cleaned away in time to prevent putrefaction.

Some animals may not like silage when offered for the first time. In these cases, some adaptive measures should be taken. For example, silage can be placed in the bottom of the trough, and covered with concentrates. When animals are adapted to silage, the offer can be increased.

Silage can be fed to all kinds of animals: replacement cattle, fattening cattle, dairy cows, sheep, goats and even pigs. The amount of silage offered depends on the animal and its age, as well as on the type and quality of silage. Taking cattle as an example, the recommended amount to be fed daily is:

Grass silage	4 kg per 100 kg liveweight,
Legume silage	3 kg per 100 kg liveweight,

Maize stover silage	4 kg per 100 kg liveweight,
Starch-rich forage (whole-maize silage)	5 kg per 100 kg liveweight,

Therefore a cow with liveweight of 500 kg may be daily fed 20 kg maize stover silage.

Sometimes the milk from cows fed on silage has a taint. Because this smell is only transmitted through the air, the following points should be observed to prevent it:

1. Handling Silage should never remain in the cowshed, and it should be offered in amounts exactly as required.

2. Feeding method Silage should not be given before milking. The effect on milk taste is more marked when the silage is fed 2 hours before milking, and least when given 6 hours after.

3. Hygiene and cleanliness Both floor and operators should be clean and the shed well ventilated.

4. Milk and milking Equipment should be kept clean, and milk cooled as soon as possible.

It is sometimes believed that ensiled forage has an adverse effect on the general health of the animal, especially on the skeleton of young animals. This criticism has no scientific evidence. It is certain that musty silage adversely affects animals, but such material should never be fed in the first place. It must be pointed out that silage is a good feed, but it is certainly not a "complete feed." For example, maize silage contains insufficient Ca and P, and should be supplemented. P content in ensiled alfalfa is sufficient for heifer growth and Ca more than enough. Animals fed on silage should be properly supplemented with the nutrients that are insufficient for the animals' requirements.

It must also be emphasized that the nutritional value of silage depends on the quality of the original forage, harvest time, conservation method, etc. Nutritional values of different silages therefore vary substantially. When it is impossible to analyse silage at the laboratory, one should refer to feed manuals and roughly assess the nutritional value of the silage to be fed, in order to formulate a ration that matches the animal's requirement.

CHAPTER 5 - FEEDING AND INDIVIDUAL SUPPLEMENTATION

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The nutritional constraints of most crop residues are low N content, high proportion of cell wall constituents, poor digestibility and low intake. Various methods have been used to attempt to improve low quality crop residues, including chemical, physical and biological treatments, supplementation of limiting nutrients and a combination of these (Preston and Leng, 1984; Liu, 1995). Cereal straws and stovers are the main crop residues, and ammoniation is the most viable method to upgrade them (Guo and Yang, 1994). This chapter discusses the feeding practices and supplementation strategies for ruminant diets based on ammoniated crop residues.

Quantity of straw offered to ruminants

Cereal straws and stovers may be used as the only feed or as part of the ration, depending on animal type and physiological stage. For the purpose of this technology, ruminants may be classified into two categories: meat animals and dairy cows.

Meat type (beef cattle, heifers, sheep and goats)

Many studies have been carried out to study the effect of ammoniated straw as the only roughage or as a large proportion of the diet of meat animals. In a trial with yearling steers, Xu (1989) compared the effects on animal performance of different levels of untreated and ammoniated wheat straw as the sole roughage. The results are summarized in Table 5-1. When untreated straw was offered at a high level (60 percent), daily gain was lowest due to poor total intake. Concentrate consumption per kg of gain was high, even at the maximum straw level, but it was much lower at the highest level of inclusion of ammoniated straw, indicating a saving effect.

Table 5-1. Intake of wheat straw, daily gains and feed conversion of steers

	Level (%)	**Ammoniated wheat straw**			**Untreated straw**		
		20	**40**	**60**	**20**	**40**	**60**
Intake	(kg/day)						
Wheat straw		1.39	2.42	3.18	1.38	2.12	2.21
Concentrate		5.26	3.84	2.17	5.15	3.23	1.47

Total		6.65	6.26	5.35	6.53	5.35	3.68
Daily gain	(g/day)	891	644	567	865	480	268
Concentrate/gain	(kg/kg)	5.90	5.96	3.82	5.95	6.73	5.47

SOURCE: Xu, 1989.

Liu *et al.* (1991a) investigated the effect of substituting ammonium-bicarbonate-treated rice straw for hay in growing heifers supplemented with 10 kg maize silage or fresh Chinese milk vetch, plus 2 kg of concentrate. Heifers consumed more DM from ammoniated straw (5.1 kg/day) than from hay (4.0 kg). They had significantly higher daily gains (780 vs 578 g/day; $P < 0.01$). Similar results were obtained with ammoniated wheat straw in young bulls (Huang *et al*., 1987) and growing lambs (Dong *et al*., 1989), and with ammoniated rice straw in buffaloes and Holstein heifers (Zou *et al*., 1988), steers (Ma *et al*., 1989), and heifers (Zhao and

Huo, 1990).

It can be concluded that ammoniated straws and stovers can be given to beef cattle, heifers, sheep and goats as sole roughage or as a major part of the diet.

Dairy cows

There are few reports on ammoniated straw for dairy cows, since it is widely believed that feeding it to high yielding cows may have adverse effects on milk production. However, the limited reports indicate that dairy cows perform well when they consume ammoniated straw.

Li and Wu (1991) compared straw intake and milk production in dairy cows given either untreated or anhydrous-ammonia-treated rice straw. Daily intake was 4.58 and 6.24 kg, and daily milk production 13.6 or 16.0 kg for untreated or ammoniated straw, respectively. In a trial with the ammonium-bicarbonate-treated rice straw, Liu *et al*. (1991b) found that 17-19 kg of milk could be obtained from Holstein cows when the ammoniated straw represented half of the intake (85 percent of roughage). These results were consistent with those of Ørskov (1987), where daily milk yield was 23.5-27.4 kg when ammoniated straw, as the sole roughage, was 35-60 percent of the diet.

It can be concluded that ammoniated straw is a good source of roughage for dairy cows, completely or partially substituting hay. However, it is certainly advisable to use other roughage sources in order to ensure a complete diet.

Supplementation with concentrate and protein

The first constraint for low quality crop residue use is usually N. It is desirable that supplementation ensures an almost continuous supply of ammonia-N. Urea is commonly used as a source of fermentable N, and can be sprayed on cereal straw or be mixed with energy supplements. At present, non-protein N supplements have not been widely fed by farmers in China, but urea is usually used as a source of ammonia to upgrade crop residues. With the development of animal production based on crop residues, ammoniation of cereal straw has been widely extended all over China (Guo, 1996).

Since fermentable N is not limiting in ammoniated straw diets, greater consideration should be given to rumen-protected amino acids. They may overcome specific deficiencies limiting production or may be catabolized to improve the supply of glucogenic substrates, which are also usually insufficient in straw-based diets (Preston, 1995). Protein supplements used in China are mainly oilseed cakes or meals, such as cottonseed cake (CSC) and rapeseed meal (RSM). Sometimes farmers provide their animals with by-products such as rice and wheat bran, or home-grown or self-mixed concentrate mixtures.

Effectiveness of protein supplementation

Typical data on animal performance is given in Table 5-2. In Henan Province, an experiment with 40 young Chinese Yellow bulls was conducted to investigate CSC supplementation levels with urea-treated wheat straw (Zhang *et al*., 1993). The cattle without CSC gained only 250 g/day, but with CSC gained significantly more (P <0.01). There were no significant differences between 2 and 3 kg, and between 3 and 4 kg of CSC, but there was between 1 and 2 kg. DM intake of wheat straw did not decrease when 1 kg CSC was supplemented, but it did at higher levels. The economic analysis indicated that a relatively high level of production and the highest profit were obtained with 2 kg of CSC.

Similar results were obtained in Hebei Province (Fan *et al*., 1993; Ma *et al*., 1990; Table 5-2). Supplementation with 0.25 kg CSC significantly improved feed utilization efficiency and feed efficiency (kg of feed DM/kg gain being reduced from 53 to 15). The group given 1.5-2.0 kg of CSC gained approximately 800 g/d, with only 8 kg feed consumed per kg gain. Further increases of CSC resulted in slightly faster gains at the expense of straw intake.

Table 5-2. Effects of supplementation with cottonseed cake (CSC) on performance of growing Yellow cattle fed untreated or urea-treated wheat straw

Straw type	Straw intake (kg DM/day)	CSC (kg/d)	Initial weight (kg)	Daily gain (g/day)	FCR(1)	Source
Urea-treated	5.0	0	182	250	19.6	
Urea-treated	5.1	1	183	602	9.9	Zhang and Yuan, 1993
Urea-	4.5	2	183	704	8.9	

treated	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	
Urea-treated	4.2	3	183	836	8.2	
Urea-treated	2.9	4	183	878	6.8	
Urea-treated	5.2	0	175.1	99	53	
Urea-treated	5.5	0.25	170.5	370	15	
Urea-treated	5.3	0.5	183.6	529	11	
Urea-treated	5.4	1.5	192.8	781	8.8	Fan *et al*,. 1993
Urea-treated	5.1	2.0	175.0	819	8.6	
Urea-	5.2	2.5	193.7	841	9.2	

treated						
Urea-treated	4.5	3.0	215.5	880	8.6	
Urea-treated	3.6	4.0	213.5	904	8.6	
Untreated	4.3	0.5	187	100	44.3	
Untreated	4.9	1.0	194	240	20.6	Ma *et al*., 1990
Urea-treated	4.8	0.5	198	485	10.8	
Urea-treated	4.3	1.0	213	660	8.0	

NOTE: (1) FCR = feed conversion ratio

Formaldehyde treatment was effective in improving protein use efficiency of RSM. In terms of nutrient digestibility and N use, formaldehyde-treated RSM compares favourably with treated soybean meal when given to sheep fed ammoniated rice straw (Liu *et al*., 1994). When an ammoniated rice straw-based diet was supplemented with 1.2 kg RSM, heifers had lower weight gains, whereas feeding a similar level of treated RSM resulted in considerably faster gains (15 percent on average) along with improved feed conversion ratio (FCR) and decreased feed cost (Liu *et al*., 1993) (Table 5-3). This was also the case when 1.8 kg of RSM was given. Adverse effects on animal health are unlikely when formaldehyde-treated RSM is supplemented in an ammoniated rice straw based diet (Wu and Liu, unpublished data).

Table 5-3. Supplementation effects of untreated or formaldehyde-treated rapeseed meal (RSM) on weight gain of heifers

		Untreated RSM		**Treated-RSM**	
Amount	(kg/day)	1.2	1.8	1.2	1.8

Number of animals		15	15	15	15
Initial weight	(kg)	329	324	361	352
Liveweight gain	(g/day)	491	556	564	665
Straw intake	(kg/day)	5.0	5.0	5.0	5.0
Feed conversion ratio		13.5	12.9	11.6	10.6
Feed cost/kg gain	(¥)	3.54	3.78	3.12	3.22

SOURCE: Liu *et al*,. 1993

Response of supplementation with untreated and treated straw

There are consistent responses in performance to supplementation with protein or concentrate, but the effects are more pronounced when the straw has been chemically treated.

Meng and Xiong (1993) studied the effect of supplementing with different levels of concentrate on growth rate of Wuzhumuqin wether lambs fed untreated or ammonia-treated wheat straw. Concentrate mixtures were chosen to obtain minimum feed cost per unit gain. The results are summarized in Table 5-4. Intake of both untreated and ammoniated straw diminished with increasing levels of concentrate, while animals consumed more ammoniated straw than untreated. Ammonia treatment increased straw DM intake on average by 72, 51, 57 and 117 percent, resulting in higher total DM intake for ammoniated straw diet. Treatment of wheat straw with ammonia resulted in a significant improvement in weight change of sheep and in feed conversion. Supplementation with concentrate increased weight gain of wethers offered either untreated straw or the ammoniated, but the nature of the response differed according the type of straw. In order to obtain similar daily gains, larger amounts of concentrate were needed for untreated wheat straw than for ammoniated diets.

This indicates that benefits of ammoniation of straw are highest when the supplement level is low. The results show that minimum concentrate consumption per unit gain was obtained when the concentrate accounted for 45 percent of diet based on ammoniated wheat straw.

Table 5-4. Feed intake, digestibility and liveweight gain of sheep fed treated or untreated rice or wheat straw plus different levels of supplement

Parameter		Treatment group				Source
		1	2	3	4	
Level of concentrate (3)	(kg/day)	200	400	600	800	
Untreated wheat straw intake	(g/day)	353	325	271	149	
Total intake	(g/day)	545	698	821	852	
Liveweight gain	(g/day)	9.8	35.1	63.6	103.7	

Liveweight gain	(g/day)	-9.8	35.1	63.6	103.7	
Concentrate/gain	(kg/kg)	-	12.0	8.9	6.9	Meng *et al*,. 1993 (1)
Level of concentrate.(3)	(kg/day)	200	400	600	800	
Treated wheat straw intake	(g/day)	608	490	425	323	
Total intake	(g/day)	809	863	956	1038	
Liveweight gain	(g/day)	35.6	85.2	87.2	109.0	
Concentrate/gain	(kg/kg)	5.5	4.4	6.1	5.7	
Rice straw intake	(g/day)	432	404	406	343	
Rapeseed meal intake	(g/day)	0	88	175	263	
Total intake (4)	(g/day)	520	580	669	694	
Liveweight gain	(g/day)	-19	1 5	6 9	67	Liu *et*

					al,. 1998[2]
Ammoniated rice straw intake	(g/day)	566	562	541	431
Rapeseed meal intake	(g/day)	0	88	175	263
Total intake [4]	(g/day)	653	738	804	782
Liveweight gain	(g/day)	20	63	74	77

NOTES: (1) Meng *et al*. (1993) worked with Wuzhumuqin wethers (mean weight of 30.2 kg). (2) Liu *et al*. (1998) worked with Huzhou lambs (mean weight of 21 kg). (3) Ingredients: 82-86% maize meal; 11.5-11.8% CSC; 0-4.2% bone meal; 0.5-1.6% lime; 0.4-1.5% salt; and 0.2-0.8% mineral-vitamin premix. (4) Including 100 g of rice bran (DMI = 88 g/day).

Similar results were reported by Liu *et al.* (1998) (Table 5-4), with RSM as a supplement for Huzhou lambs offered untreated or ammoniated rice straw. The optimum level of RSM with ammoniated rice straw was 100 g/day, whereas 200 g/day had to be supplied to obtain the same liveweight gain with untreated straw. At existing prices (RSM at ¥ 1.50/kg, rice straw at ¥ 0.22/kg, and ammoniated straw at ¥ 0.27/kg), there is a benefit of ¥ 0.08/day from ammoniation, equivalent to ¥ 7.20/sheep for the normal 90-day fattening period.

Supplementation with green forages and readily digestible fibrous feeds

It is known that small quantities green forage can improve the usage of straw diets. Thus, introducing forage supplements may be an alternative strategy for increasing nutrient intake and improving ruminant performance. A wide range of forage supplements is available in China, depending on location.

These include green forage, crop by-products and aquatic weeds.

Effects of supplementation with green forage

Chinese milk vetch (*Astragalus sinicus* L.) is cultivated in South China as green manure to improve soil fertility. Farmers traditionally offer surplus vetch to swine after ensiling. Liu *et al.* (1997) and Ye *et al.* (1996) evaluated the effect of supplementing with milk vetch silage on growth rate of heifers and rumen function in sheep given ammoniated rice straw diets (Table 5-5). Intake of ammoniated straw by heifers was slightly decreased as the level of vetch silage went up. When the vetch silage represented 20 or 30 percent of diet, growth rate was significantly higher than in the non-supplemented group ($P < 0.05$). The highest gain was obtained at the 20 percent level, when concentrate consumption per kilogram weight gain was lowest (1.25 kg) (Liu *et al*., 1997).

The average ammonia-N level in the rumen increased with the increasing level of vetch silage (Ye *et al*., 1996). However, there were small differences in pH value and volatile fatty acid profiles among all groups. Protozoa population tended to decrease more quickly with the supplement. The microbial protein concentrations in the rumen fluid was related to the levels of vetch silage and reached a peak at 20 percent, possibly associated with saponins present in milk vetch.

Liu *et al.* (2001) substituted RSM with mulberry (*Morus alba*) leaves as a supplement for Huzhou growing lambs fed ammoniated rice straw. Total substitution with mulberry leaves gave similar growth rates, but at lower cost than RSM. The authors concluded that mulberry leaves could be used to supplement ammoniated straw diets in place of RSM.

Forage supplement level would depend on the type used, availability and the cost relative to straw. A maximum of 20-25 percent of a diet seems suitable.

The substitution rate would increase with the level of supplement. A limitation in China is that supplementary forages are usually in short supply in most areas.

Supplementation with readily digestible fibre

Prerequisites for all ruminal digestive processes are development of digestive consortia and their adhesion to ingested feed particles. Any feeding strategies that enhance adhesion of rumen microbes to feed particles and improve fibrolytic activity may be beneficial to feed utilization.

Table 5-5. Feed intake and liveweight gain of heifers, and rumen function of sheep, given rice straw and different levels of Chinese milk vetch silage

Level of vetch silage (%)	**0**	**10**	**20**	**30**	**SEM**(1)
Feeding trial with heifers (Liu *et al*,. 1997)					

Number of animals	(head)	8	8	8	8	
Intake	(kg DM/day)					
Ammoniated straw		3.61	3.59	3.02	2.65	-
Milk vetch silage		-	0.49	0.98	1.53	-
Concentrate mixture		0.90	0.90	0.90	0.90	-
Total		4.50	5.00	4.90	5.10	-
Initial weight	(kg)	179	175	180	182	8.7
Weight gain(2)	(g/day)	588b	692ab	800a	777a	46.2
Feed conversion ratio	(kg/kg)	7.65	7.23	6.13	6.56	-
Rumen measurements in sheep (Ye *et al*., 1996)						
pH value		6.6	6.7	6.7	6.7	0.02

Ammonia-N[2]	(mg/dl)	11.7^c	14.2^b	15.2^b	17.0^a	1.0
Total VFA	(mmol/dl)	8.1	7.9	8.5	8.4	0.45
Protozoa diminution rate [3] (%)		14	30	35	31	0.11
Microbial protein concentration in the rumen liquids (mg/ml)		2.6	2.9	3.2	2.8	0.12

NOTES: (1) SEM = Standard Error of the Mean.
(2) Means with different superscripts differ significantly ($P<0.05$).
(3) Ratio of protozoa population before feeding to that at 6 hours post-feeding.

In a recent trial, Shi *et al*. (1997) studied the effect of added ammoniated rice straw on the growth rate of Holstein heifers receiving untreated rice straw. The results are summarized in Table 5-6. When half (w/w) of the untreated straw was replaced by ammoniated straw, heifers had significantly higher intake and gains, even slightly higher than those on ammoniated straw. A similar result was reported by Li *et al*. (1998), who compared the growth rate of cross-bred cattle offered ammoniated wheat straw or maize stover, either alone or in a 50:50 (w/w) combination (Table 5-6).

Table 5-6. Straw intake and growth of heifers fed rice straw plus various supplements or of cattle on ammoniated wheat straw, maize stover or a mixture

		Treatment		
	1	2	3	4
Heifers (Shi *et al*,. 1987) (1)				
Dry matter intake (kg/day)				
Rice straw	2.46	1.86	-	

Ammoniated rice straw		-	2.07	3.55	
Concentrate mixture		0.86	0.86	0.86	
Brewers' grains		1.03	1.03	1.03	
Total		4.35	5.82	5.44	
Liveweight gain	(kg/day)	0.66	0.84	0.81	
Cattle (Li *et al*., 1998) (2)					
Intake	(kg/day)				
Ammoniated wheat straw		3.84	7.41	-	
Maize stover		3.84	-	8.16	
Concentrate mixture		2.80	2.80	2.80	
Liveweight gain	(kg./day)	0.98	0.85	0.83	
Concentrate/gain	(kg/kg)	2.55	2.96	3.04	
Heifers (Liu *et al*., 2000) (3)					
Dry matter intake	(kg/day)				
Ammoniated rice straw		2.61	2.31	2.01	1.75

Bamboo shoot shell (BSS)		0	0.38	0.77	1.15
Cotton seed meal		0.93	0.93	0.93	0.93
Total		3.54	3.62	2.71	3.83
Substitute rate (4)		-	0.79	0.78	0.75
Liveweight gain	(kg/day)	0.622	0.629	0.744	0.690

NOTES: (1) Shi *et al*. (1987) worked with heifers (344-353 kg). (2) Li *et al*. (1998) worked with cattle of 370 kg. (3) Liu *et al*. 2 (000) worked with heifers (139-141 kg). (4) Expressed as the depression in the intake of ammoniated rice straw produced by a unit increase in the BSS intake.

Bamboo cultivation is very popular in south China. Bamboo shoot shells (BSS) are the residue from industrial-scale processing of bamboo shoots, and represent a disposal problem because they have no use and can pollute the environment. Occasionally it has been observed that fresh BSS were palatable to cattle, their CP was 10-13 percent (on DM basis) and were easily degraded in the rumen, although neutral detergent fibre was high (65-70 percent on DM basis) (Wang, 1997). Considering BSS as a source of readily digestible fibre, Liu *et al*. (2000) observed the response in growth rate to supplementation in heifers given ammoniated rice straw. The results are summarized in Table 5-6.

Straw intake linearly decreased with the increasing level of BSS, but total dietary intake increased also (a substitution rate less than 1.0). Growth rate in heifers was improved significantly by the supplementation, and the optimum level was at 21 percent of total dietary intake.

It is inferred that supplementation with readily digestible fibre may improve utilization of basal diet and animal performance. However, further work is needed on this topic.

Use of multinutrient blocks

Since the early 1980s, both production and utilization of multinutrient blocks (MNBs) as supplements for ruminant animals have increased considerably in developing countries (Sansoucy, 1995). With the development of ruminant production, much progress has been made and new technologies have been developed in the manufacturing of MNBs in China since they were introduced in the late 1980s.

MNB manufacture

Ingredients

The MNBs developed in China contain molasses, urea, minerals and proteins, with the aim of supplementing cereal straw with fermentable N, soluble carbohydrates, minerals and other nutrients. The main ingredients have been: ground maize; rice bran and wheat bran; rapeseed meal; solidifiers and binders (cement, clay, etc.); bone meal; and vitamin premix (Chen *et al*., 1993a, b; Li *et al*., 1995; Zou *et al*., 1996; Gao *et al*., 1999). Molasses, a source of easily fermentable carbohydrates and a binder, makes blocks highly palatable. It has been demonstrated that mixing urea with molasses greatly decreases the release of ammonia-N in the rumen. Mineral premix usually contains Ca, P and Na as well as micro-elements such as Fe, Cu, Mn, Zn, I, Se and Co (Liu *et al*., 1995; Zhang *et al*., 1999).

In a series of demonstration trials in Gansu Province, where the basic diet was composed of wheat straw and other stubble, Chen *et al*. (1993a, b) selected three formulas, for cows, heifers and calves (Table 5-7). Many workers used molasses as an ingredient for blocks (Li *et al*., 1995; Yang *et al*., 1996; Guan *et al*., 1998). Liu *et al*. (1995) found a block formula without molasses, since molasses is expensive and in short supply in some regions.

Lime and cement have been commonly used as solidifiers and binders. Ordinary clay has been also proved to be efficient for making blocks (Chen *et al*., 1993a, b; Guan *et al*., 1998). Farmers in some regions used loess as a binder (H.W. Ye, personal communication).

Table 5-7. Formulas of multinutrient blocks for dairy cattle (on a percentage by weight basis)

Ingredients	Cow	Heifer	Calf
Molasses	8	10	15
Urea	16	12	-
Salt	26	26	22.8
Ground maize	5	5	10
Lime	10	10	10
Clay	11.2	15	15
Bone meal	-	-	5

Mineral mixture	23.8	22	22.2
Total	100	100	100

Process for block manufacture and specifications

Depending on the technical process, MNB preparation takes two forms: by pressure (hot process), or by moulding (cold process). The moulding process needs neither sophisticated equipment nor much energy. Blocks produced by moulding had the following features (Ma *et al*., 1992): (1) When water was poured onto the surface of the blocks, blocks kept their shape after sun-drying; (2) Blocks maintained their shape intact when submerged in water for 1-2 hours, but completely dispersed after 4-5 hours; (3) Hardness increased when formaldehyde was included; (4) The shape of the blocks did not change under finger pressure.

Xia *et al*. (1994) developed a specialized machine to make blocks under pressure. This equipment saved space and labour, and the blocks could be easily produced. Drying was unnecessary since it used raw materials already dry. The blocks produced were compact, not deliquescent, and hard enough to control intake. They did not become mouldy nor did they lose shape when exposed to rain or sunshine.

Table 5-8 indicates the characteristics of two press machines for the formation of blocks, designed by Chen *et al*. (1993a, b). The blocks were made by mixing molasses and urea, and then heating. Salt was added, followed by the rest of the ingredients, having been previously mixed together. The complete mixture was then pressed and the resulting blocks were wrapped immediately. Blocks made using both press machines were hard enough, with a breaking strength of 44 kg/cm^2. The blocks were oblate, 25.6 cm in diameter and 8 cm in thickness, with a weight of 7.5 kg each.

Table 5-8. Characteristics of presses used for making the blocks

Press type	Power source	Dimensions (cm)	Weight (kg)	Working pressure (kg/cm^2)	Production capacity (kg/hour)
9YK-50 (manual)	Hydraulic jack (50 tonne)	60 ×70 × 100	240	52	50
9YK-150 (electric)	Hydraulic pump (0.75 kW)	75 × 40 × 200	640	176	150

The blocks produced by Yang *et al*. (1996) were squares or compressed cylindroids with rounded holes (ca 1.5 cm diameter) in the centre. Each block weighed 2.5 kg. The breaking strength was 56.9 kg/cm^2. They did not moisten before 24 hour under low temperature (> 0°C) and high humidity (> 80 percent).

The urea-mineral blocks designed by Liu *et al*. (1995) had a breaking strength of 40 kg/cm^2. They were easily transported and fed to the animals. Even in situations of high humidity, there were no losses from mould or from hydration when they were offered to the animals over a long period.

In 1999, MOA set up a "block expert group." Based on results of previous studies and six months of research, an industrial production technology system was proposed. The MOA appraised it, and confirmed it "in the national leading position." The blocks have sold very well.

Results of blocks with animals

Beef cattle

In a growth trial with heifers, those having access to MNBs had daily gains of 835 g/day, 112 g/day higher ($P<0.05$) than the control group (Chen *et al*., 1993a, b). Animals supplemented with blocks reached 380 kg body weight (weight at first service) 65 days earlier. Other advantages observed during animal feeding trials on farms were better skin coat, better body condition, and lower death rate. The urea-MNBs without molasses were also palatable to both cattle and goats (Liu *et al*., 1995). Local Yellow cattle on grazings with access to blocks performed better than the control (370 vs 203 g/day). The animals with blocks had better body condition and looked healthier than the control group. An increased income of ¥ 0.57 could be obtained per beast per day.

Zhang *et al*. (1993) observed that daily gains were 15.6 percent higher, and consumption of roughage and concentrate per kilogram of gain were 16.9 and 13.3 percent lower, respectively, when beef cattle were supplemented with MNBs containing non-protein nitrogenous compounds (NPN). In another trial (Ma *et al*., 1995), beef cattle with access to blocks containing NPN had daily gains 353 g higher than those with no blocks (1 478 vs 1 125 g/day).

Dairy cows

Dairy cows supplemented with MNBs produced 1.06-1.47 kg (5.3-5.9 percent) more milk than those without blocks (Wang *et al*., 1995). Less metabolic disorders occurred in the supplemented animals. Increased net income attributed to the blocks was about ¥ 1 per cow per day. Chen *et al*. (1993a, b) found that cows having access to blocks had an average milk yield of 20.7 kg/day, which was 1.3 kg (6.7 percent) higher ($P < 0.01$) than the average of the control group. Additional advantages of blocks included increased conception rate (12.2 percent), decreased occurrence of diseases (22.5 percent), improved body condition (Chen *et al*., 1992) and increased income.

Urea-MNBs was given to Holstein cows in mid lactation by Xu *et al*. (1993). Cows produced 20.5 kg of milk, which was 4.1 kg (25 percent) higher than the average of the control group. It was estimated that cows consuming the MNBs increased income by ¥ 736 per head per year.

Sheep and goats

Xu *et al*. (1994) observed increased intake and improved daily gain (26.5 percent) in sheep having access to MNBs, compared to control animals. They also produced better quality wool with higher S and mineral content. Similar results were observed by Yang *et al*. (1996).

When hybrid goats had access to urea-MNBs for two months, average intake of the blocks was 39.5 g/day (Huang *et al*., 1999). Daily weight gain for goats was 85 with and 62 g/day without MNBs. Net income was increased by ¥ 10.78 with blocks. Liu *et al*. (1995) reported results with goats, which grazed on hill pasture during the day and were offered rice straw *ad libitum* in stalls at night. Goats with free access to urea-MNBs along with rice straw at night performed better than those in the control group. Gains were significantly higher in animals with blocks (95 vs 73 g/day). The effects of MNBs on performance of growing goats were investigated by Zhang *et al*. (1999). Goats with blocks had weight gains 38.3 percent higher than those without.

Buffaloes

Effects of feeding blocks to buffaloes have been observed by some workers (Lu *et al*., 1995a; Zou *et al*., 1996). When buffalo heifers on rice straw diets were supplemented with urea-MNBs, daily gains were 650 g, compared to 620 g for control animals. Feed cost and concentrate consumption per kilogram of gain were 9.82 and 33.3 percent lower for supplemented buffaloes than those without. Animals showed no signs of poisoning despite block intakes above 1.0 kg/d, indicating that the blocks were safe. Zou *et al*. (1996) selected a formula of MNBs for growing buffaloes that contained molasses, urea, grain by-products, minerals and vitamin premix. Intake of the blocks increased with time, and was 172.4, 330.2 and 374.1 g/day at 30, 60 and 80 days, respectively, from the start of the experiment. Compared to control animals, buffaloes with blocks showed higher weight gain (22.6 percent; 395.4 vs 484.6 g/day) and used 22.5 percent less feed and 22.8 percent less concentrate per kg of gain.

Concluding remarks

Ammoniated cereal straws and stovers can be offered to beef cattle, heifers, sheep and goats as sole roughage or as large proportion of the diet. Undoubtedly, supplementation has one of the greatest potentials for improving cereal straw use by ruminants. Animal productive performance can be greatly improved by supplementing with protein sources, concentrate or highly digestible forages, or a combination. In order to obtain satisfactory animal performance, a small amount of protein supplement (below 20 percent of diet DM) is sufficient with ammoniated crop residues, but more protein supplements are needed with untreated straw. The supplementation level with forage depends on the type of forage and basal diet used. A high substitution rate would be possible when higher levels of forage are supplemented. Manufacture and utilization of MNBs as supplements for ruminant animals have increased considerably in China. Much progress has been made and new technologies have been developed since this technique was introduced in the late 1980s. It has been demonstrated that MNBs can be used to improve the productive performance of animals with access to low quality roughage. It was discovered that use of feeding blocks cut methane emissions by half, reducing its contribution to environmental pollution.
