PART 3

YAK IN NONTRADITIONAL ENVIRONMENTS

By Gerald Wiener[9]

OVERVIEW

Information is presented here on yak kept commercially in around 90 herds in the USA and Canada with a total of perhaps 2000 animals (pure and hybrid). Yak are also found in small commercial herds in parts of Europe and in New Zealand. In addition, there are a significant number of zoos and wild animal parks in several parts of the world that have, or have had, collections of yak, many of them successfully self-reproducing herds. The common factor for all of these yak is that they are in climatic and management situations which are quite atypical of those in the traditional yak-keeping territories. The successful survival and reproduction of the yak in these nontraditional environments is, therefore, of wider interest for the potential adaptation of yak to a variety of conditions worldwide.

North America

Since the early 1980s there has been a growing interest in yak by commercial breeders and ranchers in the USA and Canada hoping to exploit what they claim to be the low maintenance needs of yak and the potential for lean meat production through what is referred to as "crossbreeding" with other cattle – but should, more accurately be termed “hybridizing”. At the time of writing there are an estimated 90 breeders, but perhaps fewer, with a total of not more than 2 000 yak and hybrids between them. These numbers are lower than reported earlier (Wiener, 2002) as breeders have recently found difficulty in penetrating the meat market, except on a local basis (J. Delaney, personal communication, 2002). Individual herds vary in size from less than ten animals to more than 400. The great majority of yak breeders in North America are members of a breed Association, the (American) International Yak Association (IYAK), but some of those still registered with the Association no longer have yak.

From a biological point of view, perhaps the most interesting aspect of this commercial use of domestic yak in North America is that many of the herds are located in parts of the country where the climate and general environmental conditions are very different from those traditional for yak. Around half of all the herds, including the largest, are in areas close to the Rocky mountain range at elevations up to around 2 600 m above sea level, where yak might be expected to feel perfectly "at home". Some of the remainder are in hill areas in other parts of the country, but a significant proportion of the herds are in

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seasonally hot parts of the country at low altitudes and in typically temperate climates – some close to the Pacific coast. The single largest herd is in Nebraska, east of the Rocky mountain range at 1 280 m above sea level and with an annual rainfall averaging 420 mm.

Overall, the herds are located from northerly parts of Alberta in Canada to central USA and from the Pacific coast to close to the Atlantic. This clearly shows an ability of the yak to adapt to non-traditional conditions – in spite of the contrary view expressed in some of the early literature on the subject, which is also part of the "received wisdom".

A historical note on the introduction of yak to Canada and Alaska

The introduction of yak to Canada and Alaska in the early part of the last century represents the most northerly latitudes in the distribution of the yak (other than the progenitors of the modern yak). The origin of the yak in this region is not clearly documented. It is known that six head of Chinese yak were sent to Canada in 1909 (from England, according to Lensch *et al.*, 1996), as a gift from the Duke of Bedford, but by the following year only one male and three females had survived and for the next two years the animals failed to reproduce. This, as noted by White *et al*. (1946), was attributed to the low altitude at which the yak were kept. Reproduction started when the animals were moved to higher altitudes (and probably, therefore, lower temperatures) in the Rocky Mountain Park near Banff in Alberta, Canada. In 1919 most of the yak were transferred to Buffalo Park, Wainwright. In 1921, some yak were included in the hybridization experiments with domestic cattle and American bison then in progress at Wainwright with the aim of producing an animal for meat production for the harsh pastoral conditions of northern Canada. Few of the interspecies hybrids survived (Deakin *et al*. 1935) and this series of trials was suspended in 1928.

Similar experience occurred in Alaska (White *et al.* 1946). Over the years 1919, 1923 and 1930, a total of three male and six female Chinese yak, born in Canada, were taken to the Fairbanks Experiment Station in Alaska, at an elevation of approximately 130 m. The yak had great difficulty in breeding, but these difficulties diminished and the general condition of the yak improved when they were moved to a plateau at an altitude between 400 m and 800 m. The intention was to produce animals suitable for the grasslands in the Alaska mountains, southern Yukon territories and plains and tundra of the Alaska-Canada border. Hybrids were produced experimentally with Galloway cows whose hybrid offspring were heavier at slaughter than either the yak or the pure Galloway. However, the hybrids did not appear to withstand the extremely low temperatures of winter as successfully as the pure yak. These trials were also suspended, in the early 1930s.

In theory, it is feasible that the entire North American yak population could be derived from the single, documented, importation to Canada, but this seems improbable. Offspring from the original importation of yak survived in national parks or zoos, but these institutions may also have imported additional yak from abroad through dealers. There are unconfirmed reports that some of the present-day yak there are derived from an importation to the Bronx Zoo in 1890. Also, as the section on yak in zoos later in this Chapter shows, some significant breeding of yak, and also a few yak hybrids with cattle, occurred in North American zoos from the 1920s onward.

Surplus animals and dispersal of zoo collections could well have provided progenitors for the present commercial population – though documented evidence of that has not been found.

Characteristics and performance

Most of the information that follows was provided by members of the (American) International Yak Association (IYAK). Animal performance results are based on figures from about 16 herd owners.

The primary aim of the yak breeders in North America is lean meat production, but fibre is also valued especially in some smaller herds. Only one of the respondents to our survey trained yak for packing and trekking but not on a commercial basis. A very small number of yak are also kept out of curiosity or as pets. During the period of expansion of this niche market, much of the interest and income of breeders came from the sale of breeding stock, but this may be changing. Milk from the yak, though referred to in the promotional literature of IYAK, does not appear, as yet, to have found a market, although one or two breeders report some trial milking for the manufacture of yoghurt.

Coat colours of the yak are: all black, black with some white markings (called trim), which predominates, black and white (described as “royal”) and a “gold” colour, present in small numbers and said to be recessive to black.

Birth weights of yak calves are quoted as varying from 13 - 27 kg, weaning weights, generally at four to five months of age, as 65 - 70 kg for some farms thought to be providing above-average rearing conditions. Adult weights of yak cows were quoted in the range 240 - 360 kg and yak bulls 550 - 680 kg, though one yak bull in Canada was reported to weigh 820 kg.

Some females are mated for the first time as early as 18 months of age, but two to two and a half years is more common. Calving annually is normal, but one of the herd owners noted that half his yak cows had only two calves in three years. Bulls are not generally used for mating until three years old, although some younger ages were reported.

Few health problems were encountered but the need for routine vaccinations and deworming, especially in humid conditions, was referred to by several of the herd owners.

Feeding and management

Most of the feed is natural grazing in summer and hay in winter. Some breeders use grain as an enticement to gather the animals, but a few feed it as a supplement – especially for finishing. All the respondents to the survey provided mineral blocks and some mentioned a need for an adequate amount of copper in the block to promote health and the breeding of the yaks (as noted in Chapter 9). A greater feed efficiency was claimed for the yak and their hybrids relative to other cattle and hence a need for relatively smaller quantities of feed and pasture per kilogram live weight of animal.

Generally, the yak were kept out-of-doors all year-round. Calves remain with the dams up to weaning at, usually, four to five months old. The yak were regarded as reasonably tame and, with few exceptions, easily handled and easily confined by fencing.

Possible heat stress for yak was mentioned but did not amount to a problem. The animals sought some shade and water for cooling in periods of high heat in summer, but even this was thought to be unnecessary by some of the respondents.

Discussion

The performance information suggests that the range of birth weights of yak calves may be a little higher than those in traditional yak areas in China. Also, the inferred growth rate of calves to weaning, perhaps exceeding 400 g per day, is also higher than the gains of around 300 g quoted elsewhere in this book. However, this should not occasion surprise as the calves in North America are reared under what can be regarded as good conditions and with access to all the maternal milk, while in the traditional yak territories herders normally take some milk for domestic consumption – thus restricting the intake by the calf. Experimental results from China, quoted in Chapter 6, show similar improvements in calf growth when the calves are given access to all their dams' milk. Some of the adult weights, particularly of breeding bulls, also appear slightly higher than usually reported for domestic yak, but this is likely to be a consequence of feeding rather than a genetic difference.

The owners of the herds surveyed reported what are higher reproductive rates for their yak than are common in the more traditional circumstances. This includes both an earlier average onset of breeding and, mostly, annual calving. This is almost certainly attributable to the feeding conditions in summer and the almost universal use of supplementary feeding in winter, as well as the provision of mineral blocks and health care. Consequently there is no large loss of weight or condition of the animals over winter and during pregnancy.

Questions remain regarding the origin of the North American yak population and hence its genetic relationship to other yak populations and breeds. It is also not known how closely related the animals are within the North American yak population and whether inbreeding is or might be a problem as the genetic base of the population might well be small. Future research may resolve some of these questions.

It seems almost inevitable that over time there has been some introduction of *B. taurus* genes into the American yak gene pool. Preliminary results, from a recent analysis of some 43 blood samples from yak of three of the herds in the USA (Han Jianlin, personal communication, 2002), suggest the presence of mitochondrial DNA from cattle in many of these particular samples. However, it is unlikely that such introductions of *B. taurus* blood would be responsible for the apparent adaptation of the yak in North America to the varied and non-traditional environments. For yak, any such introduction of genes can come only through hybrid females, as the hybrid males are sterile. The process of hybridizing seems to be random and varied and without selective intent for "adaptation". Moreover, it would also be unlikely that natural selection for adaptation could have been effective over the short period of 90 years or so under consideration. These points were given more detailed consideration by Wiener (2002).

More information about the distribution and performance of the yak in North America were provided by Wiener (2002) and can also be obtained from the IYAK Web site (www.yakpage.com).

Europe

A small herd of 26 yak was established, in the 1990s, in the Zermatt region of Switzerland at an altitude of 1 600 m. The animals were acquired over a period of two or three years from a dealer, but the origin of these yak is not recorded (Agir, 1997). More recently, Michael Goe (personal communication, 2002) reported that this herd had grown to 37 yak (and one hybrid cow) with the herd in Emd (Canton Valis); in addition, he reports two other herds of 20 animals and one of 15 yak and a further number of very small herds (two to seven animals). The total number of yak for Switzerland was estimated to be 140. The yak in the herd first reported were used for trekking.

The only other herd, according to Horst Geilhausen (personal communication, 2002) that is extant in Europe, outside zoos, numbers eight to ten animals in the south Tirol of Austria. It was established in 1985. The owner is said to accompany his animals personally to the mountain pastures in the spring of the year and from this one might infer that the yak are kept in more sheltered parts over winter. (The origins were not conveyed to Professor Geilhausen). The presence of yak in parts of France, as in the last century and earlier (see Chapter 1) is no longer reported.

New Zealand

A small herd of about 15 yak is kept at the very top end of South Island of New Zealand on a farm just above sea level with an annual rainfall of 2 400 mm and a mild climate – with summer temperature often in excess of 30^{o}C.

The yak originated in the mid-1980s from the Toronto Zoo and first went to a holding in central South Island at an elevation of about 300 m, with cold dry winter but hot summer, where the yak bred well. They were transferred to their present farm in 1990 and, according to the owner (information from the year 2000), after a period of acclimatization, the yak started to reproduce well, calving annually in November (late spring-early summer). Some of the yak have been sold to other farms in the area as a foundation for new herds. The owner reports that his yak have had no health problems and, like the ranchers with yak in North America, notes that his yak appear to eat much less than his other cattle and thrive on roughage.

Yak in zoos and wild animal parks

The basic information in the first part of this section was kindly provided by the Wildlife Conservation Society in New York in the form of a Taxon report, which lists animals, past and present, by location Other information is acknowledged in the text.

Yak have been present in zoos and wild animal parks in Europe, North America and Asia for well over a century. Some of the collections, past and present, are very small and transient, relying on purchases from elsewhere. Other zoos have more substantial and self-reproducing herds, which in turn have surplus stock available for disposal. The critical point of interest, from the point of view of yak adaptability, is that these zoos represent conditions that are quite different from those experienced by yak in their native habitats. Success or failure in captivity provides some further clues therefore to the adaptability of yak to a variety of different environments.

Most of the zoos take part in a registration system for their animals – with the information published in a Taxon report. The information here is based on such a report and it provides evidence of 110 zoos and wild animal parks with yak either past or present (up to the year 2000). Not all zoological institutions, however, participate in this information scheme, so this number is a minimum estimate.

Three of the collections have had, over a period of years, well in excess of 100 yak each (Winnepeg, Canada; Whipsnade, England, with the largest number currently extant, and Bronx, New York, USA – collection now dispersed). One of the zoo collections (Milwaukee, Wisconsin, USA) dates back to 1914 (but with a last entry in 1949). One other, (San Diego) dates back to 1928 (but the last entry is in 1980), and the remainder are from 1940 onwards, with the majority starting after 1980. Many of the collections started were dispersed within ten years or so. (In terms of dates, one animal was found in these records born at the National Zoological Park in Washington as early as July 1901, many years ahead of other yak at this zoo, and then traded to Regent's Park Zoo in London the following January). For zoos or parks that had yak in the year 2000, the average number of years that they had had their yak herds was around 20. Zoos now without yak had kept their herds or animals for only half that time. A few of the zoos have exhibited only the odd yak or two and have not bred them. Table 11.2.20 summarizes the information on a country basis showing 102 locations. Because of the dispersal of many of the collections and disposal of animals, the number of yak extant (in the year 2000) is only a fraction of the total number recorded over the years.

Nearly all the yak represented in the survey were born in captivity or can be presumed to have been. But there is no information readily available on the origin of some of the early acquisitions and no information of the source of animals acquired from dealers. There is no absolute certainty that all the captive yak are pure or whether they are hybrids with infusions of blood from other cattle. However, the zoos represented in this report keep accession and breeding records, and the great majority of the animals are listed as pure domestic yak and only a small minority is labelled as hybrids or as possible hybrids.

Only three zoos claimed some wild yak in their collections; the largest of these, Chicago zoo, in the period 1974 - 1981, with 17 animals. Unlike the domestic yak in the zoo collections, none of the wild yak survived for more than three years.

It is clear from the summary in Table 11.3.1 that captive yak have existed and are still found in a wide variety of climates and environments and from the available evidence those in small herds have bred and survived successfully in captivity. The environments, captivity apart, are for the most part atypical of the conditions in the native habitats of the yak. Most of the locations of the zoos and wild animal parks are at relatively low altitudes, some close to sea level, and thus do not present the "typical" atmosphere low in oxygen. Also, summer temperatures at many of the locations will be high, even relatively so at night. Winters will be temperate in many cases, and average annual temperatures will be at higher average levels than for yak in their native territory. (This is similar to the conditions referred to earlier in relation to a proportion of the yak kept commercially in North America.)

Some reconciliation is therefore needed between the obvious tolerance of the yak of these "unusual" conditions and the reputation of yak for poor adaptation to low altitudes and high ambient temperature (based on yak-keeping experience in their principal territories and a little evidence from small-scale studies).

Table 11.3.1 Yak collections – past and present – in zoos and wild animal parks*

Country	Total No. of collection	Total No. of yak	In the year 2000	
			No. collections	No. yak
Europe				
Austria	1	2	-	-
Belgium	3	74	3	22
CIS countries**	6	31	4	24
Denmark	2	53	2	32
England	2	122	2	35
Estonia	1	49	1	16
Finland	1	51	1	1
France	3	13	1	2
Germany	13	129	6	18
Holland	8	134	4	15
Hungary	2	66	1	2
Italy	1	26	1	5
Latvia	1	16	1	2
Poland	5	80	4	29
Portugal	1	24	1	4
Spain	2	12	1	5
Sweden	2	121	1	10
Americas				
Canada	6	328	2	7
Mexico	1	1	-	-
USA	41	662	10	39
Total	**102**	**1994**	**46**	**257**

* Not all zoos participate in the information scheme represented by the Taxon reports or appear in ISIS abstracts – these zoos (and some countries) are therefore missing from the Table.

**One of these zoos is in a CIS country. At least two zoos (Moscow and St Petersburg) in the Russian Federation, but not listed in the Taxon report, are known to have had, or currently to have, yak collections.

The apparent success of commercially kept yak in parts of North America (see earlier section) further underlines this point. Winter *et al.* (1989) also refer to this conundrum. Perhaps it is all a question of the time allowed for such acclimatization and how the animals are managed on arrival.

It can be surmised, for example, that in past times on the trade routes from Tibet southward into Nepal and India, yak would fairly rapidly descend from cold mountain regions into near-tropical conditions and that this may have produced not only heat stress in the animals but a reputation for intolerance of heat, which has become part of the received wisdom.

This is conjecture, of course, and the opportunity to record the physiological responses of yak on such treks to a descent from cold to near-tropical conditions no longer presents itself readily. (Although nowadays, study of such responses would undoubtedly be considered as worthy of an academic project!)

Whipsnade Wild Animal Park

In the first edition of this book, the yak herd at Whipsnade was featured as demonstrating the point previously made, that yak can survive and reproduce well under conditions that are atypical of those in the native habitats of the yak. It is of interest in this context to provide updated information on this small but successful herd, by courtesy of the curator of Whipsnade, Nick Lindsay, and the chief veterinarian, Edmund Flach.

The park lies on the edge of the Dunstable Downs (elevation approximately 150 m, approximately 52^{o}N) in England. The climate is typically temperate. The herd was started in 1944, though records of the source are not now available. This was followed by small importations from Alberta (Canada), Berlin (Germany) and from Sweden, among others. Currently, the herd numbers about 30 animals with a second small herd established at another park with animals originating from the Whipsnade herd.

The information provided is that the yak cows do not calve annually, but each has, on average, approximately two calves in every three years. The animals grow normally and survive extremely well. Small numbers of yak have been sent to other countries (e.g. Turkey). There is no obvious seasonality to the breeding and calves (all pure yak) have been born in March, April, May, July, August, September and November. It appears that some of the yak at Whipsnade may breed as early as their second year of life. Since the foundation of the yak herd in 1944, there have been more than 100 yak in the Whipsnade herd (with the offshoot herd in addition) and the vast majority of them have been born at the park.

In summer, the animals are said to seek shade under trees and shed much of their fleece but show no obvious discomfort. The only recurrent health problems were found to be associated with copper deficiency. Following diagnosis of the condition, it has been fully controlled by regular supplementation and occasional copper injection for many years (Edmund Flach, personal communication, 1995). This matter was referred to more fully in Chapter 9 as there is a possibility that yak may be prone to this deficiency for genetic reasons because other cattle in the park are not equally affected, although receiving the same diet. Other data from the herd are presented in Chapter 4.

A note from the curator states that as of 2002, breeding of this long-standing herd was being suspended temporarily, as there has been insufficient demand for surplus animals. But the matter is under review.

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12 SOCIAL, CULTURAL AND ECONOMIC CONTEXT OF YAK PRODUCTION

by Wu Ning[1]

OVERVIEW

Yak keeping is closely bound up with the social and cultural life of the people, most particularly in the vast rangeland grazing areas of the Qinghai-Tibetan Plateau and other parts around the Himalayan mountain range. The yak is, moreover, a component of the religious practices and manifestations of Tibetan Buddhism.

Yak production underpins the economy of much of this region. To meet the challenges of a harsh and often unfriendly environment on the "roof of the world", herders have developed a complex system of management and land use involving the sharing of grazing lands and their use, for the most part in a nomadic fashion resulting in rotational use of the grazing lands. Much of this developed through agreements between families and within villages. Traditionally, pastoralists relied on their yak primarily for subsistence, but status was also conferred by possessing large numbers of yak. With the more recent moves towards a market-oriented economy, changes have been imposed or at least suggested that affect both the traditional patterns of yak keeping and the purpose of keeping the animals.

In particular, not only have the animals themselves passed into the private ownership of the herders, but, over large parts of the yak-keeping provinces of China, land has been allocated to individual families. This has been in an effort to encourage settlement in place of unrestricted movement – in other words, to change from a mobile to a sedentary method of production. There are both positive and negative aspects to these developments. In respect of range management and making best use of forage resources in times of plenty (the short summer) for the times of feed shortage (the long winter and early spring), the problems created may well be paramount.

Better opportunities for marketing yak and yak products and the attractions of a market economy encourage increased production and technological inputs to assist yak keeping. A move from traditional to modern practices, however, can create tensions and problems if these modern practices are not sensitively integrated with the vast, accumulated knowledge and experience of the herders.

This chapter aims to set out the principal considerations in the relationships of the yak, the land and the people.

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Cultural role of yak in Tibetan tradition

The primary importance of the yak is in the economy of the so-called “roof of the world”, the Qinghai-Tibetan Plateau. A number of researchers (Alirol, 1976; Goldstein and Beall, 1990; March, 1977) have discussed the importance of yak for pastoralists in the Himalayas. However, domestic yak are also of great cultural importance to the people of the Himalayan region. They are closely linked to the cultural and ritual activities of these herding societies. As illustrated with examples by Cayla (1976), the yak takes its place alongside other animals, both real and mythical, in the history, legends and mythology of the Tibetan region and neighbouring territories. For example, the use of the yak as a provider of components for local medicines is one aspect of the near mystical importance of the yak. In Nepal, especially in the Mustang area in the months of July and August, yak blood is taken from the juvenile vein and fed to weak persons. Meyer (1976) described some of the medicines and remedies associated with the yak. Olsen (1991) considered the yak to have been so important to the Tibetan people that prior to the Second World War their society could legitimately be referred to as a “yak culture” similar in many ways to the “buffalo culture” of the native Indian peoples of America (see Chapter 1).

There is a long history of interaction between the yak and Tibetan pastoral societies. Even the phenomenon of yak totem can be found in some areas on the Tibetan Plateau (Yang, 1987) – and yak are sacrificed at certain festivals. Bovine deities, believed to include yak-headed gods, were important in the religion that preceded the introduction of Buddhism into Tibet from India. In the Tibetan farming areas of Sichuan province of China, there is a special festival to offer sacrifices to “yak gods” or ancestors, called *Gerdorom*, which takes place every November. In Tibetan legend, wild yak are said to be as “stars” living in heaven and the yak is always imagined as a safeguarding god.

Almost all parts of yak body have cultural or religious values. In western Sichuan and Qimdo areas, Tibetan women place on their heads two silver ornaments embedded with coral and yak horn, from which one can imagine they are adherents of ancient yak tribes. Yak horns and skulls are both of religious importance, and they are often carved with mantras and placed in prominent places. On the Tibetan Plateau nomadic people place yak heads or skulls on walls, on the threshold of a gate or *Manidui* (shrine) and may even hang a yak corpse on the doors of monasteries in order to drive out evil spirits. Yak butter sculptures are burnt as offerings to the gods and can be found in most of the monasteries of the Tibetan areas. There is also a popular practice that, in the words of Miller *et al.* (1997), “Sometimes a community will set a domestic yak free. This ”god yak”, as it is called in Tibetan, is an offering to gods of the locale, a gift back to the environment which sustains pastoralists.” Throughout yak-raising regions, yak dances are held by herders, which signify typically the vital role that yak play in the cultural and spiritual values of the pastoral society.

Religion, ceremony, social customs and attitudes to wealth and its symbols are all intertwined with each other in the life of the people and with the integral role of the yak in all aspects. Yak are always used as a dowry when a Tibetan girl marries a young herder. Therefore, yak, apart from being indicators of wealth, play an important role in maintaining social relationships. Complex forms of social organization have developed within yak-raising societies that aid in the allocation of rangeland resources and, through trade networks with other nomadic and agricultural communities, help to secure goods not otherwise available in pastoral areas. However, with socio-economic development, especially the process of modernization, "it is possible," as suggested in the first edition of this book and repeated in Chapter 1, "that the cultural and social importance of the yak may diminish in the life of the herdsmen." And “it is also possible that the spread, however slow, of modern concepts of feeding, management and breeding, and the pressures from those proffering such technological advice on yak husbandry, may further diminish the force of traditional values." It would be a pity if these values were lost without an understanding of their profound importance and further lead to the disappearance of cultural diversity. The conservation of biodiversity and cultural diversity are of the same importance in the development of yak keeping.

Socio-economic significance of yak keeping

Over the centuries, herders have developed complex and, very often, extremely efficient pastoral systems for managing rangelands and livestock in the harsh, high altitude environment where yak are found. Herders possess great knowledge about the rangelands and the animals they herd. As Miller and Steane (1996) concluded, "The fact that numerous unique and, in many cases, prosperous yak herding societies remain to this day bears witness to the extraordinary skills of yak herders." In recent decades, however, the modernization process has brought improved access and services to previously remote pastoral areas and an increased demand for yak products (Miller, 1997; Wu and Richard, 1999). Along with reforms in land and animal tenure, the changed socio-economic issues are transforming traditional yak production systems and grazing use patterns on the rangelands.

From subsistence to marketing purpose

Many researchers have emphasized that the yak has made life possible for man in one of the world’s harshest environments. In purely pastoral areas, where cultivated agriculture is not possible, yak allow people to subsist and, in many areas, to live quite well (Miller, 1997). A wide variety of yak products are produced for home consumption and marketing. In the mixed pastoral areas where both animal husbandry and cropping is found, yak and yak-hybrids are also an important component of agricultural production systems. Apart from the home consumption of yak products, yak husbandry is also the mainstay of the regional economies. For example, in western Sichuan, an important yak-raising area in

China, 72 percent of the milk, 45 percent of the beef, 42 percent of bovine skin and 34 percent of animal fibre (including fine wool) come from yak. Because of improved outlets for yak products, the number of yak more than doubled in every yak-raising area of China in the period 1950 - 1990, and in some cases increased by as much as two and a half-fold.

In grazing areas where pastoralists rely for their subsistence mainly upon their yak, the wealth of the nomads is judged, as in other traditional pastoral societies, by the number of animals owned (Wu, 1997a). However, prestige and social status are not the only reasons for keeping as many animals as possible; possession of a large number is also thought by many nomads to provide extra insurance against death of animals in times of severe cold or drought (Scholz, 1981; Huebl, 1986). Wu (1997b) elaborated on this point by suggesting that as an insurance against disasters nomads need to strive to increase stock numbers so that in the event of severe losses of animals an adequate remainder is left to rebuild the herd. Thus, the expansion of herd size in good times is a survival strategy adopted by yak herders, which is analogous to "r-selection" in bionomic strategy. Maintaining a large stock, therefore, becomes an ecological strategy selected by nomads. Among the causes for loss of yak, cold stress is the single most harmful factor on the Tibetan Plateau and some other regions of Central Asia (Wu, 1997a; Humphrey and Sneath, 1999).

In the past two decades, alternative sources of feed and improved veterinary facilities have been reducing the losses of animals during hard winters in some areas. However, the maximizing of livestock numbers by herders has been widely perceived as having caused rangeland degradation in pastoral areas through overgrazing (Linziduojie, 1996; Li and Yong, 1993; see also Chapter 13). It has also been suggested by (Ellis *et al*., 1991) that, provided an impending climatic disaster could be predicted sufficiently well in advance and provided good market outlets exist, a sensible and potentially profitable move by herders would be to sell out their stock before disaster strikes. However, this seems optimistic, as prediction of climatic disaster is at best uncertain and might not even become known to herders in advance, and the requisite market outlets may not exist. The only thing likely to be known, ahead of time, is the condition of the animals at the start of winter. If the preceding summer has been dry and vegetation growth inadequate, the condition of the animals is likely to be poor, and they will be at greater risk of death if the winter is then especially harsh. Most of the disastrous losses of yak that appear to occur in different areas every few years have resulted from a combination of a poor summer followed by an especially bad winter (Wiener, 1996).

Trade of yak products is also an important way of capital accumulation. Income can be derived from most of the products, from the sale of pack animals and from animals for breeding. Herders also try to exploit year-to-year fluctuations in resources in order to optimize herd productivity.

If reproductive rate is higher than normal in "good" years, or if supplementary feed has been available during winter, herd size increases and greater opportunities are created for marketing.

The present commercialization in China and other countries of Central Asia with histories of centrally planned economies has accelerated the development of marketing of yak products. Many attempts have been made by governments to force pastoralists to reduce their stock numbers and to integrate the subsistence pastoralism with a market economy (Humphrey and Sneath, 1999; Miller, 1998). The market-pricing process has made pastoralists more aware of the possibilities inherent in slaughtering livestock earlier in the season. Moreover, pastoralists now own their livestock, and there clearly is an open market in animal products, especially for those in the proximity of urban areas. This is starting to alter the traditional attitudes of the pastoralists. In the more remote yak-raising areas, the marketing of yak products is still limited due to only a few market outlets and at great distance, weak communications and high transport costs. Without market intelligence for yak products, it is also difficult to evaluate trends in the market or in price changes. Reliance on individual traders with poor management and financial capabilities does not provide a good basis for large-scale marketing. Because the remoteness of most yak-raising areas from good market outlets is still a fact of life, there continues to be substantial reliance on the use of yak products for subsistence and on marketing traditional products through traditional channels. In particular, yak herders have not yet been able to tap into speciality markets for products that could bring higher prices. Moreover, the reluctance of marketers or processors to advertise and develop high-value yak products also limits these developments (Miller, 1997). However, as described in Chapter 10, the development of cheese factories in Nepal provides an example of how substantial marketing outlets for yak milk can be created.

The development of the pastoral economies is the key to poverty alleviation and to improving food security, as well as to the wider goal of creating sustainable livelihoods. Ellis *et al.* (1991) suggested that the most important development intervention for promoting pastoral survival might be to reduce isolation and to consolidate links between the pastoral ecosystem and external resources. This involves encouraging the movement of goods and livestock through trade or marketing systems and linking the pastoral area to external economies both for consumption and distribution of products. As herders' incomes and access to goods increases, their dependence upon the local environment for subsistence decreases. Helping herders explore and adopt new marketing strategies requires support from governments to safeguard the social fabric of the communities by providing credit, insurance, relief funds and market outlets. Improving the infrastructure should reduce reliance on herd number maximization as an insurance against disasters (cf. Williams, 1996; Wu and Richard, 1999).

From mobile to sedentary system

Developments in the science and technology of yak husbandry do not alter the physical conditions of the region. Seasonal mobile keeping of livestock, therefore, still characterizes most of the highland animal husbandry.

On the Tibetan Plateau, the sparseness and limitation of natural pastures and their geographic and/or orographic location encourage nomadic livestock production. Yak herds are regularly moved between different areas at different seasons and, if necessary, between different pastures within a season. Scholz (1986) emphasized that mobile livestock keeping is an “optimum active human adaptation to the physical environment of arid and semi-arid areas and is probably the only possible way of putting the barren pastures of these regions to economic use without an immense expenditure of capital”. In ecological terms, the exploitation of heterogeneity in pastoral society involves optimizing forage use through local strategies of habitat division and the dispersal of grazing pressure (Wu, 1997a; see also Chapter 13).

From studies in the eastern Tibetan Plateau, Wu (1997b) suggested that an appropriate management strategy for a mobile system of yak raising used by local herders depends on finding the right starting and termination times of the grazing season. Critical factors involved include the time of greening of the summer pastures, the height of the sward, tillering and the requirements of re-growth of the vegetation. Termination of grazing of the summer pastures in the autumn also impacts on the yield of vegetation in the following year – so this must not be left too late in the season. Detailed consideration of the ecosystem and of range management and grazing practices is found in Chapter 13.

The aim of the nomadic system is to use animals to harvest limited amounts of vegetation scattered over large distances that cannot easily be gathered by any other method. In energy terms, it is inefficient as only a very small proportion of incoming solar energy is converted into usable material; yet without this system, no benefit at all would accrue (Scholz, 1995). With the various nomadic groups following a regular pattern of movement from one grazing ground to another at different times of the year, they can always aim to be where biological productivity is at its maximum.

The rangelands on the Tibetan Plateau are ecologically heterogeneous. Exploiting environmental heterogeneity (or so-called ecosystem diversity) can also be considered an important ecological justification for nomadic movement (Wu, 1997b). Miller (1990), in his account of the rangelands of the Tibetan Plateau, regards the pastoral grouping and mobile keeping of yak as well-adapted responses to different range and environmental conditions and as ecologically sound and sustainable.

However, sedentarization has become a worldwide trend in all pastoral areas of the Old World Dry Belt (Scholz, 1995), marking a gradual move from a nomadic to a more sedentary way of life (Salzmann, 1980). Forced by external circumstances, yak herders have settled down in most yak-raising areas. While this has merit in providing an infrastructure for the community and raising the standards of social services for yak herders, there are a few potential risks. Perhaps the most important is the increased risk of environmental degradation. Lack of mobility is a key factor leading to the degradation of rangelands in many yak-raising areas (Sneath, 1998, Thwaites *et al*, 1998, Williams, 1996, Wu and Richard, 1999). The nomads' ability to track environmental conditions and mobilize herds to seek pockets of good forage is effectively eliminated when grazing areas become partitioned. Enclosure of pastures almost always accompanies settlement. The general trend is that the more productive rangeland areas are fenced first, leaving residual open range prone to faster degradation, especially in areas where some winter areas are fenced and others are not.

Traditional mobile livestock raising is founded upon a traditional social system, which secures the realization of multiple resource goals beyond the purely economic (Behnke, 1984). If the whole system changes from mobile to sedentary in the yak-raising areas, communally based local institutions are likely to be weakened or even eliminated without being replaced by an effective local administration. Excessively centralized settlements, undue expansion of enclosed pastures, irrational encouragement of longer grazing periods in winter pastures along the main roads and abandonment of seasonal migration will inevitably require higher input levels per household and can lead to a breakdown in systems of social cooperation and conflict resolution. With enthusiasm for modernization, people often ignore the fact that a nomadic society responds in its entirety to the change of environment and the availability of resources (Wu and Richard, 1999). Simply to focus on pasture or livestock development fundamentally ignores the tight linkages between culture and the land. This in turn can lead to failure of such projects in the long term – in part through unintended social consequences resulting in a breakdown of traditional institutions. Moreover, because yak are an integral component of the nomadic system on the Qinghai-Tibetan Plateau, changes from a mobile to a sedentary system with consequent changes in management and production could adversely affect the yak species. Reduced need for hardiness and survivability in a harsh environment, which may accompany such changes, could, in time, lead to a loss of these valuable attributes of the yak.

From common to private ownership

In today's market-oriented environment, there is a growing trend to promote increased agriculture and livestock production through intensification of rangeland. Generally, intensification measures are initiated through changes in tenure arrangements from communal to individual, based on the assumption that pastoral strategies involving the use of grazing commons are inefficient.

Privatization of rangeland has been regarded by some as a precondition for the protection of natural resources; and the systems of common and collective pasture ownership are regarded as the primary causes of the degradation of rangelands (Koocheki, 1993; Li and Yong, 1993). Hardin’s (1968) concept of “the tragedy of the commons” strongly influenced land tenure policies. Using grazing as an example, Hardin argued for private tenure on the assumption that access to a common resource leads to overexploitation because the livestock owner will view the grazing resource as a free commodity, thus maximizing herd size at the expense of other herders. This view has been refuted extensively in the academic literature, as his argument fails to recognize the common property arrangements generally made among herders and in reality reflects a situation of open (or unregulated) access. That situation is the exception rather than the rule in pastoral regions of the world (Wu and Richard, 1999). Despite the overwhelming evidence against Hardin's argument, his concept still holds sway among policy-makers around the globe, resulting in inappropriate land tenure policies for marginal lands.

In yak-raising areas, large sectors of pastoral societies have been involved in a privatization process coordinated by national governments, especially in Central or Inner Asia. Since the implementation of the “Household Responsibility” system” in China, the pastoral system has moved slowly away from State control and ownership (centrally planned economy) towards a more market-oriented economy, with policies to encourage private-sector initiatives and investment. Communal livestock has been divided among every family, but the tenure of pastures has remained with the State and land has not been individually allocated. Without control of pasture resources, the situation could lead to one of open access, although local agreements generally avoid this (see also Chapter 13). However, to change the perception, the Government started the individualization of rangelands from the middle of the 1980s, first in Inner Mongolia, then in Xinjiang and finally in Qinghai and Sichuan. This programme aims to substantially increase livestock off-take and pastoral incomes through more intensive management to raise the nomads’ enthusiasm for rangeland management and to rationalize land use by limiting livestock numbers to carrying capacity.

The individualization programme started with the traditional winter grazing lands; each nomad family was allocated an area of rangeland on a long-term contract (50 years) in what was essentially a privatization of the previously communally managed grassland (cf. Wu and Richard, 1999). Land allocation was based on the supposed carrying capacity of the rangeland and the number of livestock each family had. The construction of houses for nomads, sheds for livestock, fencing and a development of artificial pastures was also heavily subsidized. At the heart of these changes are the policies affecting common property tenure, not least the policies to convert land to individual tenure-ship.

The real effects of pasture allocation are still unclear because of the short time since the implementation of this programme. Attempts to create private, commercial ranges in some developing countries have not been successful (Mueller, 1999; Scholz, 1995; Williams, 1996). Large-scale pasture allocation has raised a new set of issues regarding long-term sustainability in terms of cost and rangeland health and in terms of social consequences for local communities, partly because of perceived inequalities in the allocation process. All options, therefore, need to be evaluated on a site-specific basis, keeping in mind the socio-economic and ecological realities. Pilot schemes should be carefully evaluated before being expanded to a larger scale.

Nowadays, many prosperous nomadic groups still exist on the Qinghai-Tibetan Plateau, testifying to their adaptability to prevailing socio-economic and environmental conditions. The commonalities among these still-intact pastoral areas are effective communal institutions and relatively little interference by government in land tenure and management. Sneath (1998) looked at the geographic region of northern China, Mongolia and southern Siberia and found that areas in the best condition were places that exhibited low land fragmentation, experienced relatively late land tenure changes by centralist governments and consequently still possessed relatively strong local institutions capable of controlling communal pasture access. These characteristics have also been found in pastoral areas of Africa where communal range management has been found to be more productive than private ranching schemes (de Haan, 1998, Scoones, 1996). These characteristics of success can and should be translated into new and innovative policies that support nomadism, rather than undermine it.

From traditional to modern practices

As already discussed, yak herders have intricate ecological knowledge and understanding of the rangeland ecosystem in which they live and upon which their livestock production depends. Recognition of local climatic patterns and key grazing areas allow herders to select favourable winter ranges that provide protection from snowstorms and sufficient forage to bring animals through times of stress. A wide diversity of livestock and grazing management techniques are employed in these traditional systems that enable yak herders to maintain the rangelands (see also Chapter 13).

Yak herders’ knowledge of the complexity and ecological and economic efficacy of traditional yak-herding systems should be used in designing new interventions. Unfortunately, this knowledge is not well appreciated or understood by many researchers, planners and others interested in improving yak production. Too often there is a reliance on “new” technologies and scientific methods that, while practical on government farms or research stations, are often not widely applicable in the pastoral context in which the majority of yak are raised. Many of the so-called “new” technologies derive from results obtained in lowland areas and have then been transferred into the harsh environment of the yak. The appropriateness of the new techniques is then in question if they have not been integrated with the indigenous knowledge of yak-management and adequately tested in the remote yak-raising regions.

In the foreseeable future, improvements in the livelihood and well-being of yak herders in the pastoral areas will have to continue to depend on yak production, even though globally yak are not as important as other bovines. The major issues related to yak management include rangeland degradation and a lack of understanding of the socio-economic characteristics of yak production systems (Miller, 1997), even though the precise extent and severity of rangeland degradation may be open to argument. The relatively low productivity of yak husbandry is one of the main reasons why it is often considered inefficient. However, the productivity has to be seen in the context of the hostile and cold environment of the Qinghai-Tibetan Plateau, the serious nutrient deficit in late winter and early spring and the lack of adequate infrastructure for some of the potential improvements and better marketing. The pastoral system does not allow a regular, balanced food intake because of great seasonal variation of the vegetation resources, in terms of availability and nutritive value. While there is a surplus of fodder during the warm season, there is usually a shortage of feed during the cold season that causes malnutrition or worse, resulting in negative consequences for health and reproduction. Moreover, normal herd off-take, which tends to fluctuate from year to year, is frequently made more difficult by inadequate marketing facilities. Thus, further development of pastoralism in these areas depends more on the development of a whole socio-economic system than on the advance of technologies.

The improvement of services in yak-producing areas, as the pastoral areas develop, should increase the ability of yak herders to obtain a better return for their yak products. For herders to realize these opportunities, however, will require improved extension services to address animal health, product quality and yak-product marketing. A general improvement in the educational level of yak herders would also enable them to organize themselves more effectively to increase the value of their products. Although no uniform concepts can be applied to all “nomadic regions” - the regional differences are too great - certain aspects do have supra-regional applicability. These include maintaining maximum mobility for nomads to safeguard the integrity of the grazing resources, promoting self-help and marketing and recognizing the indigenous knowledge when developing improvement strategies.

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13 ALPINE RANGELAND ECOSYSTEMS AND THEIR MANAGEMENT IN THE QINGHAI-TIBETAN PLATEAU

By Long Ruijun[1]

OVERVIEW

There are about 8.5 million sq km areas of alpine land at an elevation higher than 3 000 m above sea level distributed throughout the world, of which the single largest and the highest plateau is the Qinghai-Tibetan Plateau covering an area of nearly 2.5 million sq km. Thus, it is referred to as the "third pole” or "the roof of the world". Given the high altitude and extreme harsh environmental conditions, this high elevation grazing land ecosystem might, up to the present, be among the least affected by modern society. The alpine rangeland ecosystem of the Qinghai-Tibetan Plateau displays inherent characteristics that lead the system to being relatively stable. The alpine pastures have retained a certain level of productivity over thousands of years. It has also resulted in a weaker and slower response to some arguably advantageous management measures, and consequently they are very difficult to rehabilitate once destroyed. Temperature and moisture are thought to be two key factors that drive formation and development of the alpine rangelands. Heat (temperature) seems to play a predominant role in limiting growth and the reproductive pattern of alpine vegetation growth, while the annual rainfall mostly determines the distribution of ecozones of alpine rangelands.

In general, the yield of native alpine pastures is low and seasonal, thus leaving a feed gap between annual pasture provision and the requirements of the grazing animals. Since agricultural cultivation is not possible, continuous year-round extensive grazing - either transhumance grazing on the vast plain of the central Plateau, or seasonal rotation within certain mountain regions – is the land-use pattern throughout the Tibet-Qinghai Plateau. Thus, both livestock (including yak, Tibetan sheep and goats) and wildlife species largely depend on alpine pastures for survival. The alpine native forages have characteristically high protein, fat and sugar contents with relatively low fibre content compared with lowland plants. Another advantageous feature of these plants is that they contain a reasonable quantity of tannins, which potentially enhance the absorption of nitrogen by the host animal. The high quality of fresh alpine forages allow grazing yak and sheep to recover the bodyweight loss sustained over winter through compensatory growth during a short growing season of 90 - 120 days.

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Although degradation of alpine rangeland has occurred over decades on the Plateau, it has become worse during the past decade due to a rapid increase in human and animal populations across the Plateau. This has led, in turn, to increasing demands on the alpine rangelands. A conventional seasonal rotation or transhumance system has been considered an effective way of avoiding the rangeland degradation.

However, the distance that herds can move has been restricted since the start of the "Household Responsibility System" in the 1980s, which was intended to encourage a semi-sedentary or completely sedentary lifestyle.

The nutrient resource of the soil pool is the most important basis for the growth and maintenance of the alpine vegetation. Any small change in this soil nutrient pool will have a profound effect on other components in the system.

The varied topography, altitudes and climate give rise to great diversity in alpine rangeland types. The rangelands include the lush, alpine meadows in the Himalayan mountains and eastern Tibetan Plateau, semi-arid scrublands of the dry valleys of central Tibet, the spacious alpine steppes of Tibet's northern plains and the cold, dry deserts of the Kunlun mountains. Therefore, no single management strategy can be applied to all the alpine rangeland types.

The Plateau's rangeland-livestock husbandry has lasted for centuries. Tibetan nomads acquired complex knowledge about the utilization and management of the alpine rangelands in which they lived and upon which the animals' survival depended. Serious degradation of alpine rangeland over the whole Plateau has brought a great threat to the alpine ecosystem and its nearby environment. Coping with these problems more effectively will require a clear understanding of the vast body of indigenous knowledge of the alpine rangeland ecosystem and herders' traditional experience. This is in order to work out sound utilization and management guidelines for the rangeland and ensure that herders get the best out of their pastures. This chapter aims to contribute to that understanding.

Background and present status

The alpine rangelands where yak can be found currently cover more than 2.5 million sq km of the Qinghai-Tibetan Plateau and its surrounding territories. As referred to in Chapter 1, these rangelands are at altitudes from 2 000 m to 5 000 m with a cold, semi-humid climate. They extend from the southern slopes of the Himalayas in the south to the Altai in the north and from the Pamir in the west to the Minshan mountains in the east. The alpine rangeland resource is vital for the livelihood of the people and their livestock raising. Much of this region offers an important habitat for many wildlife species, such as blue sheep (*Pseudois nayaur*), *kiang* or Asiatic wild ass (*Equus kiang*), Tibetan antelope

(*Pantholops hodgoni*), black necked crane (*Grus nigricollis*) and the endangered snow leopard (*Panthera uncia*) (Miller and Craig, 1996; Richard, 2000). Apart from these, many areas are now designated as protected with a high potential for the development of tourism. The available alpine rangelands of the Plateau cover about 128.2 million ha, or approximately 30.7 percent of China's total area of rangelands (Bureau of Animal Husbandry and Veterinary Medicine, Ministry of Agriculture, China, 1994).

These alpine rangelands consist mainly of alpine steppe (including alpine meadow steppe and alpine desert steppe), alpine desert and alpine meadow (Table13.1). Due to the high altitude and harsh environment, agricultural cultivation is not possible on most alpine plateaux. The only way the land can be used is for livestock grazing (Goldstein *et al*., 1990). Therefore, ruminant (yak and Tibetan sheep) farming plays the most important role in the socio-economic and environmental systems of the Plateau. These rangelands, especially the verdant pastures of the eastern Plateau, offer great reserves of forage for grazing livestock, the products of which account for a significant percentage of the gross national product (GNP) of these areas (Wu, 1997).

Table 13.1 Types of available alpine rangeland on the Qinghai-Tibetan Plateau and their theoretical carrying capacity in 1994 [Source: Bureau of Animal Husbandry and Veterinary Medicine, Ministry of Agriculture, China, 1994]

Type	Areas (ha)	Percentage of total (%)	Theoretical carrying apacity (sheep units (100 ha)$^{-1}$ yr^{-1})
Alpine meadow	63 170 937	49.3	91
Alpine steppe	57 505 299	44.9	23
Alpine desert	7 527 763	5.9	8

Thirteen million yak and 41.5 million sheep (Long, *et al*, 1999a) as well as large numbers of wildlife raised on the Plateau support a human population of 9.8 million. These animals are either largely (livestock) or totally (wild herbivores) dependent on the native alpine rangelands for their survival (Long *et al.,* 1999a,b). Consequently, competition for feed between domestic and wild animals is inevitable in areas where they overlap. Continuous year-round extensive grazing (either transhumance grazing on the vast plain of the central Plateau or seasonal rotation within certain mountain regions) is a unique land-use pattern on the Qinghai-Tibetan Plateau. This form of utilization differs from other alpine rangeland ecosystems in the world where the pastures are only grazed by livestock in the summer season. Until the 1950s, a transhumance pastoral system was the main grazing pattern in most of the plateau areas, the distance travelled by herds being dependent on forage availability and quality.

Thus, the distances covered by herders could vary from tens to hundreds of kilometres, or even more, according to the particular rangeland productivity of that area. Pastoral mobility was probably the simplest and the most effective way of optimizing the use of alpine rangeland resources without harming the ecosystem, but only if the rangeland resources were sufficiently abundant to allow the livestock free access, both in space and across time.

From the 1960s to the 1970s, most of the pastoral communities living in the eastern (Sichuan and Gansu) and northern (Qinghai) parts of the Plateau have changed from a migratory lifestyle to semi-sedentary or completely sedentary grazing practices.

However, these changes are still a relatively new phenomenon within Tibetan territory, associated as they are with the Household Responsibility System policy that was implemented in China from the beginning of the 1980s (see Chapter 12). Under this system, communal livestock were divided among every family, based on family numbers, and consequently, some of the pastures used during cold season (the so-called winter-pastures near by the herders' sedentary houses) were also allocated to herders individually in yak-raising areas. The rest of the rangelands are normally situated in remote or alpine mountainous areas grazed mainly during the warm season (the so-called summer pastures). These still belong to the State or are used as communal lands and so engender less concern for graziers than the winter pastures. Of course, the Household Responsibility System is intended to benefit most herdsmen and help raise their income through culling out more livestock, improving animal husbandry and managing their rangelands in a sustainable way. But such changes from a long-ranging and highly mobile yak-herding system in the past to a short-ranging and sedentary lifestyle also carry some potential risks for the alpine rangeland ecosystem since the rangelands of the Qinghai-Tibetan Plateau are more than just a resource to sustain livestock. They form the headwaters of the six major river systems of Asia – in particular, the Yellow River is regarded as the "Mother river", and the Yangtse being the "life river" of Chinese nationality. Their diverse ecosystems of forest-alpine ecozones, shrub alpine meadows and range alpine meadows lead to extensive quantities of water being held underground and regarded as the "underground reservoirs" of the Plateau and also called the Chinese "water tower".

The Plateau, as a natural protective screen for China in its southwest, plays a tremendous role in driving and regulating climate of western and southwestern China, even the northern hemisphere. In the past two decades, animal numbers have increased rapidly. This has, in turn, aggravated grazing pressures and accelerated the rangeland degradation (Table 13.2). This degradation is now one of the most serious environmental and socio-economic issues in the Qinghai-Tibetan Plateau region accounting for 32.1 million ha and 42.5 million ha in the 1980s and 1990s, respectively. In Qinghai, the headwater areas, where the Yangtse and Yellow rivers have their source, are particularly affected. Some pastures have degraded so badly that "black patch" land has formed (i.e. rangelands with a high density of black soil patches) from which most perennial vegetation has disappeared and been replaced by annual grasses or forbs, which are normally consumed completely by animals at some times of the year. These degraded rangelands with black, denuded soil covered 3.79 million ha and 7.03 million ha of alpine rangeland in the 1980s and 1990s, respectively.

Table 13.2 Areas and distribution of degraded rangelands on the Qinghai-Tibetan Plateau [Source: after Long and Ma, 1997] (unit ha x 10 000)

Region	Available rangeland	Degraded rangeland		Percentage of degraded rangeland		Black patch rangeland		Percentage of black patch rangeland	
		1980s	1990s	1980s	1990s	1980s	1990s	1980s	1990s
Tibet	6636.1	1202.6	1990.8	18.1	30.0	184.6	327.3	2.8	4.9
Qinghai	3161.0	910.3	1005.5	28.8	31.8	120.1	213.0	3.8	6.7
Sichuan	1416.0	386.7	467.3	27.3	33.0	34.8	61.7	2.5	4.4
Gansu	1607.2	712.9	787.5	44.4	49.0	57.0	101.1	3.6	6.3
Total	**12820.4**	**3212.4**	**4251.1**			**396.6**	**703.2**		

Ma Yushou *et al*. (1998) reported that in Dari county of Qinghai province, grassland converted to “black patch” due to overgrazing, extended from 0.17 million ha in 1985 to 0.58 million ha in 1994 – an annual increase of 14.7 percent. In these areas, herbage production is only 13.2 percent of that on the non-degraded grassland, and herbage cover is less than 30 percent. Inedible and poisonous grasses accounted for up to 76 percent of the sward.

Thus, rangeland degradation is often manifested by decreased diversity of plant species, reduced sward height and vegetation cover, increased undesirable and unpalatable grass species and even the occurrence of toxic species harmful to animals. Above all, there is a sharp reduction of acceptable biomass production. If the vegetation density is insufficient to cover the ground surface, wind erosion and desertification take place. In general, the alpine rangelands of the Qinghai-Tibetan Plateau are suffering degradation, soil wind erosion and desertification. These problems make the sustainable management and utilization of the rangeland resources more difficult and, in addition, make the alpine ecosystem even more fragile and unstable than before. Overall, overgrazing is recognized as the most fundamental cause of the degradation.

Climate

Air and solar radiation

The average depth of the atmospheric layer above the alpine rangeland of the Qinghai-Tibetan Plateau is about two thirds of that in the coastal areas. The atmospheric pressure and density are only about 50 - 60 percent and 60 - 70 percent, respectively, of those at sea level. These features, together with a smaller proportion of moisture and dust in the air, lead to much short-wave light of blue and particularly ultraviolet passing through the atmosphere that can then be absorbed by the green leaf material of the alpine vegetation. Annual sunshine is between 2 000 and 3 600 hours and the value of solar radiation varies from 5 000 to 8 000 MJ sq m per year, compared with only 2 000 to 3 000 MJ sq m per year in the eastern lowland area of China at the same latitudes. Hu *et al.* (1988a) calculated the annual energy conversion efficiencies from total solar radiation and physiological radiation to above-ground biomass energy in sedges (Kobresia capillifolia) meadow as 0.11 percent and 0.22 percent respectively, while it reached 0.40 percent for physiological radiation during the growth period. These figures are relatively low compared with corresponding values of 0.16 percent, 0.32 percent and 0.69 percent found in forbs (Polygonum viviparum) meadows in the same region (Hu *et al.*, 1988b). Physiologically, high solar radiation associated with high density of short-wave light has a profound effect on plant development: It limits cell elongation and thus reduces vegetative growth and forces cell division to accelerate reproductive development. Consequently, compact, stubbed and even cushion plant forms appear above ground while a well-developed root system is formed in the topsoil layer.

Temperature

The average annual air temperature is generally below 0°C, while the average temperature in January drops below -10°C. The average in the hottest month (July) does not exceed 13°C (Table 13.3). In meteorological terms, an absolutely frost-free season does not exist on the Plateau. The growing season of native plants varies from 90 to 120 days, but periods of relatively vigorous plant growth are even shorter than that. Temperature differs between day and night by 12° - 17°C, which is propitious for the accumulation of nutrients assimilated. Zhang and Ma (1982) reported that assimilation lost through respiration at night in alpine plants is only equal to about one third of that produced by photosynthesis during the day. Thus, alpine vegetation characteristically has relatively high levels of nutrients in the form of crude protein, fat and sugar (nitrogen-free extract), and a low fibre content compared with that of lowland and tropical pastures. These compositional characteristics also help native plants resist cold weather and other harsh environmental conditions.

Rainfall and wind

Drought is another feature of the plateau climate. More than 65 percent of the area receives less than 300 mm rainfall per year; the rest has an annual rainfall not exceeding 500 mm.

With the rainfall decreasing from southeast to northwest, the alpine rangelands display a diverse assortment of plant communities, including three dominant rangeland types: alpine meadow, alpine steppe and alpine desert (Table 13.1). Alpine shrub meadow appears if rainfall is sufficient on the north slopes of mountains.

Table 13.3 Climatic characteristics of typical regions on the Qinghai-Tibetan Plateau [Source: adapted from Hu, 2000]

Location	a.s.l.[1] (m)	a.a.t.[2] (°C)	a.t.[3] in Jan. (°C)	a.t.[4] in July (°C)	d.t.d.n.[5] (°C)	a.c.t.[6] (°C)	a.r.[7] (mm)	a.s.h.[8] (hr)
Gaize	4 415	0.1	-11.6	12.1	17.4	1 012.5	166.1	3 168
Shenzha	4 672	-0.4	-10.7	9.3	13.0	1 151.3	298.6	2 916
Bange	4 700	-1.2	-11.3	8.3	12.7	967.0	308.3	2 945
Anduo	4 800	-3.2	-15.0	7.7	14.4	846.1	441.6	2 847
Tuotuohe	4 533	-4.4	-16.5	7.5	14.5	743.2	284.4	2 829
Meyun	4 468	-4.3	-16.8	6.3	14.6	672.0	299.3	2 480
Zhahe	4 503	-5.3	-17.8	6.3	15.1	545.5	288.9	2 305
Sewugou	4 416	-2.5	-14.1	8.5	14.0	910.3	393.3	2 125
Maduo	4 221	-4.0	-16.5	7.6	13.5	1 098.0	299.4	1 865
Maqin	4 200	-3.7	-15.7	7.2	12.6	1 268.0	457.2	1 721
Zeku	3 826	-1.5	-14.6	8.6	13.0	1 521.0	647.0	1 879

[1]Above sea level; [2]annual average temperatures; [3]average temperature in January; [4]average temperature in July; [5]differences in temperature between day and night; [6]annual cumulative temperature above 0°C; [7]annual rainfall; [8]annual sunshine hours.

Disasters from hailstorms occur frequently in summer and from snowstorms in the spring. Strong winds occur throughout the late winter and spring seasons, with a mean wind velocity of 3 - 4 m s^{-1} , even reaching over 5 m s^{-1} in spring. Such winds can blow away about one third of the yield of standing vegetation from winter-spring pastures.

Effect of climate on alpine rangeland formation and evolution

Climate plays the most active and effective role on rangeland formation and evolution. In terms of alpine rangeland, water and heat (temperature) have more profound effects on its formation and development than any other indigenous factor, such as soil and topography. The summer temperature of the whole troposphere above the Plateau is higher than that of surrounding regions (at the same elevation). Moreover, with stronger solar radiation to the Plateau and the low level of moisture in the air, low heat loss through evaporation is yet another feature of the Plateau’s climate. Thus, the distributional upper limits of rangeland types are much higher on the Plateau than on solitary or smaller mountains (Chang, 1981). A moisture gradient from humid and subhumid to semi-arid and arid, from southeast to northwest, results in a corresponding series of diverse rangeland ecozones on the Plateau.

In the western part where rainfall is only about 50 mm annually, the vegetation is of suffrutescent desert and desert-steppe types composed mainly of *Ceratoides latens*. In the northwestern part, the climate is very dry and cold by reason of high altitude and the more northerly latitude, and so a sparse alpine desert of low suffrutescent and cushion-like

Ceratoides compacta has developed there. On the vast flat lands of the central Plateau, the annual precipitation increases to about 200 mm, and alpine steppe vegetation of *Stipa* species prevails. In the eastern part of the Plateau there is a cold, low-pressure zone where annual precipitation normally reaches up to 600 mm. With this cold and wet climate, a special kind of alpine meadow has developed, which represents the main body of alpine rangelands. This meadow consists of sedge species and low scrub, such as *Salix* and *Rhododendron* species. This series of alpine vegetation ecosystems, from southeast to northwest, was formed and developed in the Quaternary period (Chang, 1983). Even now, the three main kinds of pastures are still the most common rangeland types in the Plateau (Table 13.1) on which more than 800 forage species are growing. Among them, the two genera of *Carex* and *Kobresia* (grass-like plants having achenes and solid stems, which belong to the *Cyperaceae* family) are by far the most important indigenous plants. This is not only because of their high biomass production, early "green-up", wide distribution and good resistance to extreme climatic conditions, but also due to an incredibly high grazing tolerance.

Grasses such as *Stipa* and *Poa* species comprise a large proportion of the alpine-steppe sward. Forbs, i.e. broad-leaf herbaceous plants, are companion species in the alpine meadow swards or interspersing plants in the alpine desert.

Vegetation characterization

Patterns of production and growth

In general, temperature is the single most important factor determining the distribution, diversity, growth rate and biomass production of alpine vegetation. Fortunately, during the short growing season, warmth coincides with water supply (rainfall). These, as already mentioned, are the most fundamental factors supporting the primary productivity of the alpine rangeland ecosystems. Productivity ranges from 1 to 4.5 tonnes DM per ha per year. Thus, a high-efficiency and unique vegetation growth pattern is formed within the ecosystem.

Three distinct phases of biomass availability to the animals can be identified: Phase I has a surplus of green forage (June - September); Phase II has a relative surplus of more mature and dry forage (October - January) and Phase III has a shortage of dry forage (February - May). Based on seasonal growth, phenological and climatic aspects, the points concerning the growth pattern of alpine herbage can be summarized as follows:

Growth

Green-up (after winter) starts relatively late but growing activity ends early. Consequently, the growth season of the native vegetation lasts for only 90 - 120 days from May to August or September (Long *et al.*, 1999a) as shown in Figure 13.1. The first (July) and second

(September) peaks of biomass production are the result of a faster growth of sedges after green-up till July, and then grasses take over.

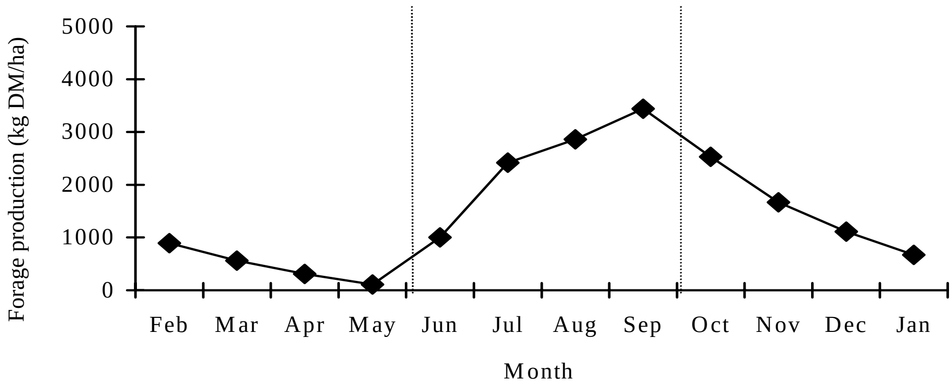

Figure 13.1 Biomass production in alpine meadow in the Qinghai-Tibetan Plateau

In view of this short growing period, the alpine plants, particularly the sedge species, have evolved strong tiller extensibility, since their seeds have poor germination. In order to finish the growth cycle (from germination to seed formation) within a short period, sedge has developed clonal or asexual ways to continue its regeneration.

Accumulation of above-ground biomass

Within the growing season, fresh biomass accumulates quickly but the maximum yield of dry matter does not appear until vegetation growth is finished. Nu Xindai (personal communication, 2002) indicated that *Kobresia littledalei*, a sedge species distributed in Dangxong valley, Tibet, showed a rapid absolute mean growth rate (expressed as DM g m^{-2} per day) of 1.1 from green-up to 15 May, 1.9 from 16 May to 15 June, and thereafter reached 2.8 from 16 June to 15 July from 1983 to 1985. Hu *et al.* (1988b) found that the biggest absolute growth rate (5.8 DM g m^{-2} per day) appeared one month after the green-up in forb (*Polygonum viviparum*) meadow, while its net primary productivity above ground was 481.1 DM g m^{-2} per year. This is higher than the value of 340.1 found in sedge (*Kobresia capillifolia*) meadow in the same part of the eastern Qilian mountain. Due to low temperatures, sedge and grass species are normally not able to generate tillers to contribute to the final biomass production in autumn.

Storage of dry biomass

Wilted herbage remaining on the rangeland from the summer's growth is available to the animals from autumn to winter. Owing to livestock trampling and grazing on the stand, a proportion of stems and leaves fall off the plants to form herbage fractions in the stand. If not consumed timeously, this biomass is liable to be lost by wind or snowstorms during spring. The proportion lost probably reaches up to 30 percent of total biomass yield per year from winter stands.

Defoliation and decomposition

Due to above-ground biomass production being generally low, there is less accumulation of the fallen herbage fractions. While the proportion decomposing varies from 51 to 63 percent annually during the warm season, the decomposition is suppressed to a large extent by relatively low temperatures. Consequently, the senescent herbage is removed by soil fauna mainly between July and September. Other factors, such as grazing activity, may reduce the rate of decomposition; in contrast, improving soil moisture and fertility would lead to enhancing of the degradability of these materials (Li *et al.*, 1982). A lower cellulose decomposition rate occurs where animal access is blocked or the meadows are under-grazed. This results in a considerable amount of the residual herbage mass being left in some areas, particularly under shrubs. In turn, this may reduce the forage growth and yield because the increased amount of dead material relative to vegetative growth creates shading by dead material, and thus reduces photosynthetic capacity.

Absence of legume species

In alpine vegetation communities there is a characteristic lack of forage legume species that, in turn, leads to an insufficiency of forage protein for livestock during the cold season. Moreover, legumes are difficult to establish in the Plateau due to its cold weather. No perennial forage legume has been developed as yet that is well adapted to the Plateau's weather. However, single or mixed grass communities can be easily established by proper selection of adapted grass species for the relatively lower land areas (around 3 000 m a.s.l.).

Accumulation of underground biomass

The underground biomass production is generally higher than that above ground, irrespective of the type of alpine rangeland. The average total underground biomass of different alpine vegetation meadows varies from a lowest of 627 g m^{-2} (*Elymus nutans* meadow) to the highest of 12 827 g m^{-2} (*Carex spp*. meadow). Other types include *Kobresia humilis* meadow (1 265 g m^{-2}), *(Polygonum viviparum*) meadow (5 702 g m^{-2}) and *Dasiphora fruticosa* (shrub) meadow (6 014 g m^{-2}) (Hu *et al*., 1988b). It is estimated that about 65 percent of total underground biomass is distributed between the surface and 10 cm down in the soil layer. The live root yield accounts for about two thirds of the total underground biomass. Due to the decomposition rate of dead root and fallen herbage lagging behind their accumulation in alpine rangelands, a large quantity of organic matter is preserved in the soil, the proportion varying - depending on soil type - from 0.49 percent in alpine desert soil to 15.7 percent in subalpine meadow soil (Table 13.4) (Xiong and Li, 1987).

Nutritive value of alpine vegetation

The quality of alpine rangelands is influenced by management, environment and plant species. Attaining the optimum stage of growth at grazing is recognized as the most significant management factor, due to the negative relationship between vegetation maturity and forage quality. (The map of the Qinghai-Tibetan Plateau in the Appendix shows most of the locations referred to in subsequent sections of this chapter).

Table 13.4 Variation in organic matter (OM) and total nitrogen (N) contents of alpine soil types to a of 10 cm [Source: adapted from: Xiong and Li, 1987]

Soil type	OM (%)	Total N (%)	Sample No
Alpine meadow soil	10.7	0.47	11
Subalpine meadow soil	15.7	0.69	13
Alpine steppe soil	1.7	0.12	6
Subalpine steppe soil	3.1	0.20	8
Alpine desert soil	0.49	0.04	2
Subalpine desert soil	0.76	0.06	2
Alpine frigid soil	0.79	0.06	7

Chemical composition profile

Sedges, as the fundamental species of many types of alpine sward, are generally components of pasture along with grasses and forbs. Sedge, grass and forb species differ in chemical composition as shown in Table 13.5, and so, their contribution to the pasture composition will also affect forage quality. For example, crude protein (CP) contents of sedge and grass species range from 6 to 16 percent on a dry matter basis - relatively lower than for forbs, which vary from 12 to 22 percent. It seems also that there is no significant variation in contents of crude fat (CF) (about 4 percent) and nitrogen-free extract (NFE) (45 - 50 percent) when samples are harvested during the flowering stage in July. Zhou and Simon (1995) reported similar results for CP content in Sunlian (the southern part of the Plateau) and in Hongyuan (northwestern Sichuan). Long *et al*. (1999a) also indicated that for Tibetan forages, increasing age at harvesting led to a significant decrease in nitrogen (N) content and an increase in neutral detergent fibre (NDF) content of both forbs and shrubs. Nitrogen content in sedges and forbs tended to be greater than that in grasses.

Intake, acceptability and dry matter digestibility

Feeding value of pasture depends on acceptability, dry-matter intake, forage digestibility and the efficiency of utilization of the end products of rumen digestion. On the grazing systems of the Tibetan Plateau, forage intake is largely influenced by pasture availability.

It may reach 4 - 5 kg DM per day for adult yak in summer and autumn, and be reduced to 1 - 1.5 kg DM per day, or even less, during late winter and early spring. Consequently, the animal's live weight varies much among seasons. On the summer pastures, acceptability and digestibility of forages become perhaps the major factors affecting the intake by the animals. Several observations (Ren and Jin, 1956; Zhou, 1984; Zhou and Simon, 1995; Long Ruijun, Hu Z.Z. and Xu Changli, unpublished data 1999) showed that sedges and grasses have a better acceptability than other species. On the basis of these studies it can be estimated that the proportions of the different kinds of forage plants in daily grazing diets in summer were sedges: 30 - 50 percent, grasses: 20 - 50 percent, forbs: 16 - 20 percent and legumes 1 - 3 percent. Cincotta *et al*. (1991) indicated that the proportion of sedge species accounted for 64.1 and 38.4 percent of the diet of yak and sheep, respectively on summer pastures of the Changtan area. Comparison among alpine forages harvested in August, September and October indicated that forbs had the highest 48-hour *in sacco* dry matter degradability, followed by sedge, grass and shrub. Figure 13.2 illustrates profiles of the 48-hour *in sacco* dry matter degradability from monthly samples of three different types of native swards that form the main body of alpine meadow on the Plateau. Although the dominant species varied from type to type and thus affected sward state (sward height, structure and mass), the trends in terms of the *in sacco* dry matter degradability are quite similar (Table 13.6). Obviously, the rates of dry matter degradability for all sward types in general are greater than 50 percent, but a big variation exists between different months throughout a year.

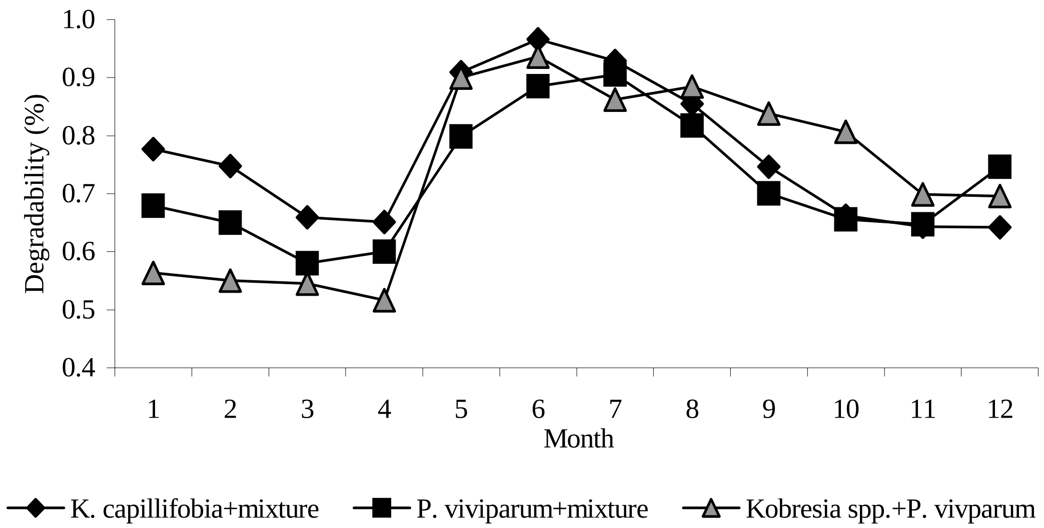

Figure 13.2 The 48-hour *in sacco* DM degradability of natural pasture samples

Table 13.5 Chemical composition of alpine plants cut at the end of July (unit: % DM basis) [Source: adapted from Long *et al.* 1999a]

Plant group species	Crude protein	Crude fibre	Ash
Sedge			
Kobresia royleana	14.7	24.1	6.8
K. pygmaea	14.5	26.6	3.5
K. stenocarpa	13.8	26.9	5.7
K. parva	13.6	25.9	5.5
K. capillifolia	13.1	23.3	5.6
Carex scabriolia	10.9	30.2	5.1
K. tibetica	11.3	33.7	4.6
K. bellardii	10.8	33.1	5.5
K. kansuensis	10.4	34.3	6.4
K. humilis	10.2	46.9	9.2
C. trofusca	7.1	33.2	4.0
Grass			
Leymus secalinum	16.6	33.4	8.0
Stipa purpurea	15.6	31.7	5.1
Elymus nutans	12.8	32.4	6.4
Poa annua	10.7	31.7	5.0
Stipa aliena	10.1	32.5	3.8
Roegneria nutans	9.1	37.7	5.9
Helictotrichon tibeticum	8.7	35.7	4.6
Stipa krylovii	6.6	41.6	4.5
Achnatherum splendens	6.3	33.4	3.4
Festuca ovina	6.3	40.2	6.3
Forb			
Triglochin maritimum	22.1	14.8	12.4
Potentilla anserina	20.1	19.5	10.2
Polyonum alatum	15.3	24.9	7.6
Polyonum viviparum	15.2	19.2	7.6
Saussurea superba	12.2	12.8	10.1
Shrub			
Dasiphora fruticosa	19.4	14.3	5.7
Salix oritrapha	16.9	11.4	4.7

Phenolics-related compounds

Ulyatt (1981) suggested that an “ideal” forage would have high protein content, high levels of soluble carbohydrate, some feature such as presence of tannins (that would either slow the release of soluble protein or render it less soluble in the rumen) and concentrations of minerals sufficient to maintain animal health. In most alpine sedge, forb and shrub species, the presence of microbial inhibitory compounds, or phenolics, have been revealed recently (Long *et al.* 1999a). Some of these inhibitory compounds were lately confirmed as being a phenolic-related compound of tannins (Long Ruijun, Hu Z.Z. and Xu Changli, unpublished data, 1999). Figure 13.3 illustrates that an appreciable quantity of tannins in a mixed alpine sward will potentially improve the forage-feeding value. The tannins protect the protein from degradation, thus providing a quantitative saving of nitrogen in the rumen and, further, allowing the bypass protein to be effectively used by the host animal in its small intestine. With a high value in fresh alpine forages, it makes grazing yak and sheep able to recover their previous bodyweight loss through sufficient compensatory growth during the short growing season.

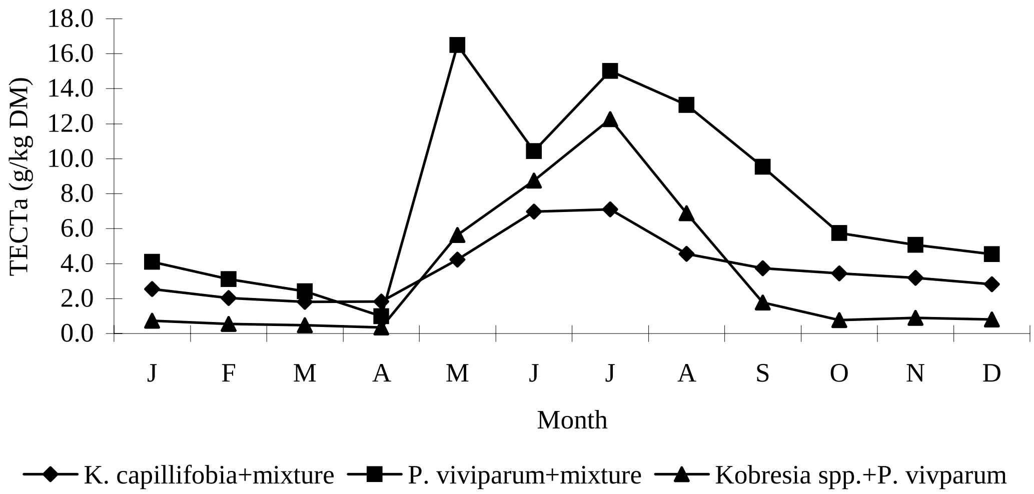

Figure 13.3 Concentration of TECTa from natural pasture samples taken monthly

Table 13.6 *In sacco* dry matter degradability (I.S.D.) of some Tibetan forages at different stages of maturity [Source: adapted from Long *et al.*, 1999a]

Forage group species	Harvesting month		
	Aug.	Sep.	Oct.
	48-hour I.S.D. (%)		
Sedge			
Carex atrofusca	77.8	72.6	59.3
Kobresia capillifolia	80.3	76.0	77.7
K. humilis	75.0	63.5	65.6
K. pygmaea	77.0	70.5	67.5
Grass			
Deschampsia caespitosa	62.1	61.9	70.1
Elymus nutans	69.7	63.1	51.8
Koeleria cristata	63.5	48.4	52.6
K. litwinowii	66.3	47.6	64.5
Leymus secalinum	76.6	77.1	60.6
Roegnevia kamoji	65.0	55.0	81.0
Stipa aliene	75.6	62.2	63.3
Forb			
Ajania frigida	81.7	74.0	65.5
Allium sikkimense	82.6	74.8	66.8
Anaphalis lactea	85.3	89.5	87.1
Carum carvi	78.5	58.3	53.6
Oxytropis ochrocephala	85.4	78.5	71.2
Polyonum alatum	75.0	74.1	53.7
P. viviparum	65.5	60.2	60.9
Potentilla repans	77.4	69.5	78.1
Ranunculus pulchollus	81.1	78.5	74.5
Trigonella ruthehica	90.1	85.0	79.9
Shrub			
Dasiphora fruticosa	51.7	44.6	32.2

Types of alpine rangeland

Alpine meadow

Alpine meadow, also referred to as “Tibetan high-cold meadow”, accounts for 49.3 percent of the total available alpine rangeland areas on the Qinghai-Tibetan Plateau. These vast grazing lands, distributed mainly in the eastern and southern parts of the Plateau, extend from 27° to 39° north latitudes and from 82° to 103° east longitudes. Due to the greater rainfall on alpine meadows than on alpine steppes and deserts, its primary productivity, in terms of biomass production and diversity of vegetation, is much higher as well. The vegetation on alpine meadow contains sedge species that include *Kobresia pygmaea, K. microglochin, K. humilis, K. bellardii, K. capillifolia, K. royleana, K. tibetica, K. setchwanensis, K. kansuensis, Carex moorcroftii, C. prewalskii, C. scabrirostris, C. ivanoviae* and *Blymus sinocompresus*; grass species that include *Elymus nutans, Stipa* and *Festuca*; forb species include *Polygonum viviparum, P. sphaerostachyum, Potentilla anserina* and *Artemisia frigida*; and shrub species that include *Hippophae thibetana, Lonicera tibetica, Dasiphora fruticosa and Salix.* Following the uneven annual rainfall and changing elevation, forage yield of alpine meadows with a ground-cover canopy of 80 - 100 percent varies widely, from a low of 1 500 kg DM per ha in eastern Tibet to a high of 4 000 kg DM per ha in southwestern Sichuan. As shown in Table 13.1, the alpine meadows have the highest theoretical carrying capacity of 0.91 sheep unit per ha per year, so that 63.2 million ha of alpine meadows may be expected to support at least 57.5 million sheep units. At present, about 8.5 million yak (60.7 percent of total yak on the Plateau) are raised on alpine meadows, which is equivalent to 34 million sheep units (1 yak = 4 sheep units). Between 15 million and 20 million Tibetan sheep are also grazing these alpine meadows. Although the real carrying capacity of the meadows seems close to theoretical capacity, overgrazing and degradation of meadows are developing extensively on the Plateau.

Alpine steppe

Alpine steppe is widely distributed in the centre of the Qinghai-Tibetan Plateau and on most of the southward-facing slopes of the mountains with a total area of about 55.5 million ha, accounting for 44.9 percent of the Plateau's total available rangelands. Water shortages lead to poor vegetation diversity and an open canopy ranging from 40 to 70 percent ground cover. In consequence, its yield varies from 350 kg to 1 000 kg DM per ha per year. Its community consists of grasses and sedges, such as *Stipa purpurea, S. glareosa, S.capillacea, S. bungeana, S. breviflora, S. krylovii, S. aliena, Festuca ovina, Poa annua, Kobresia parva, K. tibetica, Carex scabriolia* and *C. trofusca.* As suggested in Table 13.1, the theoretical carrying capacities on alpine steppe is 0.23 sheep units per ha per year. The largest proportion of livestock raised is sheep, followed by goats and then yak.

Alpine desert

The alpine desert lies mainly in the western and northwestern flat parts of the Plateau and on some upper areas of the high-altitude mountains. Extremes of dry or of cold can each form the alpine desert. This rangeland accounts for 5.8 percent of the Plateau, with the simple vegetation consisting mostly of *Ceratoides latens, C. compacta, Ajania fruticulosa, Christolea crassifolia, Stipa glareosa, and Carex moorcroftii*. The canopy ground cover reaches down as low as 20 percent and the yield of the sward is very low, varying from 100 kg to 300 kg DM per ha per year. About 12.5 ha are needed to sustain one sheep unit (equivalent to 0.08 sheep units per ha). Compared to alpine meadow and alpine steppe, the desert has less importance and receives less attention in terms of rangeland and livestock management, and goats are the dominant livestock. Some areas, so far with little human activity, are given protection by inclusion in "the national nature-protecting areas" in order to conserve wild animals, such as Tibetan antelope (*Antilope*), wild yak (*Bos mutus* or *Poephagus mutus*) and wild ass (*Equus hemionus*).

Alpine soil type and its characterization

Soil plays the most fundamental role in sustaining the alpine rangeland ecosystem, upon which diverse rangeland communities are established. As a deposited pool, wherein the nutrient transformation and energy flow of the ecosystem take place, it is also a habitat for soil micro-organisms and various animals. Nowadays, most measures to improve alpine rangeland productivity are achieved through amelioration of the condition of the soil pool. A given soil type is always associated with the vegetation community on it and, in the main, there are four different soil types in the Qinghai-Tibetan Plateau, namely that of: alpine meadow (including subalpine meadow, alpine scrubby meadow, subalpine scrubby meadow, peat-bog and peat), alpine steppe (including subalpine steppe), alpine desert (including subalpine desert) and alpine frigid soil. Table 13.4 summarizes the profile of chemical properties of these soil types and shows that the organic matter (OM) and total nitrogen (N) contents of alpine meadow soil types are much greater than those of other soil types. Similarly, the trend is for the amount of forage produced to increase with the OM and N content of the soil.

Soil micro-organisms are the other important component concerned in the status of alpine rangeland. The ecosystem and the activities of the micro-organisms have a profound effect on soil fertility and consequently impact plant growth and pasture production. Zhu *et al.* (1982) indicated that in the alpine meadow ecosystem of eastern Qilian mountain (3 200 m a.s.l.), the population of micro-organisms varies seasonally, being also affected by different soil and vegetation types. The highest numbers of micro-organisms in alpine meadow soil occur in the period from mid-July to mid-September but tend to decline after late October.

The soil mainly covered with forbs tends to have the largest number of bacteria, sedge (*Kobresia humilis*) meadow has the highest actinomycete population and shrub *(Potentilla fruticosa*) meadow has the greatest population of fungi and oligonitrophiles. In the soil of swamp meadow, the cellulose-decomposing micro-organisms are absent.

Zang J.X. *et al.* (1991) investigated the quantity and distribution of trace elements in the alpine meadow ecosystem, eastern Qilian mountain. The results showed that the alpine meadow soil (air-dried sample) is rich in trace elements, with contents as follows:

Fe 36 000 ppm, Mn 652 ppm, F 594 ppm, Zn 127 ppm, Cu 28 ppm and Se 0.23 ppm. There is a view that the Se content is inadequate; however, no plant or animal deficiency symptoms appear to have been reported to date. Significant differences existed among soil types in the concentrations of these elements.

Utilization and management of alpine rangelands

Grazing utilization systems

The zone distribution of alpine rangeland types from southeast to northwest on the Plateau leads generally to a corresponding zoning of livestock production systems. Yak are mainly distributed on alpine meadows and higher proportions of Tibetan sheep are found on alpine steppes, while goats and Tibetan sheep mainly inhabit the alpine deserts. Therefore, there are a variety of different management strategies in use on the Plateau. The pasture itself, whether owned by a family or by a group of herders or a village, can be broadly divided into four seasonal rotation grazing systems according to (i) weather, (ii) landforms, (iii) rangeland availability and productivity and (iv) tradition. The use of different pastures at different seasons and the periodic movement of the animals to new grazing sites is part of the tradition of the herdsmen and finds its counterpart in some of the elements of "modern" rotational grazing systems for which "scientific" justifications have been produced (cf. Chapter 8).

(I) Two-season rotation system

This rotation system involves the summer-autumn pasture used in the warm season and the winter-spring pasture used in the cold season (Table 13.7). The summer-autumn grazing generally occurs some time between June and November and may last 140 - 170 days. The herd then moves to the winter-spring pastures for about 192 - 225 days from November (sometimes sooner) to May - the larger part of the year. In general, the two-season rotation system is used mainly in the wide Plateau areas. During the warm season, a yak herd may be moved every 30 - 40 days, depending on the state of the sward and the size of the herd. The distance between campsites varies from 20 to 40 km.

(II) Three-season system (A)

This rotation system is characterized by summer-pasture, winter-pasture and autumn-spring-pasture (Table 13.8).

Table 13.7 The pattern of utilization on the two-season rotation system (I) of the summer-autumn and winter-spring pastures

Location	Summer-autumn pasture				Winter-spring pasture			
	Grazing period	No. days	Type (%)	Rangeland period	Grazing period	No. days	Type (%)	Rangeland period
Anangren	1/6 - 15/11	168	46	Alpine meadow	16/11 - 31/5	197	54	Riverside shrub, meadow, alpine steppe
Ali, Returebang Zhadarebu	1/6 - 31/10	153	42	Alpine steppe, alpine shrub steppe	1/11 - 31/5	212	58	Riverside meadow, riverside shrub meadow, hill desert steppe
Andu, Bange, Naqu, Senzha, Zhenrong	15/7 - 30/11	138	38	Alpine meadow, alpine steppe	1/12 - 14/7	227	62	Riverside meadow, alpine steppe
Cangdu, Jilong	1/6 - 31/10	153	42	Alpine shrub meadow, alpine meadow	1/11 - 31/5	212	58	Subalpine shrub meadow, riverside shrub meadow
Xietongmen	1/6 - 31/10	153	42	Alpine meadow	1/11 - 31/5	212	58	Riverside shrub meadow

Table 13.8 The pattern of utilization on the three-season rotation system (II) of the summer, autumn-spring and winter pastures

Location	Summer pasture				Autumn-spring pasture				Winter pasture			
	Grazing Period	No. days	Type (%)	Rangeland	Grazing period	No. days	Type (%)	Rangeland	Grazing period	No. days	Type (%)	Rangeland
Hongyuan Luqu, Menyuan, Tianzhu	1/7 - 31/8	62	17	Alpine shrub meadow, alpine meadow	1/9 - 14/12, 16/5 - 30/6	151	41	Alpine steppe, alpine shrub meadow, alpine meadow	15/12 - 15/5	152	42	Alpine meadow, riverside meadow, alpine steppe
Cuomei, Dingre, Dingjie, Langkazi, Lazun	1/6 - 31/8	92	25	Alpine meadow	1/9 - 30/11, 1/3 - 31/5	182	50	Hill steppe, Riverside meadow	1/12 - 28/2	90	25	Riverside steppe, riverside meadow

In a system carried out in the northern piedmonts of the Himalayas, animals remain on both the summer and the winter pastures for about three months each. Livestock graze the autumn-spring pastures twice – once from the beginning of September to the beginning of December and then from March to May. Three-season rotation-grazing systems are commonly found in mountainous regions. In these systems, the herders rarely move during the summer to find different sites and only move when the season ends.

(III) Three-season rotation system (B)

This rotation involves a summer pasture, an autumn pasture and a winter-spring pasture (Table 13.9). The autumn pasture is used in this system for more than two months (61 - 81 days). The activities of the animals on the summer and winter-spring pastures are as for the two systems previously described.

(IV) Three-season rotation system (C)

This rotation involves a summer-autumn pasture, a winter pasture and a spring pasture (Table 13.10). In this system, the spring pasture is separated either from the autumn-spring or from the winter-spring pastures. The livestock remain on it for two to three months. Its rangeland types are mainly alpine riverside meadows or shrub lands. The grazing features of the summer-autumn and the winter pastures are as previously described.

Management of the seasonal pastures

Winter and winter-spring pastures

The winter and winter-spring pastures are normally located on relatively flat meadows, such as riverbank mesas, wide valleys and piedmonts, or south-facing slopes at lower elevations, where pastures have the highest forage output and the best acceptability relative to the other types of pasture. Therefore, these pastures, and particularly the winter pastures, are fenced mainly in order to accumulate the biomass for grazing in winter and spring. Accumulating standing dry forages on the winter and winter-spring pastures is the traditional way of supplying feed for animals during the cold season, as the plants on the Plateau are too short to cut for making hay. This management pattern results in a large proportion of the forage nutrients being wasted and, in consequence, feeding value is much reduced from that of the original green biomass when it was set aside, while a large quantity of above-ground biomass is lost, as discussed earlier. The condition of these pastures has a profound effect on the Plateau's rangeland-livestock production systems, particularly in the provision of feed for the larger herds. Therefore, because calving and lambing takes place on them, herders pay much attention to these pastures and use some improvement practices such as fertilization, flood irrigation, toxic plant removal and rat control. Such measures are usually applied along with enclosures formed with barbed-wire fencing.

Table 13.9 The pattern of utilization on the three-rotation system (III) of the summer, autumn and winter-spring pastures

Location	Summer pasture				Autumn pasture				Winter-spring pasture			
	Grazing Period	No. days	Type (%)	Rangeland	Grazing period	No. days	Type (%)	Rangeland	Grazing period	No. days	Type (%)	Rangeland
Bianba, Biru, Jingqing, Leiwuqi, Suxian	1/6 - 31/8	92	25	Alpine Meadow	1/9 - 31/10	61	17	Alpine & subalpine shrub meadow	1/11 - 31/5	212	58	Subalpine shrub meadow, riverside shrub meadow
Baxu, Caya, Cangdu	15/5 - 31/8	108	30	Alpine meadow	1/9 - 15/11	76	20	Subalpine shrub meadow	16/11 - 14/5	181	50	Riverside shrub, shrub meadow
Jilong, Sage	1/6 - 31/8	92	25	Alpine meadow	1/9 - 15/11	76	20	Hill steppe	16/11 - 30/5	192	55	Riverside steppe, shrub meadow

Table 13.10 The pattern of utilization on the three-season rotation system (IV) of the winter, spring and summer-autumn pastures

Location	Summer pasture				Autumn pasture				Winter-spring pasture			
	Grazing period	No. days	Type (%)	Rangeland	Grazing period	No. days	Type (%)	Rangeland	Grazing period	No. days	Type (%)	Rangeland
Angren, Gangba Kangma, Xietongmen	1/6 - 14/11	168	46	Alpine meadow, shrub meadow	15/11 - 28/2	105	29	Hill steppe, Hill shrub steppe	1/3 - 31/5	92	25	Alpine meadow, riverside meadow
Basu, Mangkan, Zuogong	1/6 - 31/10	153	42	Alpine shrub meadow, alpine meadow	1/11 - 31/3	151	41	Subalpine shrub meadow, riverside shrub	1/4 - 31/5	61	17	Riverside meadow
Geermen, Tuqu, Xiaqulong	15/6 - 31/10	138	38	Alpine steppe, alpine desert	1/11 - 31/1	92	25	Alpine desert, riverside shrub	1/2 - 14/6	135	37	Riverside meadow, riverside shrub
Duilongdeqing Nanmulinmo, Nimu, Zugongqa	1/7 - 31/10	123	34	Alpine meadow	1/11 - 28/2	120	32	Hill shrub steppe, Subalpine shrub meadow	1/3 - 30/6	122	34	Riverside meadow

Summer and summer-autumn pastures

The summer and summer-autumn pastures are generally located either at the higher altitudes, often on the north facing slopes of the terrain or on the relatively flat rangelands furthest from the settled homes of the herdsmen and their families. Most of these pastures are difficult to access or may even be inaccessible except in the warm season as they may become blocked during harsh weather or by poor road conditions. In early summer each year, usually in May but depending on the particular location, the herd may still be grazing the spring, spring-autumn or winter-spring pastures. As soon as the season allows, the herd is taken to the summer pastures. Because these pastures are usually far away from the winter or spring pastures, the herdsmen and their herds may need to travel several days to reach their new campsites. The summer pastures, free from fencing, are usually utilized as communal lands for a group of families or an entire village. Hence, there is free access for the herds, and the herders are accustomed to establishing their campsites at the same places every year. Only when the yield of the summer pasture cannot meet the animals' requirements, because of drought or rangeland degradation, do the herders have to move away. These pastures are effectively managed in the long term through extensive, paper-free agreements among the families of a village. Such agreements are made by three to ten families, or occasionally more, sharing the grazing of the same summer pasture (see Chapter 12). Breeding of the stock occurs on the summer pastures, and so the calving rate is largely dependent on forage quantity and quality of these pastures.

Spring and autumn-spring pasture

The spring and autumn-spring pastures are normally located near the winter pastures and the herders' houses, or they may be situated between the winter and summer pastures. Whether or not these pastures are fenced depends on whether or not they are owned by the herders. Before vegetation turns green in spring, both the quantity and quality of the forage remaining on these pastures are at their lowest for the year. The intake by the animals can be as little as one third of the amount consumed in the autumn. As a result, as much as a third of the live weight the animal achieved in the previous autumn is lost during the late winter to early spring period (before green-up) (cf. Chapter 6). This, in turn, leads to a large number of livestock in the herd becoming sick or weak - the so-called phenomenon of "spring sickness". Some of the sickest or weakest animals may die, especially if heavy snowstorms occur in the absence of sufficient feed supplementation and at the very time when most new calves and lambs are born.

Autumn pasture

The autumn-pasture, which may or may not be fenced, is generally located between the winter and summer pastures and usually closer to the winter pastures. By the end of autumn, the animals have achieved their maximum live weight. Autumn is, therefore, the best season for culling surplus stock.

Critical grazing periods

From the point of view of pasture management on the Plateau, the two critical grazing periods are the approximate two-week periods of early spring immediately after green-up and of the late autumn, before the end of vegetation growth. Grazing activity just after green-up will lead to most growing points of plants being eaten by animals, which is, in turn, harmful to tillering and the ability of plants to re-grow. Areas of the sward that are overgrazed prior to the decline in plant growth in the autumn reduce the storage of nutrients in the root system and will therefore have poorer green-up the following spring. This will lead to less seed being produced for the soil-seed bank. The overall consequences are rangeland degradation.

In practice, it is difficult to avoid the problems associated with the two critical grazing periods unless sufficient supplementary feed can be provided in the early spring or alternative land found for grazing in the late autumn. A traditional approach, developed by herdsmen to avoid or alleviate the above situations, is to have a two- to three-year rotation (crossing-over) system between part of the winter or autumn pastures and the spring pastures. The early spring, as mentioned earlier, is also the critical period for the survival of the animals. Therefore, a sound management of the spring pasture and of the herd grazing will have a large influence on the sustainability of the Plateau's rangeland-livestock production systems. To achieve this, herders, policy-makers and researchers need to reach better mutual understanding and then work together.

The potential for improvement of the alpine rangeland

Irrigation

Flood irrigation is perhaps the most common and economic method used by herders to improve the native rangelands, whenever water is available and easily applied. Due to variation of the landforms, not many pastures can be irrigated by running water. Irrigation is applied mostly on areas of winter or autumn pastures that lie on flat areas of riverside and on open lands down-stream that allow easy flooding. Long Ruijun, Hu Z.Z. and Xu Changli (unpublished data) showed that a sedge-grass meadow developed under an annual mean rainfall of 414 mm and mean temperature of minus 0.1C° responded dramatically to irrigation. Five similar pieces of meadow, each 1.5 - 2 ha in size, were flooded thrice (with an equal amount of water each time) in June. Increasing the quantities of total extra water from zero to 0.45, 1.35, 1.80 to 2.25 tonnes per ha, led to corresponding increases in aerial biomass production with these five treatments. The increases were 1.28 to 3.56, 3.15, 5.38 to 4.79 tonnes per ha, respectively. The response of sedge, grass and forbs to irrigation varied depending on the quantity of applied water. Forbs were more responsive than sedges and grasses when 0.45 tonnes per ha of water was introduced; with 1.80 tonnes per ha water, sedges showed a greater response than forbs and grasses, while grasses were the most responsive when 2.25 tonnes per ha water was supplied. The time of flooding also has a profound effect on yield and structure of swards, the optimum being as soon as possible after green-up of the native vegetation.

Forbs and some toxic plants are considerably restricted by increasing levels of water, thus leaving a larger proportion of acceptable forage in the sward and greatly improving the feeding value of the sward.

Fertilizing

Nitrogen or phosphorus fertilizers are rarely used by herders to improve their grazing pastures due to cost and the difficulty of spreading. Nonetheless, fertilizing can enhance the biomass yield of native pastures, particularly the edible forage. When the sedge-grass meadow referred to above was fertilized once with sulphate of ammonia at the rate of 375 kg per ha (80 kg N per ha) and then flooded with 300 cu m water per ha at the end of June, its edible forage yield reached 5 674 kg DM per ha, an increase of 470 percent compared with the same pasture without any fertilizer. In addition, the green vegetation period of the native sward was extended by an extra two weeks.

Control of toxic plants and rodents

Overgrazing and degradation of alpine rangelands is always associated with an invasion by toxic plants; the greater the overgrazing, the greater is such invasion. The toxic plants commonly found include: *Stellera chamaejasme, Achnatherum inebrians, Aconitum szechenyianum*, *A. rotundifolium* and some seasonally toxic herbage from plants such as *Ranunculus spp.*, *Pxytropis spp.*, *Gentiana spp.*, *Pediculalis spp.,* and *Senecio spp.* The seasonally toxic plants are avoided by animals during the growing season but are grazed in the standing or dry sward. Winter *et al*. (1992, 1994) reported that species of *Senecio* are the predominant toxic plants found to be causing large numbers of the deaths among yak on overgrazed pastures in Bhutan. This matter is also referred to in Chapters 8 and 9.

Herders rarely use chemical control of poisonous plants. However, removal of the plants by hand is often carried out. Since most of the toxic plants are broad-leaf, the use of a herbicide, such as 2,4-D, with a dose of 0.454 kg per ha, tends to be used on State farms to remove these plants.

Rodent infestation always follows rangeland degradation and in turn, the rodents accelerate the degradation through consuming both aerial biomass and the roots of plants. The rodents also dig up much soil that then covers the surface of nearby swards. Pika (*Ochotona curzoniae*) and Chinese zokor (*Myospalax fontanierii*) are recognized as the most active rodents that invade and destroy degraded meadows, but the alpine steppes and deserts are rarely attacked by these small animals. The pikas move about during the day and *Myospalax baileyi* at night. The density of the pika distribution tends to increase on the alpine meadow in line with increasing degrees of sward degradation. But the largest number of pikas (148 per ha) is found on medium-degraded meadow. Poison bait casting and setting of rat traps are the most common measures used by herders to remove rodents from their pastures, though sometimes they are not very effective in controlling the periodic infestations. Perhaps an alternative, effective and environmentally friendly means of shrinking the rodent population to within harm-free levels, or eliminating the rodents' habitat, would be to increase the numbers of the rodents' natural enemies, such as the eagle and the fox, or to increase sward height and cover by avoiding overgrazing and through irrigation and fertilizing.

Use of forage crops and sown-grass swards

Given a pattern of native forage production in alpine rangelands as shown in Figure 13.2, an obvious imbalance exists throughout the year between feed supply from pasture provision and the requirements of the animals. The traditional way to solve the issue on the Plateau is to practice an effective seasonal rotation or transhumance system. However, an alternative measure used nowadays by many herders who live at a relatively low elevation in Gansu, Sichuan, Qinghai and southern Tibet, is to sow out a supplementary crop or sward near their permanent houses or near rivers in order to fill some of the forage gap during the cold season. Forage crops are normally the first choice for annual production. For example, oats (*Avena sativa*) for making into hay and the root crops of sugar beet (*Beta vulgaris*) and turnip (*Brassica rapa*) are planted in some relatively low-lying areas or where the temperature is sufficient for their growth.

Alternative supplementary forages are from sown perennial-grass swards that are sometimes established on fenced land. There are several cultivated perennial grass species adapted to the Plateau's harsh climate, such as *Clinelumus nutans, Elymus nutans, Bromus inermis, Agropyon cristatum* and *Poa crymophila.* These can be sown in monoculture or in mixture, the latter being the most common. Grass-forage production can be as high as 10 - 14 tonnes DM per ha two years after establishment, i.e. 2- to 5-times higher than the production from enclosed native pasture. In addition, the green-up time of the sown grasses can occur two weeks earlier than that of the native vegetation. However, in the first year of establishment, the sown grasses, because they are insufficiently aggressive, may fail to compete against the native weeds, and so the yield of the sown grass will be lower above ground. However, their root systems can become well established in the year of sowing, and this benefits survival and growth in the second and subsequent years. To achieve both high quantity and quality from the sown sward, an effective control of annual broad-leaf weeds has to be maintained throughout the sward life to ensure persistency.

In terms of haymaking from the cultivated perennial swards, cutting once a year at the early seeding stage and leaving the re-growth for grazing is recommended by Dong (2001). Without a practice of re-seeding, the yield of some monoculture swards begins to decline from the third or fourth year after establishment, while those of mixtures may last for seven to ten years when fertilizer and irrigation are used.

Postscript

The rangelands are not only vast but diverse in climate, topography, soil types and vegetation cover. Sustaining the large populations of yak, sheep, goats and the horses of the herders, as well as wild animals, creates a disequillibrium between the supply of available feed and the requirements of the animals. Typically there is an abundant supply of feed in summer and a significant deficit in winter and spring. Inappropriate but traditional practices have led to substantial degradation of the rangelands, which in turn heightens the difficulties of maintaining an increasing animal population. At the same time, the increasing demands on the rangelands further exacerbate the problems from overgrazing. However, as suggested in this chapter, a study and understanding of the interacting forces and relationships within the ecosystem and the potential for improvements would provide an opportunity for sustainable production from the unique resource represented by the high Plateau and these mountainous regions.

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14 YAK NUTRITION – A SCIENTIFIC BASIS

by Long Ruijun[1]

OVERVIEW

As discussed in previous chapters, the yak is largely dependent on natural pastures for its survival. Thus, its nutritional state varies seasonally as the supply of supplementary feeds is limited. In most herds, only very weak animals and some pregnant or lactating yak are given access to feeds in addition to grazing. Low calving and growth rates are attributed to the poor nutritional condition of the yak, in the cold season particularly. The traditional way of maintaining the animals is to allow them to put on as much fat as possible during the warm season; fat that is then used over the long cold season as an energy reserve to allow survival beyond the early spring. The tragedy of large numbers of animals dying because of snow disasters is frequent on the Qinghai-Tibetan Plateau. Nowadays, the yak population is increasing rapidly, causing rangeland degradation and, hence, further increasing the gap between feed supply from natural pastures and the animals' feed demand. Thus, the malnutrition that the yak has to suffer is likely to become worse in the foreseeable future. A good understanding of yak nutrition under grazing conditions, which could help to alleviate some of the problems, is still rather inadequate. But this chapter provides some of the evidence that is accumulating and points to several gaps in understanding and the need for validation of some of the preliminary findings.

Feed intake

Generally, yak consume less feed than other cattle, probably because of their smaller rumen capacity. Yak prefer fresh, high-quality forages, and both housing and high temperature can reduce feed intakes. Dry matter intake (DMI, kg per day) of the growing yak under indoor feeding can be estimated as DMI = 0.0165 W + 0.0486 (W is body weight in kilograms), and that of the lactating yak as DMI = $0.008W^{0.52} + 1.369Y$ ($W^{0.52}$ is metabolic body weight, Y is milk yield, kg per day).

Ruminal digestion and metabolism

The rumen of the yak is far smaller than that of other cattle. Outflow rate of rumen fluid ranges from 3.1 to 3.5 litre per hour, hence lower than in cattle. The outflow rate of digesta from the yak rumen stays comparatively constant, ranging from 11.5 percent to 14.9 percent per hour. Total volatile fatty acid (VFA) production in the yak rumen increases with the animal's age. The proportions of propionic acid and butyric acid to total VFA in the yak are higher than those in other ruminants.

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The concentration of NH_3-N in the yak rumen varies with the diet composition and feeding behaviour. Mature forages can promote lower NH_3-N concentrations in grazing yak than can young forages. Both feed type and feeding behaviour affect degradability of dietary nutrients in the yak rumen.

Energy nutrition

Lactating yak cows have better utilization of dietary energy than dry yak cows when they are given oat hay at the same level under indoor feeding conditions. An increased feeding level leads to the decreased digestibility of dietary energy in dry cows. The thermoneutral zone of the growing yak is estimated as 8° - 14°C. The fasting heat production (FHP) of the growing yak can be estimated as FHP = 916 kJ per kg$W^{0.52}$ per day. The metabolizable energy requirement for maintenance (ME_m) in growing yak is around 460 kJ per kg $W^{0.75}$ per day. Metabolizable energy requirement in the growing yak can be estimated as: ME (MJ per day)=$0.45W^{0.75} + (8.73 + 0.091\ W)\ \Delta G$ (ΔG is kg per day).

Protein nutrition

There is no difference in the digestibility of dietary nitrogen between lactating and dry cows. A relatively lower excretion of endogenous urinary nitrogen in yak suggests the possibility that the animal has evolved a mechanism to recycle more nitrogen to the rumen than ordinary cattle.

Yak can use non-protein nitrogen as efficiently as other ruminants. The endogenous purine derivative excretion in the yak is only 40 percent of that in cattle but is similar to that in buffaloes. The value of creatinine excretion for the yak when fasting is much lower than for buffaloes and cattle. Rumen degradable crude protein requirement for maintenance ($RDCP_m$, g per day) in growing yak is around $6.09W^{0.52}$ g per day. The crude protein requirements for daily gain (ΔG $RDCP_g$ g per day) in growing yak can be estimated as $RDCP_g = (1.16/\Delta G + 0.05/W^{0.52})^{-1}$. Thus the total crude protein requirement of growing yak could be calculated as RDCP (g per day) = $6.09W^{0.52} + (1.16/\Delta G + 0.05/W^{0.52})^{-1}$.

Mineral nutrition

Mineral nutrition is poorly documented. But the existing information suggests that mineral deficiencies may occur, varying from one yak-raising area to another. Seasonal deficiency of specific elements could be a common issue throughout the Plateau owing to an uneven seasonal supply of feeds. Mineral and trace element deficiencies can cause some problems to yak, but appropriate supplementation will generally improve the conditions.

Feeding

Forages on natural grassland are in surplus in summer but deficient in winter under the traditional grazing system. The nutritional status of yak can be improved by ensuring adequate protein intake in summer – but yak suffer deficiency of crude-protein and of energy from grass in winter. The use of feed supplements seems vital if the productive and reproductive potentials of grazing yak cows on the Qinghai-Tibetan Plateau are to be developed. Concentrate and urea block supplements are effective in improving the productivity of grazing yak and maintaining the body weight of animals in winter.

Introduction

The yak, like other grazing ruminants, has a highly developed and specialized mode of digestion that has evolved to maximize the utilization of carbohydrates from cellulose (Van Soest, 1987) and thus allow better access to energy in the form of fibrous feeds than that occurring in the non-ruminant herbivores. The yak has adapted, uniquely among cattle, not only to the high cellulose diet of the Qinghai-Tibetan Plateau but also to its extremely harsh climate and, as a result, has developed nutritional and metabolic features that probably differ from those of other cattle species. Yak nutrition is, however, poorly documented compared with some other aspects of yak science, such as biology and ecology characteristics, productive and reproductive performances and aspects of breeding and interspecies hybridization. Knowledge of yak nutrition has been very limited owing to the remoteness and poor infrastructure of yak territories, difficulties of on-farm research and lack of scientific information exchanges.

Until the 1990s, most of the research on digestion and metabolism of protein and energy, as well as supplementation strategies, had been conducted by the Yak Nutrition Research Group of Qinghai Academy of Animal Science and Veterinary Medicine, whose findings were collected in the publication *Recent advances in yak Nutrition* (Hu, 1997). Other researchers (Gansukh, 1997; Long *et al.*, 1997, 1998, 1999; Dong *et al*., 1997, 2000a,b; Shi *et al.*, 1997) have made contributions to the better understanding of the feeding and nutrition of the yak. Although some nutrition and feeding habits of yak still remain unclear, compared to those of ordinary cattle, the results have been used to improve yak performance on the farm. It is considered that a satisfactory performance of the indigenous animals could be achieved by effective nutritional intervention in the harsh ecological zones.

The aims of this chapter are: (i) to summarize the current advances in yak nutrition research as contained in various scientific reports and (ii) to suggest future research requirements for establishing better guidelines for yak-feeding systems.

Feed Intake

As already noted in Chapter 13, voluntary intake (VI) of the yak varies with the season and sward heights, from 18 to 25 kg of fresh forage in summer to 6 to 8 kg per day, or even much less, of wilted grass in cold-season grazing conditions. Other factors affect the intake levels, including feed types, feeding conditions, environmental climate, as well as age, size and sex of the animal.

Feed types

Han *et al.* (1990a) fed castrated yak (two to three years old) in barns seven diets and found that the dry-matter intake (DMI) of roughage decreased with the increasing content of concentrates in the diets (Table 14.1). Dong *et al.* (2000a) studied the digestion and metabolism of protein and energy in lactating yak given different diets and found that concentrates in the diets decreased the DMI of yak. Preference for fibrous feeds may result in higher intakes of roughages than of concentrates by yak, and a relatively faster passage of high-quality roughage (such as oat hay) leads to reduced mean retention time of digesta (Han, 1996) and thus results in higher intake. In both studies, the authors stated that the intakes of yak were less than those of other cattle, possibly because of the smaller rumen capacity of yak (Liu, 1991).

Feeding conditions

Liu et al. (1997) reported that the DMI of two-year-old yak (as a percentage of body weight) varied from 3.7 percent in the late growing period of forages to 3.4 percent in the mature period under grazing conditions, while that of three-year-olds ranged from 3.7 percent to 3.1 percent. Feed intake per unit of body weight under grazing was greater than in the indoor feeding. Possibly unsuitable housing and restriction to a given diet may be the main factors that reduced the feed intake of the indoor-fed yak.

Climate

Climatic factors, especially temperature, have a profound effect on feed intake and digestibility in the yak. Growing yak increased their intake levels at lower temperatures irrespective of whether they were feeding indoors (Han *et al.*, 1990a) or grazing on natural pasture. The faster rate of passage of feed particles at lower temperatures (Liu *et al*., 1997) would provide more rumen space to be filled by food.

Greater milk production on cold, cloudy days (cf. Chapter 6) may be partly attributed to the higher forage intakes of lactating yak on such days. The yak can feed normally on grasslands when the temperature is as low as -30° to -40°C, or even lower in a harsh winter. In contrast, the yak moves and grazes less at higher temperatures (cf. Chapter 4), and, consequently, feed intake falls.

Age, size and sex of yak

As shown in Table 14.2, the DMI varies with the age and size (body weight) of the yak. There is a good linear correlation between the DMI of yak and their body weight (W) or metabolic body weight ($W^{0.75}$ or $W^{0.52}$). Han *et al.* (1990a) found it was much better to use body weight than metabolic body weight to estimate the DMI for growing yak. On this basis, Liu *et al.* (1997) deduced the equation: DMI (kg per day) = 0.0165 W + 0.0486 (r = 0.959) for growing yak.

Table 14.1 Dry-matter intakes of growing yak from various diets under indoor feeding (± SD) [Source: Han *et al.*, 1990a]

Diets	No. of animals	Body weights (kg)	Daily intakes (kg)	Intake/body weight ratio	Environmental temperature (°C)
87% Concentrate + 13% wheat straw	6	134.1 ± 33.7	3.1 ± 0.87	0.023 ± 0.001	14.2
48% Concentrate + 52% wheat straw	8	159.3 ± 31.3	3.4 ± 0.52	0.022 ± 0.001	14.2
28% Concentrate + 72% wheat straw	8	166.5 ± 31.6	3.0 ± 0.58	0.018 ± 0.001	11.6
40% Fresh grass, 40% fresh bluestem and 20% fresh alfalfa	4	178.3 ± 36.4	3.7 ± 0.37	0.022 ± 0.002	16.7
Oat hay	10	145.2 ± 30.7	3.4 ± 0.88	0.024 ± 0.005	– 6.1
Oat straw	10	145.2 ± 30.7	3.4 ± 0.70	0.024 ± 0.003	– 5.8
Wheat straw	10	145.2 ± 30.7	2.0 ± 0.49	0.014 ± 0.002	– 4.3

For lactating yak, extra feed is needed to meet requirements for milk yield. Therefore, milk production must be taken into account when calculating DMI. The following equation (Dong *et al.*, 2000a) can better describe the relationship: $DMI=0.008W^{0.52}+1.369Y$ (where Y is kg per day of standard milk of 4 percent fat content [r=0.992]).

Table 14.2 Feed intake of grazing yak on natural grassland at various growth stages of forages (±SD) [Source: Liu *et al.*, 1997]

Growth stage of forage	Age of animal	No. of animals	Body weight (kg)	Daily DMI		
				kg	g/kg $W^{0.52}$	g/kg $W^{0.75}$
Premature	2 year	7	115.3 ± 2.7	3.9 ± 0.32[a]	311.9	111.4
	3 year	7	154.4 ± 1.4	6.0 ± 0.82[b]	418.5	131.3
Mature	2 year	7	125.9 ± 2.3	3.8 ± 0.53[a]	300.9	98.9
	3 year	7	168.1 ± 1.1	5.8 ± 0.45[b]	393.5	121.0

Note: Means with different superscripts are significantly different (P<0.01).

Feed digestion and metabolism in the rumen

For ruminants, a number of factors, including gastrointestinal size and capacity, rumen fill, rumination, digestive capacity, absorptive gut surface and quality of available forage affect feeding strategy (Van Soest, 1987). Yak, standing apart from other ruminants, have their own rumen characteristics and digestive capacity under different feeding strategies.

Rumen volume

Liu *et al.* (1991) determined the volume of the yak rumen contents (l) by using polyethylene glycol (PEG) as a marker and found that for a yak of 150 kg body weight, the rumen content varied from 32.3 to 35.8 l (Table 14.3). When the rumens of these animals were filled with water after slaughter the mean-water content was 34.8 l (Liu *et al*., 1991). The maximum size of the yak rumen, reported by Liu Haibo (1989), was approximately 66.8 l. Compared with cattle, yak had a much smaller rumen volume (Liu *et al*., 1991; Han, 1990a).

Table 14.3 Rumen fluid content of yak and outflow rate of rumen fluid (±SD) [Source: Liu *et al.*, 1991]

Animal identity	Body weight (kg)	Outflow rate of rumen fluid (l/h)	Rumen content by using PEG (l)		Rumen content by filling with water (l)
			Mean ± SD	C.V.	
A	129	3.1±0.48	33.2 ± 2.4	7.2	34.8 (mean)
B	117	3.4±0.16	32.3 ± 1.4	4.5	
C	196	3.1±0.16	35.8 ± 0.2	0.6	
D	156	3.5±0.48	33.8 ± 1.8	5.3	

Outflow rate of rumen fluid and digesta

Outflow rate of rumen contents is positively correlated with the protein degradability but negatively correlated with the synthesis of microbial protein in the rumen. Many factors, such as feed availability, air temperature, composition of diet, state of feed (solid or liquid) and size of feed particles, can affect the outflow rate (Han *et al.*, 1996).

Table 14.4 shows that dietary intake is positively related to the outflow rate of rumen fluid. A lower outflow rate of rumen fluid with a higher proportion of roughage in the diets indicated that lower quality feeds required more time to be fermented and degraded in the rumen (Han, 1996). The relatively higher intakes under grazing conditions may lead to faster outflow of rumen fluid than under indoor-feeding conditions (Han, 1996). No effects of the level and source of dietary nitrogen on the outflow rate of rumen fluid were observed in yak, although a quicker outflow of rumen fluid with increasing levels of nitrogen in the diet occurred in buffalo (Han, 1990a).

Table 14.4 Outflow rate of rumen fluid and digesta in yak fed with various diets under indoor feeding (±SD) [Source: Han *et al.*, 1996]

Diets	No. of animals	Dry-matter intake (kg/d)	Outflow rate of rumen fluid (%/h)	Outflow rate of digesta (%/h)
CP* level in diet (%)				
8	4	2.8 ± 0.02^{Ab}	10.3 ± 3.3^{A}	13.3 ± 0.9^{a}
12	4	2.7 ± 0.18^{Ab}	9.0 ± 0.9^{A}	13.9 ± 0.6^{a}
Roughage: concentrate ratio				
7:3	3	2.7 ± 0.15^{Ab}	10.4 ± 0.5^{A}	11.8 ± 0.9^{a}
5:5	3	2.8 ± 0.11^{Ab}	12.6 ± 0.8^{A}	14.9 ± 1.8^{a}
3:7	3	1.7 ± 0.36^{Bd}	3.9 ± 0.9^{B}	12.8 ± 0.8^{a}
Source of nitrogen				
Rapeseed cake	3	2.3 ± 0.64^{c}	9.8 ± 3.6^{A}	14.7 ± 1.7^{a}
Pea	3	2.3 ± 0.56^{c}	8.6 ± 3.4^{A}	13.7 ± 1.2^{a}
Bean	3	2.7 ± 0.31^{Ab}	8.5 ± 4.1^{A}	11.5 ± 1.2^{a}

Note: Within columns, the means with different superscript capital letters are significantly different at P<0.01; the means with different lower case superscripts are different at P>0.05.

*CP = crude protein

Outflow rate of rumen fluid in the study of Liu *et al.* (1991) ranged from 3.1 to 3.5 litres per hour, somewhat lower than in cattle.

Irrespective of the composition of the diet, nitrogen level and source, and feed intake, the outflow rate of digesta from the yak rumen remains comparatively constant, ranging from 11.5 to 14.9 percent per hour (Table 14.4).

Volatile fatty acid production

Production of volatile fatty acid (VFA), an original energy substrate, can reflect the fermentative capacity of the rumen. This fermentative capacity is determined to a considerable degree by dietary composition and, therefore, is greatly influenced by feeding behaviour (Van Soest, 1987). The effect of dietary composition and feeding level on fermentation in the yak rumen under indoor-feeding conditions was reported by Xie *et al.*, (1992). According to this report, the production of propionic acid and ratio of acetic acid to propionic acid for a maintenance diet (72 percent of concentrate and 28 percent of roughage, and the intake just meeting maintenance requirements) were significantly lower than those of a roughage diet eaten to appetite (22 percent of concentrate and 78 percent of roughage). The production of total VFA and acetic acid from a concentrate feed eaten to appetite (44 percent of concentrate and 56 percent of roughage) were greater than those from the roughage feed, but the ratios of acetic acid to propionic acid of these two feeds were similar (Table 14.5). A difference in fermentation was observed between indoor feeding and grazing conditions by Liu *et al.* (1992). Yak grazing fresh forages in the early growing period of grassland produced more total VFA and propionic acid than yak fed indoors with a mixture of concentrate and wheat straw and yak grazing withered and wilted forages. And total VFA production in the rumen was higher for indoor-fed yak than for yak grazing on withered and wilted forages. It was found in both reports that the production of the more efficient energy sources, propionic and butyric acids, were higher in the yak than in other ruminants, such as cattle, deer, goats and buffalo, regardless of whether the animals were fed indoors or grazing. Gansukh (1997) working with yak calves between the ages of 30 and 120 days found that the average amount of total VFA frequently increased with age.

NH_3-N concentration

NH_3-N (ammonia nitrogen), one of the fermentative products of feed in the rumen, is the source of microbial protein. As with VFA production, the concentration of NH_3-N in the yak rumen varied with diet composition and feeding behaviour. Bi *et al.* (1989) found that more NH_3-N can be provided for grazing yak by alpine steppe (dominated by grass) than by alpine meadow (dominated by sedges). According to Yan (2000), mature forages can provide less NH_3-N to the grazing yak than the young forages. Xie *et al.* (1989) reported no significant difference in rumen NH_3-N concentration between two- and three-year-old yak under indoor-feeding conditions, although the values were lower than those from yak grazing on the alpine steppe and higher than those from yak grazing on the alpine meadow as already described.

Dry matter and protein degradability

Nutrient degradability in the yak rumen varies with the type of feed and feeding behaviour. Xie *et al.* (1990) determined *in sacco* degradability of several protein feeds in the yak rumen under indoor feeding and grazing conditions (Table 14.6). The crude protein degradability of plant materials was significantly higher than that of animal materials, and fishmeal and bone meal had higher crude protein degradability than blood meal among animal materials.

Both dry-matter and crude-protein degradability of bone meal and sesame cake were higher under grazing than under indoor feeding, although no significant differences between feeding situations were observed among other feeds.

Table 14.5 Volatile fatty acid production in the yak rumen at various indoor feeding levels (1×10^{-2} mol/l) ($\pm$SD) [Source: Xie *et al.* 1992]

VFA	Maintenance feed (72 % of concentrate & 28% of roughage)	Roughage feed (22% of concentrate and 78% of roughage, voluntary intake)	Concentrate feed (44% of concentrate and 56% of roughage, voluntary intake)
Total	3.4 ± 0.68^{A}	3.4 ± 0.30^{A}	4.1 ± 0.51^{A}
Acetic acid	1.6 ± 0.35^{A}	1.5 ± 0.13^{A}	1.7 ± 0.21^{B}
Propionic-acid	0.8 ± 0.12^{A}	1.0 ± 0.10^{B}	1.2 ± 0.18^{B}
Butyric-acid	0.8 ± 0.21^{A}	0.7 ± 0.06^{A}	1.0 ± 0.11^{A}
Acetic/ Propionic	2.0^{A}	1.5^{B}	1.5^{B}

Note: Within rows, the means with different superscripts are significantly different (P<0.01); means with the same superscripts are not different (P>0.05).

Energy nutrition

Dietary energy digestion and metabolism

Differences in the efficiency of the utilization of dietary energy are due to the gastrointestinal capacity for fermentation and the proportion of the diet that is catabolized in that fermentation (Van Soest, 1987). The former depends on animal characteristics that include sex, age and physiological state (growth, lactation, etc.), and the latter is highly related to diet composition and feeding level.

Long *et al.* (1998) observed that lactating yak had better utilization of dietary energy than dry yak cows when they were fed at the same level with oat hay under indoor-feeding conditions. A further study with lactating yak (170 - 200 kg) conducted by the same authors indicated, however, that yak cows had a lower efficiency of metabolizable-energy utilization for milk production (averaging 0.46) than dairy cattle and this in turn suggests that it may be one of the features of energy metabolism developed by the yak under long-term natural selection to concentrate the available energy to withstand the harsh environment and thus ensure survival.

Table 14.6 Dry matter (DM) and crude protein (CP) degradability of various feeds in the yak rumen under indoor feeding and grazing conditions [Source: Xie *et al* 1990]

Feeds		Feeding situation	DM degradability (%)		CP degradability (%)	
			Mean	CV[1]	Mean	CV[1]
Plant materials	Soybean cake	Indoor feeding	94.4	3.4	93.1	3.9
		Grazing	91.2	5.3	90.2	5.5
	Rapeseed cake	Indoor feeding	88.9	0.16	88.2	0.71
		Grazing	88.2	0.68	96.5	0.21
	Sesame cake	Indoor feeding	94.3	0.53	97.9	0.34
		Grazing	87.0	1.4	94.9	1.1
	Average		90.4		93.6	
Animal materials	Bone meal	Indoor feeding	46.4	4.5	83.8	1.5
		Grazing	41.4	1.8	75.3	1.2
	Fish meal	Indoor feeding	60.7	7.8	74.8	8.0
		Grazing	60.6	7.8	69.5	9.5
	Blood meal	Indoor feeding	34.9	15.2	38.2	39.1
		Grazing	34.5	16.4	28.1	24.7
	Average		46.4		61.6	

[1] CV = coefficient of variation

Table 14.7 Features of the energy metabolism of yak fed on various diets [adapted from Han *et al.* 1990]

Trial	Yak (3 per group)		Intake (DM)		Energy (MJ/d)					Percentages of GE						ΔG/d
	Age	BW	Conc.	straw												
	(yr.)	(kg)	(kg)	(kg)	GE	FE	UE	CH_4E	HP	DE	UE	CH_4E	ME	HP	RE	(kg)
I	2	86-93	0.45	0.40	14.4	5.7	0.24	1.3	11.8	60	1.7	8.8	49	80	-31	-0.26
	3	128-151	0.84	0.40	20.8	7.5	0.46	1.8	15.8	64	2.2	8.8	53	75	-22	-0.47
II	2	86-94	1.00	0.40	23.5	7.4	0.47	1.7	11.8	68	2.0	7.4	59	50	9	0.16
	3	120-143	1.68	0.40	34.7	10.2	0.89	2.6	15.9	71	2.6	7.5	61	46	15	0.20
III	2	87-96	1.40	0.40	30.1	8.7	0.58	2.1	13.9	71	1.9	7.0	62	46	16	0.19
	3	124-156	2.52	0.40	46.5	14.1	1.10	3.4	20.7	71	2.3	7.0	62	43	19	0.57
IV	2	93-103	1.80	0.40	36.7	11.5	0.69	2.5	16.9	69	1.9	6.9	60	46	14	0.39
	3	133-166	3.36	0.40	62.4	15.5	1.11	1.1	25.5	75	1.8	6.6	67	41	26	0.71
V	2	99-109	2.20	0.40	43.0	10.0	0.44	2.8	21.8	77	1.0	6.6	69	51	18	0.35
	3	145-177	4.20	0.40	75.1	17.0	0.83	4.2	35.4	77	1.1	5.6	71	47	24	0.65

BW, Bodyweight; Conc, Concentrate; Straw, Wheat straw; GE, Gross energy content of diet; FE, Faecal energy; UE, Urine energy; CH_4E, Methane energy; HP, Heat production; DE, Digestible energy; RE, Retained energy; ΔG/d, daily weight gain.

Table 14.7 demonstrates that shifting the dietary proportions of concentrate and wheat straw has a profound effect on efficiency of feed energy utilization in growing yak. The ratios of retained energy in body tissues to gross energy content of diet range from minus 31 percent to plus 26 percent when changing animal diet from I (lowest amount of concentrates) to V (highest amount of concentrates). The lower metabolic hormone levels of growing yak reflected a slower growth rate related to an adverse eco-environment (Han, 1994). Another experiment (Dong *et al.*, 2000b) indicated that digestibility of dietary energy decreased by 2.9 - 6.8 percent with increasing forage feeding levels in dry cows.

Fasting heat production

Basal metabolism is generally defined as the heat production of a completely quiescent animal in a post-absorptive state, within a thermoneutral environment. Although this state can be achieved with human beings, it is extremely difficult to achieve with animals like the yak. Consequently, the term "fasting metabolism" has been adopted for them. Table 14.8 shows a profile of fasting heat production (FHP) (kJ per kg $W^{0.75}$ per day) in growing yak that remained fairly constant compared to that in the Qinghai yellow cattle. The comparatively stable FHP in yak may be related to the ability of yak to take in more oxygen, particularly at the higher altitudes (see Chapter 4). At the elevation of 2 261 m, the absolute FHP for the growing yak was higher than that of the growing Qinghai yellow cattle, but the reverse was the case at higher altitudes. Clearly, basal metabolism of animals living at higher elevations, like the yak, is lower than that of animals living at lower elevations. In Table 14.8, there is a significant difference between age groups in both yak and Qinghai yellow cattle (i.e. the FHP value for a one-year-old calf is higher than that for a three-year-old heifer). This difference is also found in other species of animals.

Hu (1994) suggested that the respiratory quotient (RQ) of the growing yak determined by metabolism significantly declined with increasing altitude, from 0.744 (2 261 m) to 0.696 (3 250 m) and 0.545 (4 272 m). But with no significant difference among age groups, the values less than 0.7 indicate disordered metabolism (perhaps ketosis). Lower atmospheric pressure and oxygen contents in the air at higher altitudes may be the main factors that lead to reductions in the respiratory quotient of growing yak. Corresponding information from other species would be interesting but appears not to be available. Hu (1994) also indicated that ambient temperature has a great effect on FHP and other physiological indices in the yak (see Tables 14.9 and 14.10). But the FHP remained fairly constant and, correspondingly, the body temperature, heart rate and respiratory rate of yak were stable in the environmental temperature range of 8° - 14°C. So the thermoneutral zone of the yak was estimated as 8° - 14°C (see Chapter 4).

Further work by Hu (1994 and 1997) on the measurement of the relationship of bodyweight (W) and surface area of the growing yak, by using the method of plaster (pasting paper) on the animal's body, showed that the highest correlation existed between surface area and $W^{0.52}$. An equation of FHP = 916 kJ per kg $W^{0.52}$ per day (n=25 r=0.8469, P<0.01) was obtained.

In the light of the equation, Hu concluded that yak calf's FHP value is clearly lower than that of the dairy cattle calf and Holstein heifer and that the heat lost per 1 kg $W^{0.52}$ from yak is lower than for other cattle species. The lower fasting heat production of the yak and its stability at different altitudes are probably an adaptive response to life in an alpine-cold and oxygen-depleted environment and to the nutritional deprivation that yak experience in winter and spring. These features could be the result of long-term natural selection.

Table 14.8 The fasting heat production (FHP, KJ per kg $W^{0.75}$ per day) of growing yak and cattle at different altitudes in summer [Source: adapted from Hu, 1994]

Height above sea level (m)	Age (months)	Yak			Qinghai yellow cattle		
		n	BW*(kg)	FHP	n	BW*(kg)	FHP
2 261	12	3	49.9	351.5	3	98.4	292.4
3 250	12	3	44.6	328.8	4	102.6	414.4
4 271	12	3	57.7	376.2	3	115.7	516.4
2 261	24	7	99.5	305.3	4	138.5	250.5
3 250	24	4	104.7	321.4	4	143.9	353.3
4 271	24	3	101.8	324.8	3	140.4	387.9
2 261	36	6	141.1	302.2	4	229.5	219.1
3 250	36	4	126.2	327.7	4	238.1	357.4
4 271	36	3	150.1	281.1	3	212.7	359.9

*Bodyweight.

Metabolizable energy for maintenance

The energy requirement for maintenance is a useful term for expressing the level of the exogenous nutrient supply. It is defined as the metabolizable energy (ME) input per day at which the animals are in energy balance. Han *et al.* (1990b; 1991) used a respiration mask method to estimate the metabolizable energy requirement for maintenance (ME_m) in growing yak and found its value to be 460.2 kJ per kg $W^{0.75}$ per day. In the same experiment, the authors also estimated the efficiency of utilization of metabolizable energy for maintenance (k_m) in growing yak to be around 0.66.

Table 14.9 Regression equations between fasting heat production (FHP) and ambient temperature (T °C) [Source: Hu, 1994]

Range of temperature (°C)	*Y=a+bx*	n	*R*	*r* significance
(-30) - (-20)	FHP = 891 - 18.4T	37	-0.2917	P<0.05
(-20) - 0	FHP = 1 188 - 15.5T	40	0.4744	P<0.01
0 - 10	FHP = 1 155 - 13.8T	46	0.2431	P<0.10
8 - 15	FHP = 1 080 + 0.7T	52	0.0066	P>0.10
15 - 23	FHP = 1 017 + 10.5T	48	0.2735	P<0.05

Table 14.10 Critical upper-limit temperature (°C) leading to a rise in physiological indices [Source: Hu, 1994]

Physiological index	Yak	Holstein-Friesian	Jersey	Swiss brown	Indian zebu
Body temperature	14.0	21.1	23.9	26.7	35.0
Heart rate	15.0	32.2	37.8	35.0	37.8
Respiratory rate	13.0	15.6	15.6	15.6	23.9

Energy requirements for standing and walking

As the yak is a grazing animal, two of its most common activities are standing up and moving on. Han *et al.* (1989) compared the energy requirements for standing and walking in yak with those in Qinghai yellow cattle at an elevation of 3 000 m. Table 14.11 shows that the yak (115.3 kg) generates much more heat (J per kg $W^{0.75}$ m) in the course of walking than do the larger Qinghai yellow cattle (170.5 kg) and other cattle or dairy cows. The energy expenditure of the yak is a little higher in the course of standing (V_0) than that of Qinghai yellow cattle. The author attributes the difference in heat production to the difference in body size and breed, as smaller animals are expected to generate more heat during walking (Blaxter, 1962). Table 14.11 also indicates that the higher the speed of moving the more heat is generated both in yak and Qinghai yellow cattle. Correspondingly, the respiratory quotients of the animals in the course of standing and walking with speeds of 1 metre per second or 1.5 m per second are, respectively, 0.68, 0.65 and 0.59 J per kg $W^{0.75}$ per minute for yak, and 0.79, 0.73 and 0.77 J per kg $W^{0.75}$ per minute, respectively, for cattle.

Energy requirements for growth

Han *et al.* (1990b) estimated metabolizable energy requirements for growth (ME_g) in growing yak (n=7) through an energy balance trial on six two- to three-year-old animals by rationing their intakes of concentrate to a series of levels. The daily metabolizable energy requirement of growing yak was estimated as: ME (MJ/d) = $0.45W^{0.75} + (8.73 + 0.091\ W)\ \Delta G$, where W is the body weight and ΔG is daily gain (kg), and the efficiency of utilization of metabolizable energy for growth (k_g) in yak is 0.49.

Such a high value might be considered to apply only to diets rich in concentrates. However, similar results were obtained from other trials when animals were given coarse fodders (Han *et al*., 1992 and Dong *et al*., 2000a).

Table 14.11 Energy expenditure (EE, J per kg $W^{0.75}$ m) of yak and other cattle species moving at various speeds at an elevation of 3000m
[Source: adapted from Han *et al.*, 1989]

Animal	Age (months)	Live weight (kg)	EE in movement by speed (V, m/s) of: $V^*_0=0$	$V_1=1$	$V_2=1.5$	Source
Yak	24 (n=4)	115.3	0.35	1.93	2.35	Han *et al.* (1989)
Qy cattle[1]	24 (n=4)	170.5	0.31	1.48	1.75	Han *et al.* (1989)
Cattle					2.00	Hall&Brody (1934)*
					2.10	Ribeiro (1976)*
Dairy cow					2.00	Ribeiro (1977)*
					2.09	Webster (1978)*
				1.39	1.19	Jiang (1987)*
					2.00	ARC (1980)*

[1]Qy cattle = Qinghai yellow cattle. *J per kg $W^{0.75}$ per minute).
* Quoted by Han *et al*., 1989

Energy requirements for lactation

Data on energy requirements for lactation are still scarce, as only preliminary studies on dietary energy digestion and metabolism in lactating yak have been conducted by a few researchers (Long *et al*., 1998; Dong *et al*., 2000a).

Protein nutrition

The animal needs protein to support its functions, including tissue maintenance, growth of lean tissue, wool and the products of conception and for milk-protein synthesis.