potential to enhance food production

Nine

Background: Sheep grazing on pastoral land, Naqu - *Nyima Tashi*

Top Inset: Winter wheat field in Dailong County - *Nyima Tashi*

Bottom inset: Crop production in Central Tibet (Nimu County) - *Nyima Tashi*

Yaks grazing near Namtso - Nyima Tashi

Chapter 9
Potential to Enhance Food Production

The potential to enhance food production is an important aspect of regional food availability and food security. It can be defined as the maximum amount of food produced from cropping and animal husbandry in ideal conditions, or the potential ability of cropland and rangeland to produce food in a particular eco-region or administrative region. Analysis of the potential for enhancing food production is necessary to plan for food production and food security.

Meticulous and thorough studies of the potential of food production have been undertaken from various perspectives—land productivity, crop productivity, climatic productivity, and carrying capacity of land resources—on different scales, in different regions, and by different methodologies. For several decades, great attention has been paid to the capacity of land resources to support a population. Regardless of the approach, it is important to know what production can be achieved to meet the future demands of an increasing population. Keeping this in mind, analysis of maximum food grain production, maximum yields; carrying capacity of rangeland, and productivity of livestock was performed.

Several studies of potential food production in Tibet have been carried out. Liu Yanghua's (1991) study on potential productivity of cropland and rangeland in the middle reaches of the Yalongzangpo River, where the majority of the Tibetan population is concentrated, looked at the maximum potential yields of crops such as barley and wheat, the potential productivity of cropland, the carrying capacity of rangeland, and the interdependence of land resources, food production, and population. This research became the guideline for integrated development of agriculture in this region. As part of a study of the whole of China, Shang Jiali (1989) estimated the carrying capacity of land resources and estimated the maximum yield of crops in Tibet. The productivity of Tibetan agriculture (Du Jun 1995), the potential productivity of climatic resources for food grain (Wang Xianming 1996), and the potential increase in production from agricultural technology (Deng He 1996) have been discussed. Yang Gaihe (1995) focused on the potential productivity of cropland and rangeland, and the supporting capacity of food production based on the existing area of cultivated land and pastureland. Yu Zhijian (1997) studied the potential of greenhouses in food production and the potential distribution of food produced in them. Other studies focused on resource management and assessment of agricultural productivity and the potential productivity of technology innovation and dissemination (Nyima Tashi 1998a; Yang Yichou 1995).

This study will focus on the spatial differentiation of potential productivity of cropland, potential yields, and rangeland carrying capacity. It aims to identify potential areas for food grain and oilseed production, areas with scope for livestock development, gaps between actual and potential yields for various crops, and constraints to increasing food productivity.

Potential Productivity of Cropland

Potential productivity of cropland has been estimated by a number of scientists using different methods (Dang Anrong 1997; Liu Yanghua 1992). Based on these estimates and county administrative-based data, a GIS was used to map and reclassify the potential productivity of cropland (Figure 9.1).

Figure 9.1 shows the spatial distribution of potential productivity of cropland. Four regions can be identified.

- *High-potential productivity*. This includes three counties along the Nyachu River, four counties in the watershed of the Lhasa River, and three counties in the middle reaches of the Yalongzangpo River. Potential productivity of cropland in these counties is more than 15t ha^{-1} on average. It is the grain bowl of Tibet, producing over 40% of the total grain.
- *Mid-potential productivity*. This includes five counties in Shigatse Prefecture and most of Linzhi Prefecture. Potential productivity of cropland ranges from 10-15t ha^{-1}.
- *Low-potential productivity*. This area includes some counties in eastern Tibet, south-western parts of Shigatse Prefecture, and southern parts of Shannan Prefecture: twenty-six counties in total. Potential productivity is about 5-10t ha^{-1}.
- *Non-cropping area or slight potential*. This includes all of northern Tibet where the average altitude exceeds 4400m. Counties in the southern parts of this region may have land suitable for cropping, but the plots are often extremely small. Most parts have either cropland of less than 5t ha^{-1} of potential productivity or no cropland at all.

All the data were analysed according to food-production systems (Table 9.1) and adminis-

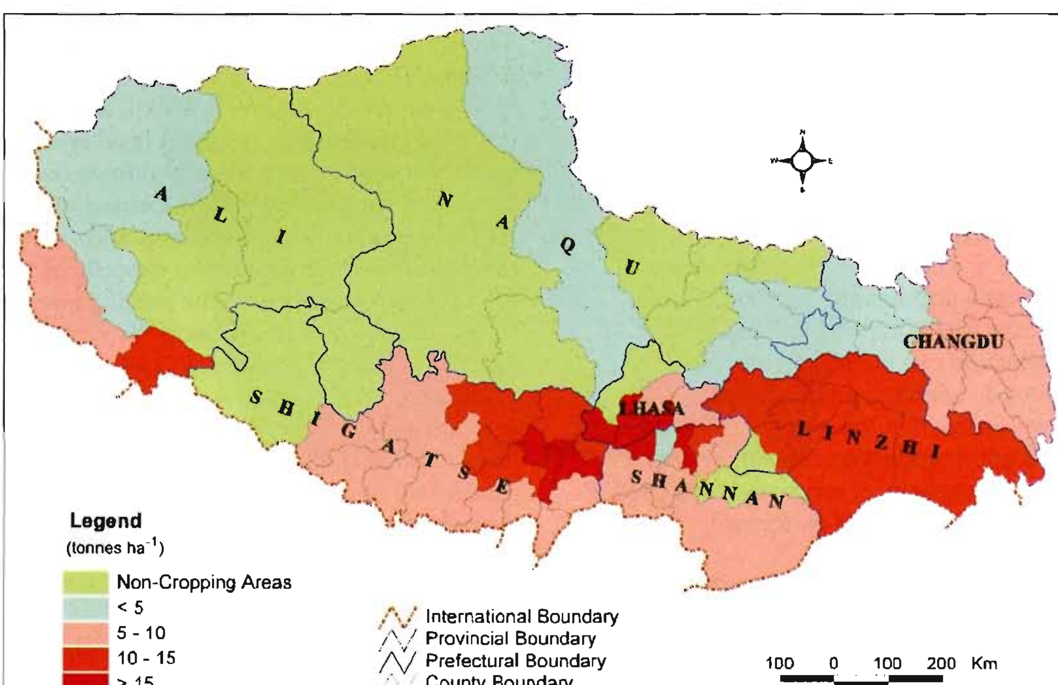

Figure 9.1: **Potential productivity of cropland**

trative prefectures (Table 9.2). The potential productivity of climate (light, temperature, and water) and the potential productivity of cropland (light, temperature, water, and land) were calculated and compared to actual yields.

Table 9.1 suggests that the potential productivity of cropland varies greatly among food-production systems. Crop-dominated zones have greatest potential productivity of both climate and cropland: 24.63t ha^{-1} of potential productivity of climate and 13.35t ha^{-1} of potential productivity of cropland. These figures are 53.2 and 62.6% higher, respectively, than the average. The potential of the pastoral production system zone is 56.5 and 77.9% lower, respectively, than the average.

Actual yields in the crop-dominated production system zone (3.23t ha^{-1}) are 56.7% higher than the average. In the pastoral production system zones, where cropping is practised, yields are only 0.75t ha^{-1}, which is 63.5% lower than the average (Table 9.1 and Figure 9.2).

There is great variation in potential productivity of both climate and cropland among the seven prefectures (Table 9.2). Lhasa Municipality possesses the highest, with potential productivity of both climate and cropland at 24.5t ha^{-1} and 13.4t ha^{-1}, respectively. However, there is hardly any potentially productive cropland in Naqu and Ali prefectures, although some counties, such as Pulan County and Suoxian County, have considerable potential. Shigatse Prefecture could become the future grain bowl of Tibet, with its vast area of cultivated land and reasonably good biophysical conditions for crop production, although water is scarce in

Table 9.1: **Potential productivity (t ha^{-1}) of climate and cropland in food-production systems and comparison with average of Tibet (%)**

	Crop-dominated production system		Agro-pastoral production system		Pastoral production system		Agro-forestry-pastoral mixed production system		Total Tibet
	t ha^{-1}	% from average	t ha^{-1}	% from average	t ha^{-1}	% from average	t ha^{-1}	% from average	t ha^{-1}
Potential productivity of climate	24.63	53.2	12.59	(-21.6)	9.66	(-56.5)	15.79	(-1.7)	16.07
Potential productivity of cropland	13.35	62.6	5.56	(-32.2)	1.81	(-77.9)	9.50	15.7	8.21
Actual yield	3.23	56.7	1.91	(-7.2)	0.75	(-63.5)	2.36	14.5	2.06

Table 9.2: **Potential productivity (t ha^{-1}) of climate and cropland in prefectures and comparison with average of Tibet (%)**

	Lhasa		Changdu		Shannan		Shigatse		Naqu		Ali		Linzhi		Tibet
	t ha^{-1}	% from ave.	t ha^{-1}	% from ave.	t ha^{-1}	% from ave.	t ha^{-1}	% from ave.	t ha^{-1}	% from ave.	t ha^{-1}	% from ave.	t ha^{-1}	% from ave.	t ha^{-1}
Potential productivity of climate	24.54	52.7	13.48	(-16.1)	18.24	13.5	19.01	18.2	5.92	(-63.1)	11.59	(-27.8)	18.35	14.1	16.07
Potential productivity of cropland	13.43	63.5	5.64	(-31.3)	10.35	26.0	9.62	17.1	2.19	(-73.3)	3.99	(-51.4)	12.06	46.8	8.21
Actual yield	2.59	27.5	1.53	(-24.6)	3.09	52.2	2.43	19.7	0.38	(-81.2)	0.93	(-54.1)	2.68	32.0	2.03

Note: The actual yield is calculated based on the standard measurement of area.

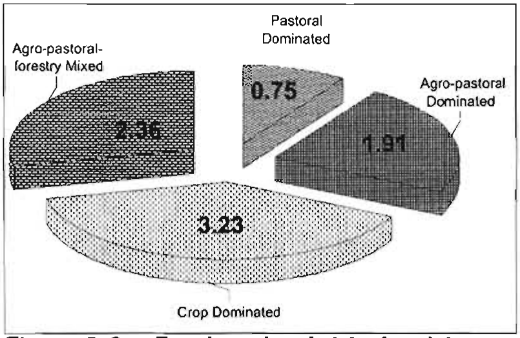

Figure 9.2: **Food grain yield of cultivated land (t ha^{-1})**

some areas. The potential productivity of both climate and cropland are 19t ha^{-1} and 9.6t ha^{-1}, respectively. This is over 17% higher than the average. The so-called grain bowl of Tibet, Shannan Prefecture, produces the highest yield, 52.5% higher than the average. The potential productivity of cropland in this prefecture is 10.35t ha^{-1}, but there is not much room to expand cropland.

Lhasa Municipality possesses the highest potential productivity of cropland, 63.5% higher than the average. Linzhi Prefecture, where there is high potential productivity of the climate, comes second but is confined by a sloping topography that lowers the potential productivity. The rank-order of other prefectures is Shannan, Shigatse, Changdu, Ali, and Naqu. Despite different levels of input on farm land and different crop management, the ranking of actual yield is similar

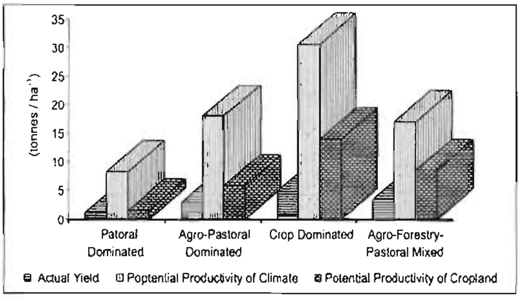

Figure 9.3: **Potential productivity and actual yield of cultivated land in Tibet (t ha^{-1})**

Note: The actual yield is calculated based on the standard measurement of area.

to the ranking of potential productivity, except that Shannan Prefecture is highest and Lhasa Municipality drops to third. This indicates that actual yield is controlled by both potential productivity of cropland and management of the land, including irrigation, inputs, and agronomic practices. There is an obvious need to improve the managerial skills of farmers. If this is accomplished, food grain self-sufficiency could be achieved.

In order to understand the differences between potential productivity of climate and cropland, and actual yield (and the constraints to production), gaps in productivity were calculated for each food-production system. There is a huge gap between potential productivity of climate and cropland, and between potential productivity of cropland and actual yield. It is clear from Figure 9.3 that there are not only big differences among food-production systems but also among parameters.

Table 9.3 elaborates upon this in more detail. It shows that in the crop-dominated production system, the yield gap P1 (the gap between potential productivity of climate and cropland) and the yield gap P2 (the gap between potential productivity of cropland and actual yield) are both high and quite close. This indicates that both land suitability and management constrain food grain production. In the agro-pastoral-forestry mixed production system, yield gap P2 is higher than yield gap P1; this means there is greater potential to increase food grain yield by improving management than by improving land suitability. In the pastoral production system, there is low potential productivity of cropland, and the actual yield is heading towards maximum cropland productivity. In the agro-pastoral production system, yield gap P1 is higher than yield gap P2; this means that land productivity has a greater impact on potential than management. On average, both yield gaps are considerable, signifying that improvement of land suitability, land fertility, and farming management are crucial for increasing food grain production.

Table 9.3: **Productivity and gaps in food-production systems (t ha^{-1})**

Yields and yield gaps	Crop-dominated production system	Agro-pastoral production system	Pastoral production system	Agro-forestry-pastoral mixed production system	Tibet
Potential productivity of climate	24.6	12.6	9.7	15.8	16
Potential productivity of cropland	13.4	5.6	1.8	9.5	8.2
Actual yield	3.2	1.9	0.8	2.4	2.1
Yield gap P1	11.3	7	7.9	6.3	7.9
Yield gap P2	10.1	3.7	1	7.1	6.2

Note: Yield gap P1 = potential productivity of climate minus potential productivity of cropland; yield gap P2 = potential productivity of cropland minus actual yield.

Yield gaps are also estimated for prefectures. Yield gap P2 in Lhasa and Linzhi prefectures is high at 10.8t ha^{-1} and 9.3t ha^{-1}, respectively. In Naqu and Ali prefectures, it is 1.8t ha^{-1} and 3.1t ha^{-1}, respectively. Shannan and Shigatse prefectures are quite similar and yield gap P2 is about 7t ha^{-1} in each case (Table 9.4).

To summarise, Tibet possesses a substantial potential productivity of on average 8.2t ha^{-1}. Estimating from the existing cultivated land, total food grain production could reach 2.67 million tonnes. The total production of food grain in 2,000 was about 1 million tonnes, less than 40% of the estimated potential production of cropland. There is a tremendous gap between the theoretical yield of cropland and the actual production.

Potential Productivity of Crops

The gap between the potential productivity of cropland and the actual average yield is tremendous. Is there any possibility of using more of the potential productivity of climate and cropland? What is the theoretical maximum yield? Which crops can use the potential land productivity most effectively? What are the gaps between managerial levels of cropping? What are the constraints to further increasing food grain production to meet future demands?

Potentially attainable crop yields

In most cropping areas, there is great potential to increase the productivity of land. For the last few decades, agricultural scientists have endeavoured to improve crop yields through innovative technologies, cropping systems, introducing new crop varieties, improvement and application of improved seed and fertiliser, and crop protection. Two important factors have to be considered. One is biological productivity, which is different for different crops and varieties. The other one is the managerial level or economic and technological capability for crop farming, determined by farmers' knowledge, technological innovation, agricultural infrastructure, level of agricultural input, and related policies.

Table 9.4: **Productivity and gaps by prefecture (t ha^{-1})**

	Lhasa	Changdu	Shannan	Shigatse	Naqu	Ali	Linzhi	Total Tibet
Potential productivity of climate	24.5	13.5	18.2	19	5.9	11.6	18.4	16.1
Potential productivity of cropland	13.4	5.6	10.4	9.6	2.2	4	12.1	8.2
Actual yield	2.6	1.5	3.1	2.4	0.4	1.	2.7	2.1
Yield gap P1	11.1	7.8	7.9	9.4	3.7	7.6	6.3	7.9
Yield gap P2	10.8	4.1	7.3	7.2	1.8	3.1	9.4	6.2

Note: Yield gap P1 = potential productivity of climate minus potential productivity of cropland; yield gap P2 = potential productivity of cropland minus actual yield.

In the late 1970s and early 1980s, experiments on high-yielding crop varieties investigated the maximum yield under various management options. Many of the experiments were successful in producing high yields in selected small areas. A few experiments were also carried out on a larger scale or in farmers' fields. For example, Feimai, the high-yielding variety of winter wheat, produced 13t ha^{-1} in a 0.11 ha field in Shigatse at the altitude of 3836m in 1978. Similarly, a variety of spring barley, Ximalaya No 6, yielded 12t ha^{-1} in Shigatse in 1982. Likewise, Oral, a rape seed variety introduced to Tibet from Canada, produced 6t ha^{-1} in Lhasa in 1979 in an experimental plot of 0.08 ha. These experiences suggested that higher yields could be attained through better management and use of high-yielding crop varieties. In the late 1980s and early 1990s, these methods were replicated on a larger scale. High-yielding varieties of spring and winter barley, spring and winter wheat, and rape seed were tested. The main approach was to package the technologies that were already available and demonstrate them to farmers. This work was limited to the middle reaches of the Yalongzangpo River where farm size is relatively large and there are adequate water resources and production conditions.

Regional co-operation for testing newly released varieties of crops such as barley, spring wheat, and rape seed was undertaken in high-altitude regions of the agro-pastoral production system zone and lower altitudes of the agro-pastoral-forestry mixed production system zone. These experiments suggested that crop yields could be increased by using high-yielding varieties and better management.

For the purpose of this study, all data on high-yielding crops in different eco-regions and levels of agronomic management were collected: historical record of highest yield[1], highest yield in experimental plot[2], highest yield in ideal farm land[3], actual yield in 1997[4], and average yield in recent five-year period[5] (Table 9.5).

These data were collected from different sources and may not be truly comparable. However, it is still meaningful to compare them to see in what circumstances a particular crop could produce the highest yield.

In the crop-dominated production system zone, the average historical record of highest yields for grain and rape seed are 12t ha^{-1} and 6.6t ha^{-1}, respectively. The highest yield in experimental plots for grain was 7.7t ha^{-1}, and for rape seed 3.4t ha^{-1}. Actual average yields of grain and rape seed in 1997 were 3.3t ha^{-1} and 1.4t ha^{-1}, respectively. This indicates a yield gap. Similar situations can also be seen in the agro-pastoral production system zone and agro-pastoral-forestry mixed production system zone. In addition, there are big differences between food-production systems influenced by different management and biophysical conditions. All yields in the crop-dominated production system are much

[1] Historical record of highest yield is the yield of a crop variety produced in one plot under best conditions and management in each zone. The minimum experimental area was 30 m^2.

[2] Highest yield in an experimental plot is the average yield of a crop variety produced in a minimum of three plots under best conditions and management in each zone. Different crops were tested in each zone. Each crop was planted in a plot of 30 m^2 in replicates of three. All varieties used were newly released cultivars.

[3] Highest yield in ideal farm land is the yield of a crop variety produced under ideal farm land and management conditions in each zone. The result was obtained by the farmer's own management supervised by a scientist. The minimum area was over 666.66 m^2. The ideal farm land was located on flat river-bank with fertile soil and access to irrigation.

[4] Actual yield was the yield of a crop in 1997 in each zone with the farmer's normal level of management.

[5] Average yield in recent five-year period is the average crop yield in recent five-year period in each zone using the farmer's management.

higher than the average in Tibet, while the agro-pastoral production system has much lower yields than the average (Table 9.5).

To summarise, maximum crop yields have been attained in various circumstances. Compared with actual crop yields, there is great potential to attain much higher yields and to increase grain and rape seed production. To attain potential maximum yields in practice, it is important to see why there is a gap, what the constraints are, and how to close the gap.

Potential for increasing crop yields

Generally, there are three possibilities for increasing production. The first is to expand cropping land or the sown area of crops, the second is to increase cropping intensity, and the third is to improve the per unit crop yield. At present, there is little scope for expanding cropping land because of poor economic capability. Intensification of cropping is also not possible on a large scale at the moment owing to low temperatures, technological limitations, and financial incapability. Increasing the per unit yield is possible and has great potential.

If it is assumed that potentially attainable crop yields can be obtained, then the yield gaps between different levels of management and the maximum potential can be defined as the potential for increasing crop yields, as illustrated by Figure 9.4. The yield gaps derived in Table 9.6 were based on the approach of Figure 9.4.

Yield Gap 2 for both food grain and oilseed production is highest in the crop-dominated production system: 4.3t ha^{-1} and 3.2t ha^{-1}, respectively (Table 9.6). This indicates that

Table 9.5: **Yield changes at different management levels (potentially attainable yields) food-production system (t ha^{-1})**

Productivity	Average grain yield							Average rape seed yield						
	Crop-dominated production system		Agro-pastoral production system		Agro-forestry-pastoral mixed production system		Average	Crop-dominated production system		Agro-pastoral production system		Agro-forestry-pastoral mixed production system		Average
	Crop yield (t ha^{-1})	Compare with average (%)	Crop yield (t ha^{-1})	Compare with average (%)	Crop yield (t ha^{-1})	Compare with average (%)		Crop yield (t ha^{-1})	Compare with average (%)	Crop yield (t ha^{-1})	Compare with average (%)	Crop yield (t ha^{-1})	Compare with average (%)	
Potential productivity of cropland	14.1	4.6	5.9	(-3.6)	8.6	(-0.9)	9.5							
Historical record of highest yield	12	3.5	5.8	(-2.7)	7.6	(-0.9)	8.5	6.6	1.4	3.6	(-1.4)	4.8	-0.2	5.0
Highest yield in experimental plot	7.7	1.3	4.9	(-1.5)	6.5	0.1	6.4	3.4	0.5	2.2	(-0.7)	3.2	0.3	2.9
Highest yield in ideal farmland	6.2	0.5	4.7	(-1)	6.2	0.5	5.7	2.4	0.3	1.9	(-0.2)	2.1	0	2.1
Average yield in 1997	3.3	0.1	2.8	(-0.5)	3.3	0.2	3.1	1.4	0.2	1.2	(-0.1)	1.4	0.1	1.3
Average yield in recent five-year period	3.1	0.3	2.1	(-1.0)	3.1	0.3	2.8	1.3	0.1	1.1	(-0.1)	1.2	0.0	1.2

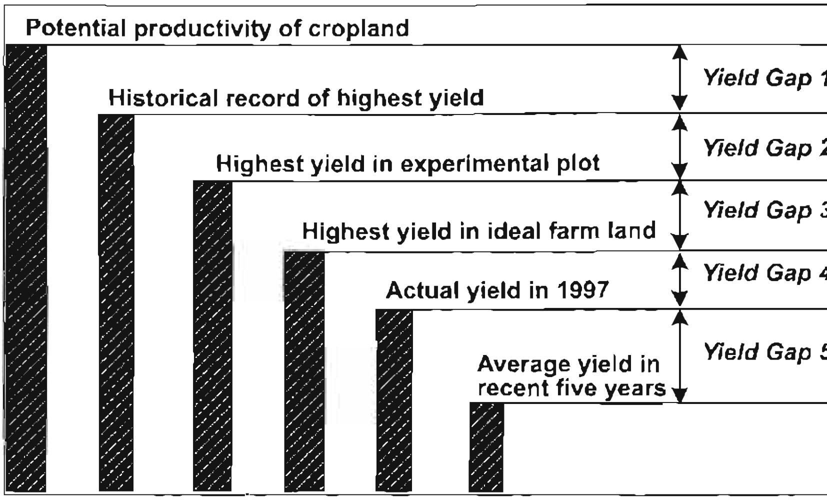

Figure 9.4: **Yield gaps**

breeding for high-yielding varieties or using high-yielding varieties with the best possible crop practices has great potential to boost crop yields in this area. Yield Gap 4 (the yield gap between the highest yield in ideal farm land and the actual yield in 1997) is high in all three food-production areas. This indicates that improvements in farm management and the quality of farm land are keys for increasing per unit yield of crops.

The yield gaps can be analysed as constraints to increasing yield. Yield Gap1 can be seen as the biological constraint, Yield Gap 2 as the technological constraint, Yield Gap 3 as the result of cultivation limitations and varietal selection, and Yield Gap 4 as farm-management constraint and poor quality of farm land. Yield Gap 5 is affected by the agricultural production level over time. In Tibet, poor management and poor quality of cropland are the most crucial factors that constrain increases in food grain and oilseed production.

Attainable crop yields

Attainable yields and yield gaps for crops in each food-production system were analysed. The yield that is attainable differs not only among food-production systems but also among crops.

Table 9.6: **Potentially increasable yields of food grain and oilseed (t ha^{-1})**

	Average food grain yield				Average oilseed yield			
	Crop-dominated production system	Agro-pastoral production system	Agro-pastoral-forestry mixed production system	Average in Tibet	Crop-dominated production system	Agro-pastoral production system	Agro-pastoral-forestry mixed production system	Average in Tibet
Yield gap 1	2.1	0.1	1	1				
Yield gap 2	4.3	0.9	1.1	2.1	3.2	1.4	1.6	2.1
Yield gap 3	1.5	0.2	0.3	0.7	1	0.3	1.1	0.8
Yield gap 4	2.9	1.9	2.9	2.6	1	0.7	0.7	0.8
Yield gap 5	0.2	0.7	0.2	0.3	0.1	0.1	0.2	0.1

In the crop-dominated production system, potential productivity of cropland is about 14.1t ha^{-1}. The historical record of highest yield of food grain crops is about 12t ha^{-1}, of which 9.5t ha^{-1} was for spring barley, 9.8t ha^{-1} for winter barley, 14.1t ha^{-1} for spring wheat, and 14.8t ha^{-1} for winter wheat. The historical record of highest yield for rape seed is 6.6t ha^{-1} from a variety of canola from Canada. Over 7t ha^{-1} is commonly attained in experimental plots of barley and wheat. With promotion of standardised cultivation, more than 6t ha^{-1} of barley and wheat, and 2.4t ha^{-1} of rape seed are produced in many areas. However, the actual average yields of cereals and rape seed in 1997 were only 3.3t ha^{-1} and 1.4t ha^{-1}, respectively (Table 9.7).

Yield Gap 2 is the largest: 4.3t ha^{-1} on average for barley and wheat, and 3.3t ha^{-1} for rape seed. Yield Gap 4 is high in all situations. Therefore, improvements in crop variety selection, level of farm management, and quality of farm land can potentially increase crop yields.

In the agro-pastoral production system zone, there is hardly any winter barley or winter wheat. Spring barley is the predominant crop. In the lower valleys, spring wheat is also cultivated. Rape seed is often grown with peas. The potential attainable yield is much lower than in the crop-dominated production system zone. Historically, spring barley and spring wheat have produced maximum yields of 5.4t ha^{-1} and 6.2t ha^{-1}, respectively. Rape seed has yielded about 3.6t ha^{-1} in some areas in certain conditions. However, the actual average yields in 1997 were low: 2.8t ha^{-1} for food grain and 1.2t ha^{-1} for rape seed (Table 9.8).

The yield gap between the highest yield from ideal farm land and the actual average yield in 1997 (Yield Gap 4) is the largest. Relatively poor management and quality of farm land are the dominating factors that constrain increases in yield in this area. Land levelling, improving soil fertility, technology extension, such as improved varieties, fertiliser, and promotion of irrigation systems, are crucial for improving per unit yields. Biologically, there is considerable potential for both food grain and oilseed production. Using improved varieties and the package approach of technology extension will substantially improve per unit yield.

In the agro-pastoral-forestry mixed production system, it is possible to grow all food grain and oilseed crops. Winter wheat and winter barley are the dominant crops. Spring wheat and spring barley are distributed in either high altitude areas or low altitude areas

Table 9.7: **Crop yields, attainable yields, and yield gaps in the crop-dominated production system (t ha^{-1})**

Yields and yield gaps	Grain crops				Grain crop on average	Rape seed
	Spring barley	Winter barley	Spring wheat	Winter wheat		
Potential crop productivity					14.1	
Historical record	9.5	9.8	14.0	14.8	12.0	6.6
Highest yield from experimental plot	7.2	7.3	7.1	9.0	7.7	3.4
Highest yield from ideal farmland	5.8	5.3	5.4	8.4	6.2	2.4
Average yield in 1997	2.9	3.1	2.9	4.1	3.3	1.4
Average yield in recent five-year period	2.6	2.9	2.9	4.1	3.1	1.3
Yield gap 1					2.1	
Yield gap 2	2.3	2.5	6.9	5.8	4.3	3.2
Yield gap 3	1.4	2.0	1.7	0.6	1.5	1.0
Yield gap 4	2.9	2.2	2.5	4.3	2.9	1.0
Yield gap 5	0.3	0.2	0.0	0.0	0.2	0.1

Table 9.8: **Crop yields, attainable yields, and yield gaps in the agro-pastoral production system (t ha⁻¹)**

Yields and yields gaps	Grain crop		Grain crop on average	Rape seed
	Spring barley	Spring wheat		
Potential crop productivity			5.9	
Historical record of highest yield	5.4	6.2	5.8	3.6
Highest yield in experimental plot	4.7	5.1	4.9	2.2
Highest yield in ideal farmland	4.5	4.9	4.7	1.9
Average yield in 1997	2.6	3.0	2.8	1.2
Average yield in recent five-year period	2.0	2.3	2.1	1.1
Yield gap 1			0.1	
Yield gap 2	0.7	1.1	0.9	1.4
Yield gap 3	0.2	0.2	0.2	0.2
Yield gap 4	1.9	1.9	1.9	0.7
Yield gap 5	0.6	0.7	0.7	0.1

where it is possible to harvest two or three crops a year. Rape seed is grown in most of the region, but over limited areas. Maize and rice are also grown in some parts. Out of a total sown area of 1,000 ha of rice and 3,100 ha of maize in Tibet, over 99 and 90%, respectively, are concentrated in this area.

There is promising scope for increasing cropping intensity. Three crops in two years in many regions and two crops in one year in some parts can be achieved with sufficient heat and water resources. However, crop production potential through increasing cropping intensity has not been fully utilised. The magnitude of cropping intensity is relatively low compared with other parts of China with similar biophysical conditions. In recent years, there has been some progress in establishing two-crop systems (winter barley and maize). The fundamental approach to promoting this is to train and mobilise local farmers to adopt multiple cropping systems through demonstration and 'know-how' training activities. However, this is unlikely to become widespread in the near future. Currently, the most effective way of increasing food grain and oilseed production is to focus on improvements of per unit crop yields.

The potential productivity of cropland in this area is on average 8.6t ha^{-1} for cereals. Historically, winter wheat has yielded 9.2t ha^{-1}. On ideal farm land, food grain and oilseed crops have yielded 6.2t ha^{-1} and 2.1t ha^{-1}, respectively. However, the actual average yields of cereals and rape seed in 1997 were only 3.3t ha^{-1} and 1.4t ha^{-1}, respectively.

The difference between the highest theoretical yield from ideal farm land and the actual yield in 1997 is large. Sloping and poor topographic conditions are factors that constrain an increase in yield. Unfortunately, it is not easy to change topographic conditions. Farming on flat areas and land levelling would help to increase crop yields. Poor technology application and management also constrain improvements in crop yield. Breeding and choice of new varieties of food grain and oilseed crops, improvements in cultivation techniques and cropping systems, strengthening of crop protection, and effective and efficient use of fertiliser and manure could boost per unit yields.

To summarise, increasing per unit crop yields is a useful approach to increasing production of cereals and oilseed. Potential cropland productivity has a distinct spatial distribution. The potential productivity of cropland in central Tibet around Lhasa and Shigatse is much higher than other parts. Percentage of potential productivity currently used is low. The total potential production of cereals based on potential productivity of cropland would be 2.6 million tonnes. However, total food grain production in 1997 was only 0.8 million tonnes, 30% of potential. If this could reach 50%, the total production of cereals would be 1.3 million tonnes yr^{-1}, which is sufficient to meet the demands of 2.5 million people.

Potentially attainable crop yields are promising, and there is considerable potential for increasing yield. To increase per unit crop yields, it is desirable to improve cultivation technologies, strengthen land levelling and quality improvement, improve the varieties of crops and application of improved cultivars, and train farmers through packaged technologies.

Prospects and Potential of Various Crops

Over 30 crops are grown in Tibet, including barley (mainly naked barley), wheat, rape seed, broad beans, beans, corn, millet, soy beans, peanuts, beans, hyacinth beans, soldier beans, white beans, red beans, potatoes, sweet potatoes, rice, sesame, flax, hemp, broom, corn, millet, oats, buckwheat, amaranth, and quinoa (Gu Maozhi 1995; Wang Baohai 1997). Barley and wheat are the predominant food grain crops, peas and broad beans the most important pulse crops, potatoes dominate tuber crops, and rape seed dominates oilseed crops. With the development of greenhouse technologies, many vegetable crops are now available.

Naked barley is the staple food grain crop. Traditional varieties usually yield about 1.5t ha^{-1}. With progress in varietal breeding and improvement of cultivation techniques, 3.5t ha^{-1} is now common, and on fertile soil where improved agricultural techniques are used, 6t ha^{-1} is possible with high-yielding varieties. There is potential to increase barley production through further use of high-yielding varieties and appropriate farming techniques. The greatest potential is in semi-arid and high-altitude frigid areas. Improved varieties produce 3t ha^{-1} in these areas, 20% higher than traditional varieties. Assuming that 60% of this area could attain the same rate of increase, total production could be doubled. Barley also possesses high value for processing into products that are increasingly demanded by outside markets, such as qingkelu (a soft drink), zangxiangchun (a kind of whisky), and tsampa. Moreover, barley straw is an important source of animal feed; more than 500,000t of barley straw are produced each year. However, only about 30% is used as feed. Assuming that this percentage could be increased to 50%, that would be equivalent to feed production from 400,000 ha of rangeland. Ammoniating and fermenting barley straw is a recent development. Further development and popularisation of this technique will improve the feed quality and benefit livestock-raising. Barley is one of the crops most tolerant of frigid environmental conditions and poor soil; its

Table 9.9: **Crop yields, attainable yield, and yield gaps in the agro-pastoral-forestry mixed production system (t ha^{-1})**

Yields and yield gaps	Grain crops				Grain crop on average	Rape seed
	Spring barley	Winter barley	Spring wheat	Winter wheat		
Potential productivity of cropland					8.6	
Historical record of highest yield	6.4	7.3	7.7	9.2	7.6	4.8
Highest yield from experimental plot	5.5	5.9	7.0	7.5	6.5	3.2
Highest yield from ideal farmland	5.2	5.6	6.7	7.3	6.2	2.1
Average yield in 1997	3.2	3.4	3.2	3.7	3.3	1.4
Average yield in recent five-year period	2.7	3.3	3.2	3.5	3.1	1.2
Yield gap 1					1.0	
Yield gap 2	0.9	1.4	0.7	1.7	1.1	1.6
Yield gap 3	0.3	0.3	0.3	0.2	0.3	1.1
Yield gap 4	2.0	2.2	3.5	3.6	2.9	0.7
Yield gap 5	0.5	0.1	0.0	0.2	0.2	0.2

further promotion as a forage crop in the high-altitude pastoral production system may propel livestock development (Wang Baohai 1998). Winter barley possesses much potential. In the lower river valleys of the Lhasa River and the Yalongzangpo River, yields are over 10% higher than for spring barley. Since it matures earlier than spring barley, it is also possible to grow one forage crop, usually 2t ha^{-1} of fresh peas, rape seed, or turnip. The area of winter barley cultivation is limited, and if expanded, will increase total barley production substantially.

Wheat is a traditional Tibetan crop. Previously, only spring wheat was grown in areas above 3,000m. Since 1960, winter wheat has been successfully introduced to high-altitude areas. By 1978, the total area of winter wheat cultivation had reached 52,000 ha; currently, it is about 45,000 ha. Regardless of type, in normal conditions wheat produces 4.5t ha^{-1}. However, with improved cultivation techniques and improved varieties, yields of more than 6t ha^{-1} on a large scale are possible, and winter wheat can produce more than 7.5t ha^{-1} (Hu Songjie 1995). Replacement of spring wheat by winter wheat has great potential to increase production. One of the key constraints to expansion of winter wheat is poor grain quality, manifested as low protein and gluten content, which hinders bread- and noodle-making. Nearly 100,000t of wheat flour is imported from central China every year to meet this demand. Furthermore, development of early-maturing winter wheat will provide an opportunity to grow forage after harvesting the wheat in early autumn. Improvement of wheat straw for animal feed will also make a positive impact on livestock development in the crop-dominated production system areas.

Pulse crops are dominated by peas and broad beans. Soybeans and lentils are grown in southern Tibet but only in small areas. Peas are predominantly cultivated in the agro-pastoral production system, and are mostly grown along with barley and rape seed. The yield is 2-4t ha^{-1}. On some high-productivity land, yields can reach 4.5t ha^{-1} (Hu Songjie 1995). Pea greenery is often used for forage, and the grain is also used as a concentrate for animal feed. Only about 0.1% of human food derives from peas. The protein content is 20-24.6%. Peas are usually mixed with barley and made into tsampa to improve nutritional value. Tsampa made from pure pea grain is often taken as breakfast and it is more common in western Tibet. Peas are an important crop for nitrogen fixation and help to maintain soil fertility. However, the area of pea crop is shrinking owing to the increasing area given to wheat and barley. Improving the varieties of peas sown is increasingly important for recovery of the area of the pea crop. Broad beans are commonly cultivated in river valleys. However, the area of broad bean cultivation is less than 1% of the total cropping area. About 2.5t ha^{-1} is the common yield for broad beans, but some experiments show that yield can reach 4.2t ha^{-1}. Total crude protein content is 28% (Hu Songjie 1995). With improvement in the varieties used, broad bean yields can reach 7.5t ha^{-1}. Broad beans are also a good source of forage and concentrated feed for livestock. Processing broad beans for snacks has started recently, and demand is increasing.

Potatoes are mainly used as vegetables, and are widely cultivated. The total sown area of potatoes is about 8,700 ha, comprising about 0.4% of the total sown area. On average, yield is about 30t ha^{-1}. With improved varieties, yield can be over 35t ha^{-1} and up to 45t ha^{-1} on highly productive farm land using technologies such as better seed, protection from disease, application of manure, and better management during the growing period. Extension of improved varieties, enhancement of cultivation and cropping management, better seed choice, promotion of intercropping with maize, application of plastic-film technology, introduction and development of processing technologies, and improvement of storage technology for the winter are keys for promoting and increasing production.

Rape seed is the primary oilseed crop. All three types of *Brassica* (rape seed) are grown. The total area of rape seed cultivation is around 34,000 ha, which accounts for 10% of the total sown area. Traditionally, rape seed was grown with barley and peas. In the early 1980s, the yield was about 1.2t ha^{-1}; now it is about 2t ha^{-1}. In many demonstration fields, high-yielding varieties of *Brassica napus* and *Brassica junipus* can yield 5.1t ha^{-1} and 6.1t ha^{-1}, respectively. Low erucic acid and low glucosinolate varieties, mainly introduced from Canada and known as canola, are well adapted to the Tibetan environment. Some improved rape seed varieties have now become dominant in central Tibet, where the residue after oil extraction is used for animal-feed concentrate. Extension of canola varieties, changes in cultivation techniques, and promotion of oil-processing could boost oilseed production.

Rice, peanuts, gingeli lentils, and soybeans are also well adapted to southern Tibet. Maize is a new crop in central Tibet following the introduction and development of plastic-film technology and introduction of new varieties. It is a potential crop for developing silage feed for livestock.

Vegetable and Fruit Production Potential

The total area of vegetable cultivation is 9570 ha, and average yield is about 13t ha^{-1}. The traditional vegetables are dominated by earthnut and tuber types such as potatoes, turnips, radishes, garlic, and green Chinese onions. There are few fruits or leaf-vegetables (Hu Songjie 1995). All these vegetables have the common characteristics of tolerance to cold, long storage life, high yields, and multiple uses. They have played an important role in ensuring food security. However, with changes in vegetable consumption, other varieties are demanded. With the introduction of greenhouses, it is possible to diversify the varieties of vegetables grown to include tomatoes, eggplant, capsicum, and cucumbers, which are now grown in greenhouses even at 4,200m. With further enhancement of economic capability, larger areas and more productive greenhouse-vegetable production can be developed. At present, there are 200 ha of greenhouse vegetables sown, only 2.1% of the total area of vegetable cultivation. In most cases, greenhouses can increase yields by one to two times of those achieved outside. The average yield of eggplant, cucumbers, capsicum, and tuber crops is usually about 45t ha^{-1}, 125-200% more than outside. Assuming that the percentage of greenhouse-vegetable cultivation reaches 5% of the total area of vegetable cultivation, total production of vegetables could be around 140,000t.

The total area of fruit trees cultivated is about 1860 ha, the average yield is around 3.2t ha^{-1}, and the total production is about 6,000t. There are small areas of tea (about 200 ha) with yields of about 0.4t ha^{-1}. Apples and plums were hardly available above 3,600m before 1960. Introduction of fruit trees and development of orchards took place during the 1960s and 1970s. New varieties and species of fruit such as apple, peach, Chinese plum, and watermelon (in greenhouses) were introduced to areas of 3,600-4,000m. Many state-owned farms established orchards and produced considerable amounts. In the early 1980s, the responsibility system was introduced. Most state-owned farms were dismantled and many orchards were contracted to individuals. The fast development of horticulture in central China has meant more, better, and cheaper fruit exports to the Tibetan market. Owing to the low quality and poor taste of apples and plums produced in Tibet, and poor facilities for storing fruit off-season, local fruit cannot compete with imported fruit. Without a market, orchards are no longer sustainable. Almost all orchards around Lhasa and Shigatse have now been abandoned or are seriously degraded in terms of production and fruit quality. Other factors that restrict development of horticulture above 3,600m are frost-damage to flowering in fruit trees and early frost-damage to fruit. It is highly risky to grow fruit in this area. In some seasons, there used to be great loss from late frost damage. However, new varieties of fruit trees now effectively avoid frost damage. Another problem is fruit quality. Introduction of high-quality, early-maturing species and varieties should be given high priority. If high-quality fruit trees are grown, better quality and more marketable fruit can be produced. It has been the same with tea production. Tibet could produce high quality tea, but it is limited by variety.

Potential Food Production from Wild Plants

Tibet is rich in edible wild plants — including many kinds of mushrooms, toadstools, pine mushrooms, troma (an earthnut), Tibet rhodiola, and aweto (a fungus).

Yellow mushrooms commonly grow in high-altitude alpine-meadow rangeland. With a total production of over 1 million kg, this is the favourite mushroom of herders and farmers. It can be eaten raw or cooked, and it grows naturally. Toadstools are popular in China. They are nutritious, with total crude protein content of about 24.5%, and contain 18 amino acids and vitamins. They are important for local people as a source of protein.

In the forest area of south-eastern Tibet, pine mushrooms are widely distributed. In recent years, they have been collected by local people and exported to Japan. In the county of Gongbujianda of Linzhi Prefecture, collecting pine mushrooms has become an important activity for additional income. Locally, pine mushrooms are dried and packed, and then sold in the market.

Troma, an earthnut, is widely distributed in most pastoral and river valleys. Tromadesi (mixed boiled troma with boiled rice and sugar) is prepared during festivals and for special occasions. The crude protein content in troma is more than 19.2%, and it contains many kinds of amino acids, micro-elements, and vitamins. There is potential to make infant food from troma, and the guess is that that it will have good market prospects.

Tibetan rhodiola is made into soft drinks and other products that have a market in other parts of China and abroad. Its main medicinal property is to enhance the body's capability to absorb oxygen, and it is good for reducing altitude sickness. It is widely distributed in the rangeland.

Aweto, *Cordyceps sinensis* or Chinese caterpillar fungus, is highly valued, selling for about US$2,000 per kg in both domestic and international markets. It is a food supplement with a total protein content of about 25% and a fat content of 8.4%.

Wild peach and walnut are also widely distributed. Wild peach is processed into canned fruit for the Chinese market.

Realising Production Potentials through Technological Inputs

Using improved crop varieties

The productivity of a crop variety can be improved by breeding and selection, and during the last 40 years over 100 improved varieties have been released. With direct improvement of biological productivity and modified cultivation techniques, per unit yield had doubled by 1998. It has been estimated that 14% of the increase in production of cereals and oilseed has been contributed by improved crop varieties (Hu Songjie 1995). In some areas, replacement of varieties has taken place three or four times, and on average there has been a 14% yield increase after each replacement. Spring barley yield has increased by 20% and spring wheat by 8.5%. The introduction of winter wheat and its improved varieties has increased food grain production by 82.6%. Extension of new varieties or replacement of old varieties often requires improvements or changes in cultivation techniques. With improved cultivation techniques, the whole production system is more productive. Over the last 30 years, extension of new varieties with modified cultivation techniques has resulted in a 60-70% increase in food grain and oilseed production, With the new varieties responsible for 36.6 and 8.5% of the increases, respectively (Hu Songjie 1995). The cost-benefit ratio of replacing of crop varieties and modifying cultivation techniques was estimated as 1:5. In general, extension of improved varieties and modification of cultivation techniques possess great potential for increasing production and contribute to increasing food grain and oilseed production substantially.

However, in most of the agro-pastoral and crop-dominated production systems, improved varieties have not replaced local races. Also, changes in cultivation techniques have not taken place. Breeding for a new variety needs over eight years. Breeding programmes for high-altitude and non-irrigated areas have not been undertaken. Production of cereals and oilseed will increase rapidly if improved varieties are developed.

Using improved cropping system and cultivation techniques

Over the last 40 years, five agricultural technologies were successfully introduced to farmers in Tibet: agro-machines, fertiliser, green-manure crops, winter wheat, and agro-chemicals. Application of agro-machines such as sowing machines, modified ploughs, and threshing machines for wheat and barley caused a revolution in crop production and transformed farming in Tibet. Crop production increased by 30-50% because of application of agro-machines for ploughing and sowing. Application of fertiliser, green-manure technology, and agro-chemicals increased per unit yield by 8.8% on average (Hu Songjie 1995). Similar gains may now be possible in the crop-dominated production system zone following large-scale campaigns using the package approach. Integrated improvement of low-yield cultivated land in Linzhou County of Lhasa and integrated management of cropping system land in Qushui County of Lhasa have increased food grain production by over 66%. Work on increasing crop production is now aimed at improving the total system rather than single crops or techniques. By doing this, the cost-benefit ratio of agricultural production is about 1:5 on average. Introduction and modification of local dry land agricultural technology increased the productivity of food grain crops more than 15% (Hu Songjie 1995). Appropriate application of agro-chemicals is reducing the loss of cereals from damage by diseases and insects by more than 20,000t each year. Using plastic-film technology for cultivation of maize is now common in central Tibet and is showing great potential for producing silage for livestock development. Technology introduction, innovation, and extension have been given high priority by local governments and will further boost crop production.

Livestock Production Potential

Livestock production is the predominant sector of the Tibetan economy. Meat and milk are the main products. The carrying capacity of rangeland has been studied from different perspectives (Liu Yanghua 1992; Tibetan Bureau of Land Planning 1992b; Yang Gaihe 1995). The supporting capacity of crop straw as animal feed has also been analysed (Tibetan Bureau of Land Planning 1992b; Yang Gaihe 1995). Xiao Huaiyuan (1994) attempted to analyse the capacity of agricultural by-products to support livestock production. However, livestock production potential and quantities of meat and milk production still remain unknown. In this report, production potentials for meat and milk were calculated based on an analysis of carrying capacity of rangeland, potential capacity of raising livestock using crop straw as animal feed, and supporting capacity of agricultural by-products.

Potential carrying capacity of rangeland

Over the last 30 years, there has been much development in raising livestock, with the total number of animals increasing from 17 million in 1965 to 23.8 million in 1995, an increase of 39%. Total production of meat and milk have reached 103,000t and 185,000t, respectively (Zhang Xiaopin 1997). However, growth has been at a cost in terms of rangeland overgrazing, in particular, and degradation of livestock productivity, in general. There has been a lack of input to the rangeland; output has always exceeded input. This lack of sustainable use has caused overgrazing (57% overstocking in Naqu Prefecture), degeneration (49% of Naqu), and declining productivity (20% since the 1980s), and the situation is becoming worse (Ling Hui 1998). Carrying capacity has decreased by 20-40% compared to the 1970s (Bai Tao 1995), and desertification, alkalisation, increases in poisonous plants, and increasing damage from mice and insects are common. They lead to degradation of the rangeland environment and lowering of productivity (Bai Tao 1995; Ling Hui 1998).

Sustainable use of potential carrying capacity is crucial to livestock development. In the early 1990s, the total carrying capacity of rangeland was 40-60 million sheep-equivalent units[1] (SEU; Bai Tao 1995; Liu Yanghua 1992). More recently, total carrying capacity has dropped to 34.2 million SEU (Yang Gaihe 1995). It is now estimated that carrying capacity is less than 30 million SEU at about 40 SEU 100 ha^{-1}.

The potential carrying capacity is not only low but also unevenly distributed. In the vast pastoral land of northern Tibet, the average potential carrying capacity is about 15-40 SEU 100 ha^{-1}; in the wider valleys of central Tibet around 41-70 SEU 100 ha^{-1}; in south-eastern Tibet 71-300 SEU 100 ha^{-1}: and in some areas it reaches 300-520 SEU 100 ha^{-1} (Figure 9.5. In practice, however, this area has a sloping topography and is wet and unfavourable for livestock development.

The spatial distribution of potential carrying capacity is exactly the opposite of the distribution of rangeland and is limited by biophysical conditions and socioeconomic development. In the pastoral production system zone, where livestock is given high priority, there is little capacity to increase numbers of livestock and livestock production. On the other hand, in southern Tibet, where carrying capacity is considerably higher, increases in livestock are limited by lack of grazing land, sloping topography, and the low priority given to livestock development.

Moreover, carrying capacity is not only unevenly distributed spatially but also between seasons. The difference in potential carrying capacity between summer and winter is about 50 sheep units per hectare (Bai Tao 1995). There are tremendous differences in stocking rate between cold and warm seasons. In the warm season, most of Tibet is understocked and there is potential to raise more animals (Figure 9.6), whereas in the cold season, almost all areas are overstocked; only a few counties in the far south possess limited potential to raise more livestock (Figure 9.7). On average, large parts of the north and centre are overgrazed by existing numbers of animals (Figure 9.8).

Comparison of food-production systems shows that the stocking rate in the cold season is high in all systems. In the pastoral production system zone, there is great overstocking in the cold season and slight overstocking in the warm season. In the crop-dominated production system zone, there is substantial overstocking in both warm and cold seasons (Figure 9.9).

The ratio of carrying capacity in warm season to cold season is more than 2.7 overall, while the ratio of numbers of livestock in warm to cold season is only 1.1. There is great potential to raise more livestock in the warm season (about 13 million

[1] A sheep-equivalent unit is a measure used for counting animals. For example, one yak is five sheep-equivalent units; this means that one yak has the same impact as five sheep.

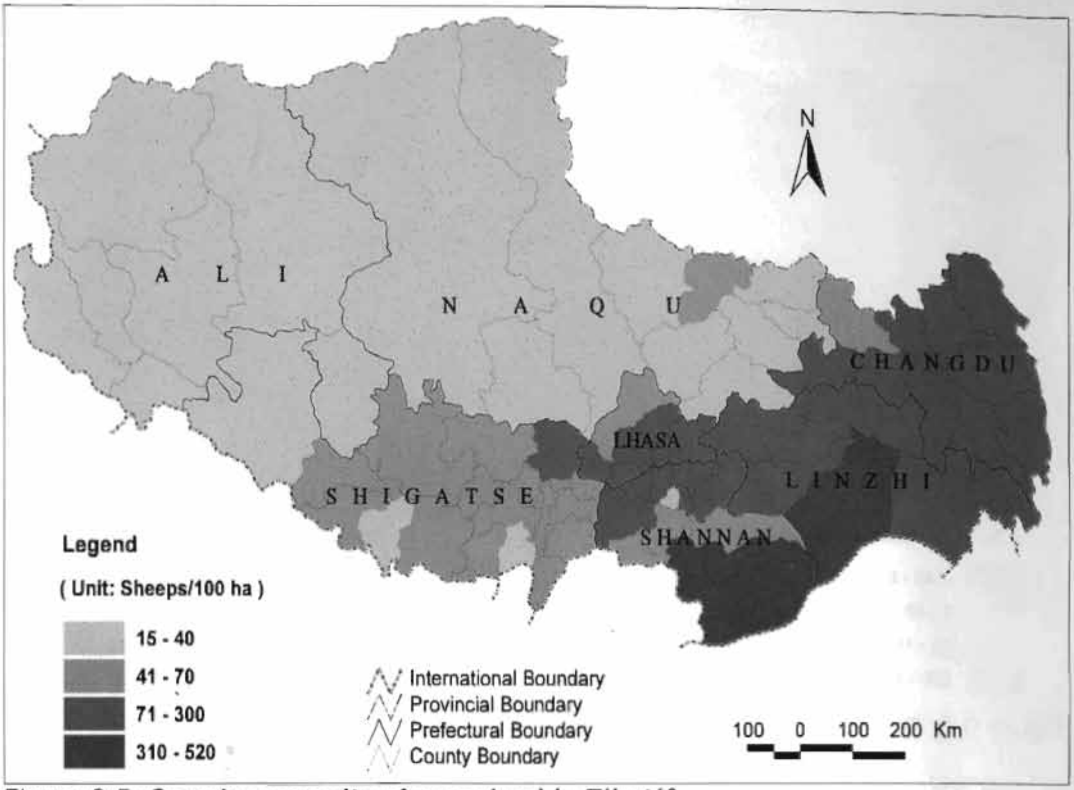

Figure 9.5: **Carrying capacity of rangeland in Tibet[2]**

SEU), but in the cold season there is already 15.5 million SEU of overstocking (Table 9.10).

Overstocking is exacerbated by the following conditions.

- Conservation and rehabilitation of rangeland are largely ignored. Over the past several decades, improvement and development of artificial grassland has not made much progress. Currently the total area of rehabilitated rangeland — re-seeding, irrigation, fencing, and artificial grassland — makes up only 0.02% of the total rangeland area. (In the USA, it accounts for over 20%.)
- Degradation of rangeland and decline in the capability to withstand natural disasters is becoming an increasing problem in pastoral production system zones. Over 20%of rangeland in Naqu and 18.8% of pasture in Shannan are seriously degraded. There is a lack of effort in developing appropriate fencing, irrigation systems, controls for disease and mice damage, eradication of poisonous plants, and replanting and fertilising of grassland. The proportion of poisonous plants has increased from 15 to 45% in some areas. The area of grass-cutting and winter grazing is decreasing year by year alongside an increase in animals. Production of grass has decreased by 60% since 1960. There is no established forage reserve in the form of stored hay to reduce livestock loss and preserve body weight during the winter.

[2] The estimate of the carrying capacity of rangeland is linked to county administrative boundaries. The basic data for potential carrying capacity were provided by Dr Liu Yanghua, Director and Professor at the Institute of Geography, Chinese Academy of Sciences, in 1996

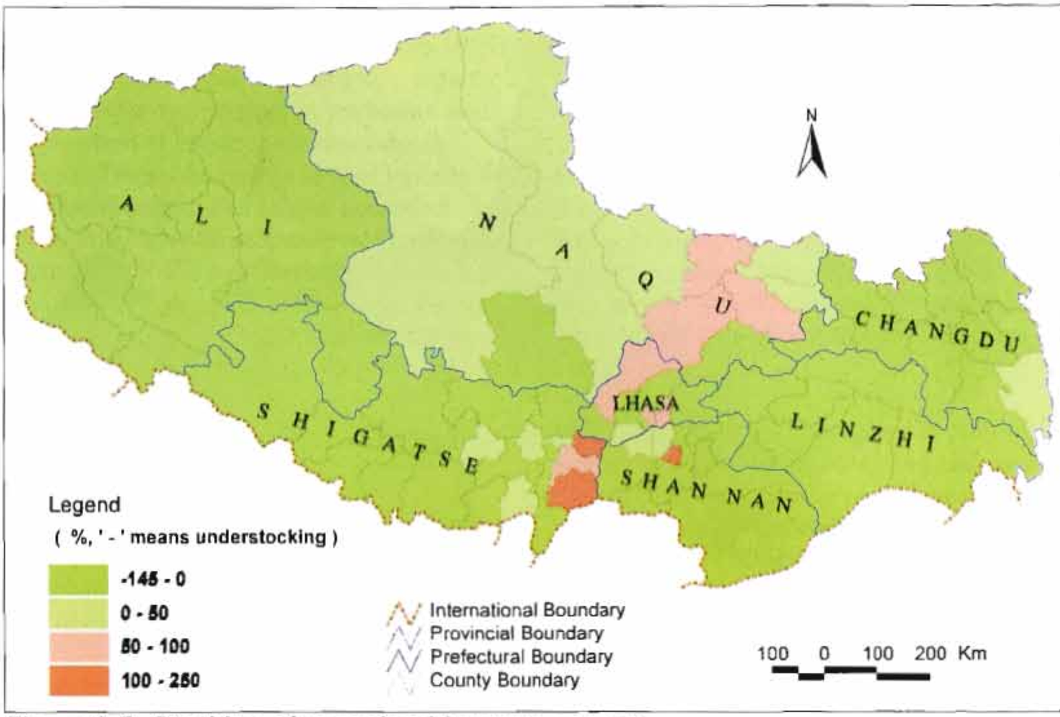

Figure 9.6: **Stocking of rangeland in warm season**

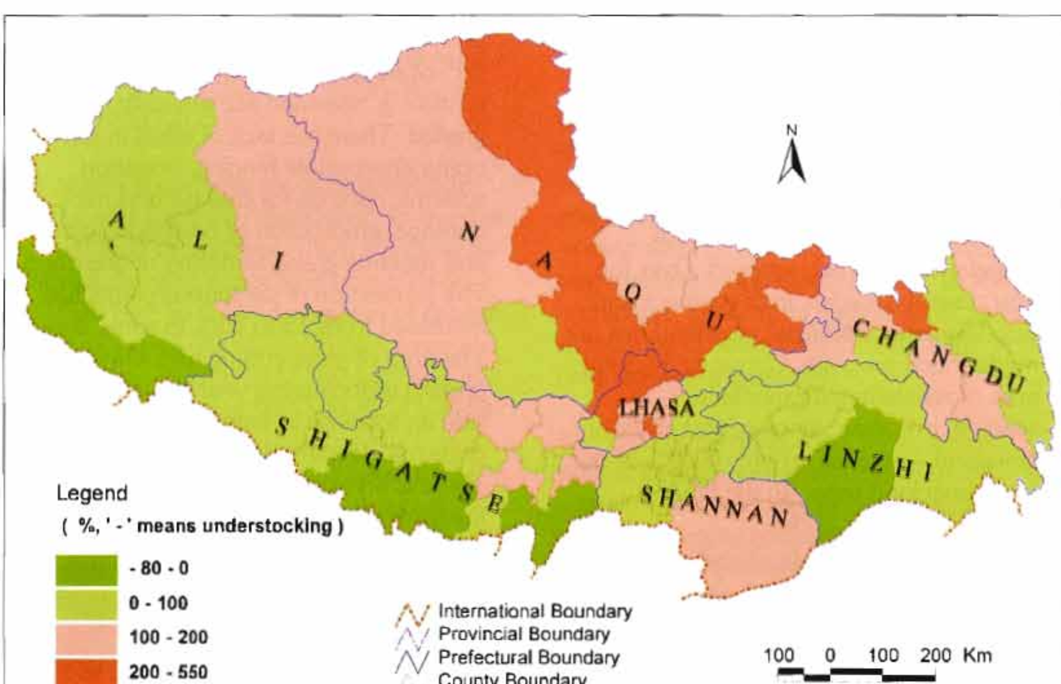

Figure 9.7: **Stocking of rangeland in cold season**

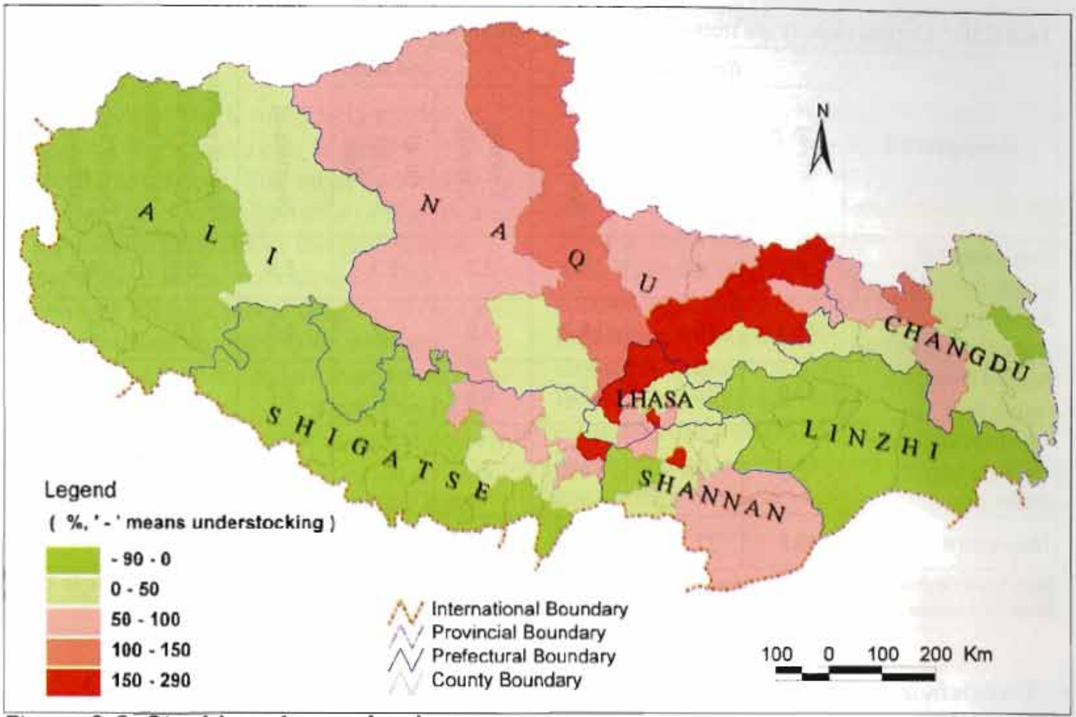

Figure 9.8: **Stocking of rangeland on average**

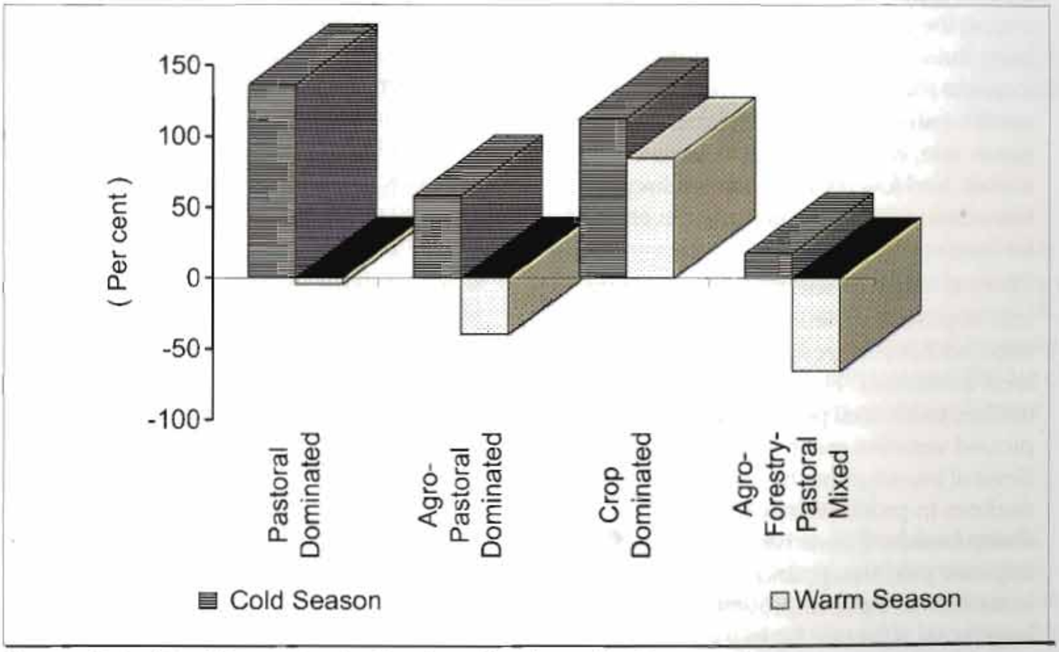

Figure 9.9: **Stocking rates in the four food-production systems**

Table 9.10: Carrying capacity and stocking status of rangeland (million SEU)

Farming system	Warm season			Cold season			Ratio of carrying capacity in warm to cold season	Ratio of livestock numbers in warm to cold season
	Carrying capacity	No. of livestock in July	Overstocking	Carrying capacity	No. of livestock in Dec.	Overstocking		
Crop-dominated production system zone	6.4	8.5	2.1	2.8	5.7	2.9	2.3	1.5
Agro-pastoral production system zone	22.3	13	(-9.2)	7.9	12.7	4.8	2.8	1
Pastoral production system zone	13.9	12.7	(-1.2)	5.5	12.7	7.2	2.5	1
Agro-forestry-pastoral mixed production system zone	7.2	2.7	(-4.4)	2	2.7	0.7	3.6	1
Tibet in total	49.8	37	(-12.8)	18.2	33.8	15.6	2.7	1.1

Note: Dr Liu Yanghua of the Institute of Geography, Chinese Academy of Sciences provided data for the carrying capacity of rangelands. The Bureau of Statistics of Tibet Autonomous Region, China, provided the number of livestock.

- There is frequently an inappropriate livestock-population structure with a large proportion of small, old, unproductive animals in the flock. The proportion of productive animals for milk and meat is 23% on average. The reason herders give for this is the high death rate of animals during the winter, which compels them to keep more livestock. They feel they cannot increase the off-take rate. The production system exhibits a vicious cycle of high death rate, more livestock to keep over winter, and low off-take rate leading to low economic benefit and poor livelihoods for herders.
- There is a lack of scientific management and improved varieties. Traditional varieties have a strong capacity to adapt to local conditions. However, at present, neither traditional pure breeds nor improved varieties are increasing production. Several investigators have reported declines in productivity of local yak and sheep breeds. Efforts have been made to improve yak, sheep, and cow breeds, but extension of these improved breeds on a large scale is limited by low economic capability and the biological adaptability of the animal. Per area and per animal production of milk and meat still remain the lowest in China, mainly because of lack of good-quality feed, particularly over the winter, lack of proper veterinary services, and poor feeding strategies. With growth in the human population and the need to sustain the livelihoods of nomads, more livestock products are required. However, the low productivity of individual animals means that this can only be attained by increasing the number of livestock. Without improvement in the carrying capacity of rangeland, this leads to overgrazing.
- Contradictions between livestock ownership and rangeland tenure still remain unsolved. The commune system ended and implementation of the responsibility system of agricultural and livestock management began in 1980. Each person was allocated a fixed number of animals so that everyone had equal assets. However, the rangeland was not allocated to individuals and still belongs to the government. When livestock are owned privately and rangeland is public, there is no incentive for individual herders to conserve,

serve, improve, or institute sustainable use of rangeland. This leads to overgrazing and degradation.

- Livestock products are poorly marketed, and the commodity rate of livestock production is low. The more livestock a herder has, the wealthier he or she feels in nomadic society. Over the past several decades, this has not changed. The average off-take rate is only 18-30%. Of the off-taken animals, over 50% are consumed by the herders themselves. Few livestock products, particularly meat and milk, are sold outside the nomadic society.

Potential of crop straw as animal feed

Crop straw is one of the most important sources of feed in traditional livestock-production systems. In the crop-dominated and agro-pastoral production system zones, crop straw is the only feed available for livestock in winter and spring. In Linzhou County of Lhasa in 1996, over 85% of the feed in winter and spring was crop straw. A similar situation was found in Shigatse County. Over 89% of crop straw used as feed is barley. Barley straw has on average 48% total digestible nutrients (TDN) and 4.3% crude protein (CP) compared to wheat straw's 41 and 3.6%, respectively (Christensen 1999). Pea straw is also an important source of animal feed in the agro-pastoral production system zone. In many areas where the altitude is high and the crop may not mature for grain, it is cultivated with barley for forage. One promising trend is the growing of alfalfa and other green forage crops in central Tibet. Many herders plant oats and barley for feed. Nevertheless, crop straw is an irreplaceable source of animal feed.

The total amount of cereal straw produced was estimated at 960,000t in 1997, based on 800,000t of food grain production. The ratio of food grain production to cereal straw is 1:1.2. Cereal straw also includes pea straw; rape seed straw is hardly used as feed. Barley straw accounts for 76% of total production. In the crop-dominated production system zones, winter wheat straw accounts for more than 50%.

Current use of crop straw is not optimal. The rate of using cereal straw for feed is about 26%. Farmers often do not manage crop straw properly. In most cases, farmers simply pile the straw beside the house or on the roof. There is rarely any further processing — such as application of ammonia and micro-organisms to ferment the straw so that digestible nutrients are increased. Moreover, there is no facility for feeding straw to animals, such as troughs or racks; straw is simply spread on the ground. Large amounts are wasted. In some villages, straw is used as fuel for cooking.

In recent years, the introduction of fermentation of straw, together with troughs and chopping of straw, has been successful in fully using straw for animal feed. In Tsetang Township and Gongga County of Shannan Prefecture in 1997 and 1998, many farmers adopted the combined package of fermentation of straw, chopping, and feeding with troughs. Local extension staff and farmers feel that this approach could enhance the utilisation rate by up to 60%. Another approach adopted by farmers in Dazi County of Lhasa is mixing chopped barley straw with wheat or corn flour as well as forage from alfalfa. In this way, additional energy and protein were provided so that livestock obtained a higher ration of total digestible nutrients and crude protein. The total utilisation rate improved by up to 62%. Assuming that the utilisation rate of straw reaches 60%, more than 2 million SEU can be additionally supported, based on an estimate of 200 kg of barley straw for one sheep as a supplement to grazing.

Feed-production potential

In addition to crop straw as feed for animals, forage, fodder, hay, silage, and concentrated feed are important for raising livestock productivity. To increase livestock yields by promoting improved and intensive production, high-quality animal feed will be required.

Currently, over 173,000 ha of wasteland are available for developing forage and silage production. If 40,000 ha of this land were cultivated for forage and grass, then, after three years, an additional 1.5 million SEU could be supported (Hu Songjie 1995).

Alfalfa, clover, peas, turnips, radishes, and rye grass are well adapted to conditions in Tibet. Promoting these feed crops and adequately using solar energy and water resources in lower river valleys would substantially boost overall livestock development. It is advisable to first increase the per unit yield of cereals and oilseed, and then devote larger areas to forage or maize production for silage by using plastic-film technology. The total biomass production of maize in the Lhasa River Valley could reach 4-5t ha^{-1} without plastic film; with plastic film, production could be 9t ha^{-1}. Four kg of silage fed to cows can increase milk production by 1 kg (Hu Songjie 1995).

Expansion of the sown area of winter barley is now possible in central Tibet through multiple-cropping systems. One harvest of green forage of alfalfa, turnip, or rape seed can be produced after harvesting winter barley. About 30-60t ha^{-1} of fresh forage are produced with this multiple-cropping system. Expansion of winter barley to 10,000 ha would allow more than 35,000 grazing SEU to be supported.

Besides these opportunities, with an increase in food grain and oilseed production, more than 100,000t of food grain could be used for processing into livestock feed. There are over 243,000t of agricultural by-products such as wheat bran, oilseed meal, and lees. They are not properly used as animal feed and are wasted.

Given the existing carrying capacity of rangeland, full use of barley and pea straw for feed, substantial use of wasteland to produce feed, development of forage and silage, and adequate use of agricultural by-products, 30% more livestock could be sustained. Based on this assumption, total carrying capacity in Tibet was estimated at 38.6 million SEU at current production levels (Table 9.11). Comparing this capacity with existing numbers of animals, the threshold has been reached. At the existing level of livestock production, population structure, and rate of off-take, 140,000t of meat and 230,000t of milk can be produced. Further increases in meat and milk production will depend not only on improved livestock productivity by breeding, but also on improving rangeland, increasing the utilisation

Table 9.11: **Total potential supporting capacity and stocking status of rangeland (10,000 SEU)**

Farming systems	Total capacity			Capacity of natural rangeland		
	Total supporting capacity	Ratio of overstocking in warm season	Ratio of overstocking in cold season	Supporting capacity of natural rangelands	Ratio of overstocking in warm season	Ratio of overstocking in cold season
Crop-dominated production system	9.5	13.3	45.5	3.4	32.6	49.5
Agro-pastoral production system	13.4	(-68.7)	35.7	12.2	(-41.5)	60.4
Pastoral production system	11.8	(-14)	81.4	10	(-8.9)	319.3
Agro-forestry-pastoral mixed production system	3.9	(-89.6)	14.9	3	(-61.8)	11.9
Total Tibet	38.7	(-34)	41.3	28.6	(-25.7)	85.3

Notes: Dr Lui at the Institute of Geography, Chinese Academy of Sciences provided data for the carrying capacity of rangelands. The author estimated the total supporting capacity of livestock production in Tibet.
SEU = sheep equivalent units

rate of crop straw, developing forage, processing agricultural by-products for feed, restructuring the livestock population, and increasing rate of off-take.

Potential for improving livestock breeds

In 1995, the number of sheep and goats was 17.6 million head and the number of yak and cattle was 5.4 million head. The average off-take rate of sheep and goats was 23% and of yak and cattle 12%. The total production of meat and milk was 120,000t and 178,000t, respectively. Average per capita consumption of meat and milk was 13.1 kg and 48.1 kg, respectively.

The total number of livestock is now almost equal to the total capacity for raising them. Control of the number of livestock is now underway, and local governments are looking at increasing per animal productivity as a way to increase livestock production. The potential productivity of improved breeds is crucial to increasing livestock production.

In terms of new breeds, in most areas the milk and meat production of yak can be increased 30% through cross-breeding among the main breeds of Pali Yak, Sibu Yak, Jiali Yak, and Dandxiong Yak. Local breeds of cattle are well adapted to the harsh conditions; most are tolerant to crude feed and have a high capability for grazing the pastoral land. However, milk and meat productivity are low. Improvement through cross-breeding between local cows and exotic large-framed cows has succeeded in increasing milk production more than five times and increasing body weight by 46-57% (Hu Songjie 1995). These improved cow breeds need better quality and larger quantities of feed. A 40% increase of wool, meat, and milk production of sheep was also achieved by similar cross-breeding. However, as of 1996, there were only 15,000 head of improved yak, 15,000 head of crossbred sheep, 40,000 head of improved cows, and 35,000 head of improved goats in Tibet. The proportion of these improved and crossbred livestock in the total is still small.

In general, there is a large proportion of old and small yak and sheep. In the crop-dominated production system, promotion should focus on cow and zo, while in the agro-pastoral and pastoral production system zone, yak, sheep, and goats predominate. In the low agro-pastoral-forestry mixed production system, pig and poultry production would be more profitable. Commercialised poultry production and pig-raising in suburban areas holds much potential. Many farmers from central China raise poultry such as chicken and duck, and combine that activity effectively with greenhouse vegetable production by using residues of vegetable farming as feed for poultry and pigs. More local people are also starting to raise chickens. Young chickens, pigs, and ducks are brought from China; after about one year, they are ready for off-take. Urban-based livestock development is promising because of the huge market. However, farmers in suburban areas would need training to raise poultry and pigs. Increase of female yak (dri) and sheep to proportions of 50 and 60%, respectively, would increase milk production (Hu Songjie 1995). In general, livestock production can only be sustained when it fits local biophysical conditions and there is a market for livestock products.

Potential Fishing Production

There is great potential for developing a fishing industry, as most rivers and lakes of Tibet have great reserves of fish. It was estimated that total fish reserves are about 200,000-300,000t. Scientists estimated that 6653t of fish can be harvested per year (Yu Yungui 1994). Nevertheless, the fishing industry is constrained by cultural background. Many lakes are considered holy. However, local people in the Yangdroyongcuo area have started fishing, and it is a source of additional income for local herders.

Food Processing and Adding Value

At present, food-processing techniques for grain, oil, meat, milk, sugar, beverages, tinned food, fermented food, and puffed food are applied extensively. There is increasing demand for foods produced in pollution-free regions such as Tibet. But the food-processing industry in Tibet is still primitive, and there have been few efforts to develop it. Traditional food has not been improved by application of modern food-processing technologies. During the last several decades, 35 food-processing plants have been established; there are now about 720 people involved in food processing (Statistic Bureau of Tibet 1997). By 1995, total output value of the food industry was about 35.1 million yuan, comprising 1% of the total agricultural production value. By contrast, in central China, the food industry's production totalled 18.9% of the total agricultural production value (Lu Liangsu 1993).