02

Livestock in geographic transition

This chapter deals with the changing use of land[1] by livestock and some of the environmental impacts of that use[2]. Land management has a direct impact on the biophysical conditions of the land including soil, water, fauna and flora.

Land use has both spatial and temporal dimensions. Types of land use can spread or shrink, scatter or concentrate, while land use at a single location can be stable, seasonal, multiple and/or transitory. Land use is driven by a wide range of factors: some are endogenous to the land (e.g. bio-physical characteristics), some relate to the individual or the society using the land (e.g. capital availability, technical knowledge), some, finally, depend on the institutional and economic framework in which the land-user operates (e.g. national policies, markets, services).

Access to land and its resources is becoming an increasingly acute issue and source of competition among individuals, social groups and nations. Access to land has driven disputes

[1] With UNEP (2002), we define land as the terrestrial bioproductive system that comprises soil, vegetation - including crops, other biota, and the ecological and hydrological processes that operate within the system".

[2] Land-use changes include land cover-changes as well as the changing ways in which the land is managed. Agricultural land management refers to the practices by which humans use vegetation, water and soil to achieve a given objective. e.g. use of pesticides, mineral fertilizers, irrigation and machinery for crop production (Verburg, Chen and Veld Kamp, 2000).

and wars throughout history and, in some areas, resource-related conflicts are on the increase. For example, disputes over access to renewable resources, including land, are one of the principal pathways in which environmental issues lead to armed conflicts (Westing, Fox and Renner, 2001). This may be the result of a reduced supply of land (because of depletion or degradation), distribution inequities or a combination of these factors. Increasing land prices also reflect the increasing competition for land. (MAFF- UK, 1999).

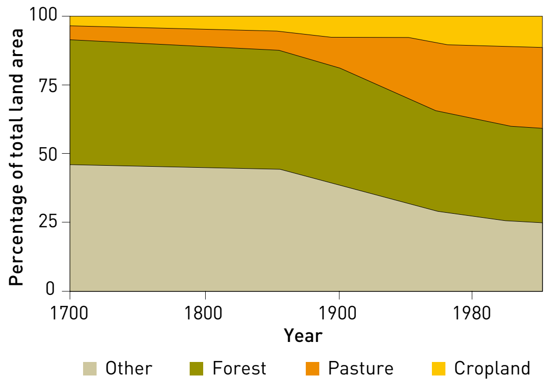
In this chapter, we will first look at the broad trends in land use and the forces that drive them, and introduce the "livestock transition" as a basic concept central to the understanding of livestock-environment interactions. We will then take a closer look at how the demand for livestock food products is distributed in relation to population and income. We will then turn to the geographic distribution of the natural resource base for livestock production, especially feed resources. This includes grazing land and arable land, particularly where surplus crop production is being used as feed for livestock production. Resources for livestock production and demand for animal products are balanced through livestock production systems that interact with both the resources and demand side. We will look at the changing geography of production systems and the way transport of feed and animal products resolve geographical mismatches and bring about different competitive advantages. Finally, we will review the main land degradation issues related to the livestock sector.

2.1 Trends in livestock-related land use

2.1.1 Overview: a regionally diverse pattern of change

The conversion of natural habitats to pastures and cropland has been rapid. Conversion accelerated after the 1850s (Goldewijk and Battjes, 1997) (Figure 2.1). More land was converted to crops between 1950 and 1980 than in the preceding 150 years (MEA, 2005a).

Figure 2.1 **Estimated changes in land use from 1700 to 1995**



Source: Goldewijk and Battjes (1997).

Table 2.1 presents regional trends over the past four decades for three classes of land use: arable land, pasture and forest. In North Africa, Asia, Latin America and the Caribbean land use for agriculture, both for arable and pasture, is expanding. The expansion of agriculture is fastest in Latin America and sub-Saharan Africa, mostly at the expense of forest cover (Wassenaar *et al.*, 2006). In Asia (mostly Southeast Asia) agriculture is expanding, and showing even a slight acceleration. In contrast, North Africa has seen crop, pasture and forestry expanding at only modest rates, with low shares of total land area covered by arable land. Oceania and sub-Saharan Africa have limited arable land (less than 7 percent of total land) and vast pasture land (35 to 50 percent of total land). Expansion of arable land has been substantial in Oceania and is accelerating in sub-Saharan Africa. There is a net reduction of forest land in both regions. Local studies have also found replacement of pasture by cropland. In sub-Saharan Africa, where cropping and grazing are often practised by different ethnic groups, the advance of crops into pasture land often results in conflict, as shown by major disturbances in the Senegal river basin between Mauritania and Senegal, and in North Eastern Kenya, between the Boran and the Somalis (Nori, Switzer and Crawford, 2005).

Box 2.1 Recent trends in forestry expansion

The Global Forest Resources Assessment 2005 suggests that forest still covers less than 4 billion hectares, or 30 percent of the total land surface area. This area has been in continuous decrease, although at a slowing pace. The net loss in forest area is estimated at 7.3 million hectares per year over the period 2000 to 2005, compared to 8.9 million hectares per year over the period 1990 to 2000. Plantation forests are generally increasing but still account for less than 4 percent of total forest area (FAO, 2005e). On average, 2.8 million hectares of forest were planted each year over the period 2000 to 2005.

These global figures mask differences among regions and forest types. Africa, North, Central and South America and Oceania showed net forest cover losses over the period 2000 to 2005 (FAO, 2005e), with the two latter bearing the largest losses. In contrast, forest cover increased in Asia over the same period, owing to large-scale reforestation in China, and continued to increase in Europe, although at a slowing pace. Primary forest area in Europe and Japan is expanding, thanks to strong protection measures.

Forest cover embraces a range of land usages. Wood production continues to be a major function in many forests. Trends are diverging though: Africa showed a steady increase in wood removal over the period 1990 to 2005, while production is decreasing in Asia. Forests are increasingly designated for the conservation of biodiversity. This kind of forest (mainly in protected areas) increased by an estimated 96 million hectares over the 1990 to 2005 period, and by 2005 accounted for 11 percent of all forests. Soil and water conservation is seen as a dominant function for 9 percent of the world's forests.

Source: FAO (2005e).

Western Europe, Eastern Europe and North America show a net decrease in agricultural land use over the last four decades, coupled with stabilization or increase in forest land. These trends occur in the context of a high share of land dedicated to crops: 37.7 percent, 21 percent and 11.8 percent in Eastern Europe, Western Europe and North America, respectively. The Baltic States and Commonwealth of Independent States (CIS) states show an entirely different pattern, with decreasing land dedicated to crops and increasing land dedicated to pasture. This trend is explained by economic regression causing the abandonment of cropland, and by structural and ownership changes that occurred during transition in the 1990s. Map 1 (Annex 1) further shows the uneven geographical distribution of cropland, with vast areas remaining mostly uncropped on all continents. The main patches of highly intensive cropping are found in North America, Europe, India and East Asia.

The massive expansion of arable and pasture land over the last four decades has started to slow (Table 2.1). At the same time, human populations grew more than six times faster, with annual growth rate estimated at 1.9 percent and 1.4 percent over the 1961–1991 and 1991–2001 periods respectively.

Extensification gives way to intensification

Most of the increase in food demand has been met by intensification of agricultural land use rather than by an expansion of the production area. The total supply of cereals increased by 46 percent over the last 24 years (1980 to 2004), while the area dedicated to cereal production shrank by 5.2 percent (see Figure 2.2). In developing countries as a whole, the expansion of harvested land accounted for only 29 percent of the growth in crop production over the period 1961–99, with the rest stemming from higher yields and cropping intensities. Sub-Saharan Africa,

Table 2.1

Regional trends in land use for arable land, pasture and forest from 1961 to 2001

	Arable land			Pasture			Forest		
	Annual growth rate (%)		Share of total land in 2001 (%)	Annual growth rate (%)		Share of total land in 2001 (%)	Annual growth rate (%)		Share of total land in 2002[2] (%)
	1961–1991	1991–2001		1961–1991	1991–2001		1961–1991	1990–2000[2]	
Developing Asia[1]	0.4	0.5	17.8	0.8	0.1	25.4	-0.3	-0.1	20.5
Oceania	1.3	0.8	6.2	-0.1	-0.3	49.4	0.0	-0.1	24.5
Baltic states and CIS	-0.2	-0.8	9.4	0.3	0.1	15.0	n.d.	0.0	38.3
Eastern Europe	-0.3	-0.4	37.7	0.1	-0.5	17.1	0.2	0.1	30.7
Western Europe	-0.4	-0.4	21.0	-0.5	-0.2	16.6	0.4	0.4	36.0
North Africa	0.4	0.3	4.1	0.0	0.2	12.3	0.6	1.7	1.8
Sub-Saharan Africa	0.6	0.9	6.7	0.0	-0.1	34.7	-0.1	-0.5	27.0
North America	0.1	-0.5	11.8	-0.3	-0.2	13.3	0.0	0.0	32.6
Latin America and the Caribbean	1.1	0.9	7.4	0.6	0.3	30.5	-0.1	-0.3	47.0
Developed countries	0.0	-0.5	11.2	-0.1	0.1	21.8	0.1	n.d.	n.d.
Developing countries	0.5	0.6	10.4	0.5	0.3	30.1	-0.1	n.d.	n.d.
World	0.3	0.1	10.8	0.3	0.2	26.6	0.0	-0.1	30.5

[1] Data on pasture excludes Saudi Arabia.
[2] Data for 2000 obtained from FAO, 2005e.
Note: n.d. - no data.
Source: FAO (2005e; 2006b).

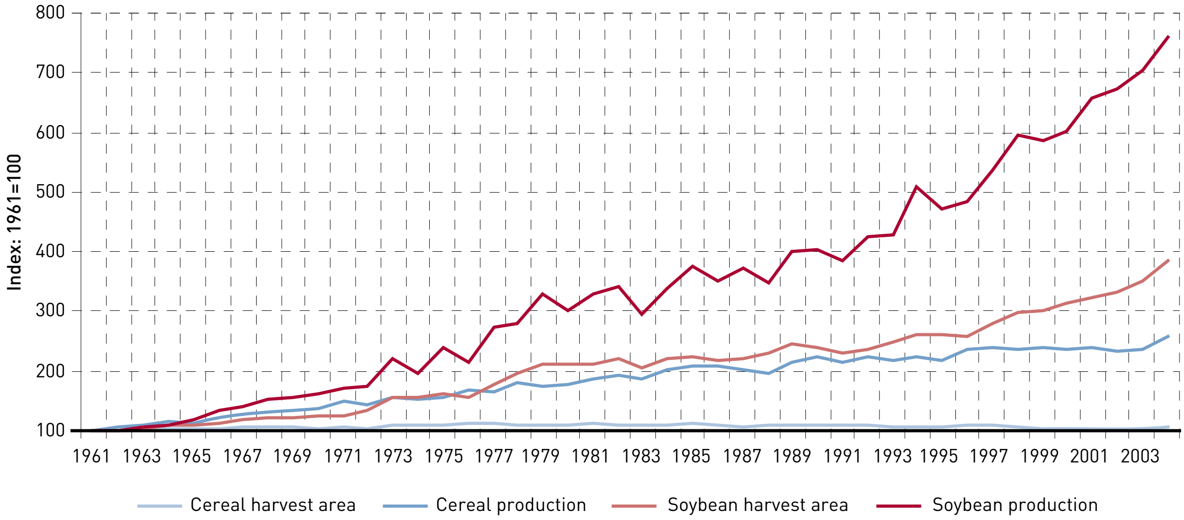
where area expansion accounted for two-thirds of growth in production, was an exception.

The intensification process has been driven by a range of factors (Pingali and Heisey, 1999). In Asia, where extraordinary growth in cereal productivity has been achieved, rising land values owing to increasing land scarcity have been the dominant factor. Cereal yields have also substantially increased in some Latin American and African countries. With lower population densities than in Asia, the forces influencing intensification have been the level of investments in market and transport infrastructure and the extent to which countries engaged in export-oriented trade. In contrast, productivity gains were low in sub-Saharan Africa, despite population growth. Relative land abundance (in comparison to Asia), poor market infrastructure and lack of capital contributed to the modest performance.

Technically, increased productivity can be achieved by increased cropping intensity (i.e. multiple cropping and shorter fallow periods) by higher yields, or by a combination of the two. Higher yields are the result of technological advances and higher input use in crop production – notably irrigation, modern high-yielding plant varieties, fertilizers and mechanization. Use of tractors, mineral fertilizers and irrigation increased strongly between 1961 and 1991, and much more slowly afterwards (see Table 1, Annex 2). In comparison, use of mineral fertilizers has substantially decreased since 1991 in developed countries, as a result of more efficient resource use and environmental regulations aimed at reducing nutrient loading.

While scope for productivity increases still exists, Pingali and Heisey (1999) show that the productivity of wheat and rice in lowland Asia has lately been growing at a dwindling pace. Key factors explaining this slowing trend are land degradation, declining research and infrastructure investment, and increasing opportunity cost

Figure 2.2 **Total harvested area and total production for cereals and soybeans**



Source: FAO (2006b).

of labour, although new technological developments (i.e. hybrid rice) might enable new growth. Arable land expansion will likely continue to be a contributing factor in increasing agricultural production. In particular, this will be the case for developing countries, where arable land expansion, increases in cropping intensity and yield increases accounted for 23, 6 and 71 percent, respectively, of crop production growth over the 1961 to 1999 period, and they are expected to account for 21, 12, and 67 percent, respectively over the 1997/99 to 2030 period (FAO, 2003a). In developed countries, in contrast, the increase in production is expected to be reached with a constant or locally declining arable area. The foreseen shift to biofuels, and the increased demand for biomass that will result may, however, lead to a new area of crop expansion, especially in Western Europe and North America.

2.1.2 Globalization drives national land-use changes

Changes in agricultural land use are driven by a wide range of factors. Ecological conditions, human population density and level of economic development provide the broad context of land use, along with more localized factors specific to each area. Individual and social decisions leading to land changes are also increasingly influenced by changing economic conditions and institutional frameworks (Lambin *et al.*, 2001).

Two concepts are central in explaining agricultural land-use changes: profit per unit of land and opportunity cost. Profit per unit of land[3] describes the potential interest for an operator to engage in a particular use of the land. Profit generally depends on the biophysical characteristics of the land, on its price, and factors including accessibility to markets, inputs and services. On the other hand, the opportunity cost[4] compares the economic and social costs of two or more ways of using the same piece of land. Opportunity cost includes not only the private costs of production, but also direct and indirect costs borne by society, such as losses

[3] The surplus of revenue generated over expenses incurred for a particular period of time.

[4] Opportunity cost can be defined as the cost of doing an activity instead of doing something else.

of ecosystem services. For example, part of the opportunity cost of cropping an area would be loss of the possibility of using it for recreational purposes.

In a context where non-marketable ecosystem services are not priced, decisions on land use are predominantly driven by calculation of private profit per unit of land, usually based on tradable goods and services. As a result, the non-marketed benefits are often lost, or external costs are imposed on society. However, the environmental and social services provided by ecosystems are receiving increasing recognition.

A case in point is the growing recognition of the wide range of services provided by forest, a type of land use generally antagonistic to agricultural use, although modern agroforestry technologies do produce some synergies. Forests are increasingly used for conservation of biodiversity (see Box 2.1). This is a global trend, although the pace is significantly slower in Oceania and Africa.

Soil and water conservation is also seen as a dominant function for 9 percent of the world's forests. Recreation and education activities are another use of forest that is on the increase and represent the primary management objective for 2.4 percent of the forest in Europe, while 72 percent of the total forest area was acknowledged to provide social services (MEA, 2005a).

Roundwood removal, on which the calculation of profit per unit of forest land is usually based, was estimated at US$64 billion worldwide in 2005. This has been decreasing in real terms over the last 15 years (FAO, 2005e). In a case study of the economic value of forest in eight Mediterranean countries, non-wood forest products, recreation, hunting, watershed protection, carbon sequestration and passive use accounted for 25 to 96 percent of the total economic value of the forests. Non-marketed economic values (e.g. watershed protection, carbon sequestration, recreation, non-timber forest products) were estimated higher than commonly measured economic values (e.g. grazing, timber and fuelwood) in three countries (Italy, Portugal and the Syria Arab Republic), though they were lower in five (Algeria, Croatia, Morocco, Tunisia and Turkey) (MEA, 2005a).

As economies continue to liberalize, local agricultural goods compete with equivalent goods produced farther away. Increasingly, therefore, agricultural land-use opportunities are competing across continents. Both profit per unit of land and opportunity costs of agricultural land use vary immensely around the globe, depending on agro-ecological conditions, access to markets, availability of production inputs (including services), existence of competitive land usage and valuation of ecosystem services. Agricultural production relocates accordingly, resulting in changes in use of agricultural land and also of forests and other natural areas. For example, New Zealand lamb competes with local produce in Mediterranean markets. New Zealand lamb is produced at a relatively low cost because of much lower opportunity cost of land (mainly owing to a much lower recreational demand) and higher productivity of pasture. As a result, the marginal pastures traditionally used for sheep production in the EU Mediterranean basin are progressively being abandoned to natural vegetation and other recreational usages.

The process through which former agricultural land reverts to forest has been called the "forest transition". Mainly, the term has been applied to developed countries in Europe and North America (Mather, 1990; Walker, 1993; Rudel, 1998).

During the early period of colonization and economic growth, settlers and farmers cleared land rapidly to provide agricultural goods required by local populations. Later, as urban development came to dominate and trade expanded, rural populations moved to cities, and agricultural markets traded with increasingly distant locations of demand and supply. There were huge gains in agricultural productivity in areas with high agricultural potential.

This resulted in substantial land-use shifts: farming moved into the remaining unused fertile lands, and marginal locations were abandoned, especially in remote areas with poor soil characteristics. More productive land with good accessibility remained in production. As abandoned land reverted to natural vegetation cover, this led to net reforestation in parts of Europe and North America, from the end of the nineteenth century on (Rudel, 1998). Forest transition is an ongoing trend in Europe and North Africa and has shown similar patterns in Asia, although national policies may have fostered the process in the latter (Rudel, Bakes and Machinguiashi, 2002). Map 2 (Annex 1) shows areas of net forest area gain in the USA, Southern Brazil, Europe and Japan.

2.1.3 Land degradation: a vast and costly loss

Land degradation is widely recognized as a global problem having implications for agronomic productivity and the environment as well as effects on food security and quality of life (Eswaran, Lal and Reich, 2001). Although the magnitude of the problem is broadly shared, there are a number of definitions for land degradation, interpreted in different ways among various disciplinary groups. We here refer to the definition of the United Nations Environment Programme (UNEP) where "Land degradation implies a reduction of resources potential by one or a combination of processes acting on the land, such as: (i) soil erosion by wind and/or water, (ii) deterioration of the physical, chemical and biological or economic properties of soil; and (iii) long-term loss of natural vegetation" (UNEP, 2002).

Agricultural land degradation is of particular concern on several grounds, as it reduces productivity, which in turn leads to further expansion of agricultural land into natural habitats. It also requires additional natural resources to restore the land (e.g. lime to neutralize acidity, water to flush out salinity), and can generate pollution with off-site impacts (Gretton and Salma, 1996). Intensification and extensive land use can both result in environmental impacts, though in different ways. Intensification has both positive and negative effects. Increased yields in agricultural systems help to reduce the pressure to convert natural ecosystems into cropland, and can even allow for re-conversion of agricultural land back to natural areas, as observed in OECD countries.

However, the increased inputs of fertilizers, biocides and energy that intensification involves have also increased pressure on inland-water ecosystems, generally reduced biodiversity within agricultural landscapes and generated more gaseous emissions from higher energy and mineral fertilizers inputs (MEA, 2005a). On the other hand, extensive use of land for pasture or cropping has also often led to the deterioration of vegetative cover and soil characteristics.

Environmental implications of land degradation are multiple. Among the most critical issues are the erosion of biodiversity (through habitat destruction or pollution of aquifers), climate change (through deforestation and the loss of soil organic matter releasing carbon to the atmosphere) and depletion of water resources (through alteration of the soil texture or removal of vegetation cover affecting water cycles). These mechanisms and their significance will be described in detail in the following chapters.

The differences in definitions and terminology for land degradation are responsible for the variations between results from studies that have attempted to evaluate the extent and rate of this process. Oldeman (1994) produced one of the generally accepted estimates of the extent of global land degradation. It estimates that about 19.6 million km^2 are degraded, mostly because of water erosion (Table 2.2). This figure does not, however, include loss of natural vegetation and, based on the above UNEP definition, is therefore more an estimate of soil degradation rather than of land degradation. Still, according to Oldeman (1994), about one-third of the land used as forests and woodlands appears to be degraded in Asia (ca 3.5 million km^2), against 15 to 20 percent in Latin America and Africa. Land degradation of pasture is mainly an issue in Africa

(2.4 million km²), although Asia, and to a lesser extent Latin America are also affected (2.0 and 1.1 million km² respectively). Finally, about one-third of the agricultural land is degraded in Asia (2.0 million km²), against half in Latin America, and two-thirds in Africa.

Desertification is a form of land degradation, taking place in arid, semi-arid and dry subhumid areas and resulting from various factors, including climatic variations and human activities (UNEP, 2002). Dregne and Chou (1994) estimated that degraded lands in dry areas of the world amount to 3.6 billion hectares or 70 percent of the 5.2 billion hectares of the total land areas considered in these regions (Table 2.3). These figures include loss of vegetal cover and are not directly comparable with the previous ones. Reich *et al*. (1999) further estimate that in Africa, about 6.1 million km² of land are under low to moderate degradation risk and 7.5 million km² are under high and very high risk. Cumulatively, desertification is estimated to affect about 500 million Africans, seriously undermining agricultural productivity despite good soil resources.

Yield reduction is one of the most evident economic impacts related to land degradation. In Africa, it is estimated that past soil erosion may have depressed yields by 2 to 40 percent, with a mean loss of 8.2 percent for the continent (Lal, 1995). In South Asia, water erosion is estimated to reduce harvests by 36 million tonnes of cereal equivalent every year, valued at US$5 400 million, while water erosion would cause losses estimated at US$1 800 million (FAO/UNDP/UNEP, 1994). Worldwide, it is estimated that 75 billion tonnes of soil are lost every year, costing approximately US$400 billion per year, or about US$70 per person per year (Lal, 1998). Analysis conducted at the International Food Policy Research Institute (IFPRI) (Scherr and Yadav, 1996) suggest that a slight increase in land degradation relative to current trends could result in 17–30 percent higher world prices for key food commodities in 2020, and increased child malnutrition. Besides diminishing food production and food security, land degradation hampers agricultural income and thereby economic growth, as shown by analysis supported by country models in Nicaragua and Ghana (Scherr and Yadav, 1996). Land degradation can ultimately result in emigration and depopulation of degraded areas (Requier-Desjardins and Bied-Charreton, 2006).

Long-term effects of land degradation and, in particular, the reversibility of land degradation processes and the resilience of ecosystems are subject to debate. Soil compaction, for example, is a problem in vast areas of cropland worldwide. It is estimated to be responsible for yield

Table 2.3

Estimates of all degraded lands in dry areas

Continent	Total area	Degraded area[1]	Percentage degraded
	(million km²)	*(million km²)*	
Africa	14.326	10.458	73
Asia	18.814	13.417	71
Australia and the Pacific	7.012	3.759	54
Europe	1.456	0.943	65
North America	5.782	4.286	74
South America	4.207	3.058	73
Total	**51.597**	**35.922**	**70**

[1] Comprises land and vegetation.
Source: Dregne and Chou (1994).

Table 2.2

Estimates of the global extent of land degradation

Type	Light	Moderate	Strong + Extreme	Total
	(................... million km² ....)			
Water erosion	3.43	5.27	2.24	10.94
Wind erosion	2.69	2.54	0.26	5.49
Chemical degradation	0.93	1.03	0.43	2.39
Physical degradation	0.44	0.27	0.12	0.83
Total	**7.49**	**9.11**	**3.05**	**19.65**

Source: Oldeman (1994).

reductions of 25 to 50 percent in parts of the EU and North America, with on-farm losses estimated at US$1.2 billion per year in the United States. Compaction is also an issue in Western Africa and Asia (Eswaran, Lal and Reich, 2001). Soil compaction is, however, relatively easily reversed by adapting ploughing depth. Water and wind erosion, in contrast, have irreversible consequences, for example mobile sand dunes (Dregne, 2002). Reversal of the land degradation process often requires substantial investments, which may fall beyond investment capacity or do not grant satisfactory returns under current economic conditions. Rehabilitation costs of degraded land were estimated on average at US$40/ha/year for pastures, US$400/ha/year for rainfed cropland and US$4 000/ha/year for irrigated cropland in sub-Saharan Africa, with average investment periods of three years (Requier-Desjardins and Bied-Charreton, 2006).

2.1.4 Livestock and land use: the "geographical transition"

Historically, people raised livestock as a means to produce food, directly as meat and dairy products and indirectly as draught power and manure for crop production. Since conservation technology and transport facilities were poor, goods and services from livestock were used locally. Livestock were kept geographically close to human settlements, in most cases while pastoralists grazed animals on their migrations.

Distribution trends have varied according to the type of species. Monogastric species (e.g. pigs and poultry) have predominantly been closely associated with human populations, in household backyards. The reason is that monogastric species depend on humans for feed (e.g. household waste, crop by-products) and for protection from predators. The distribution of human populations and monogastric species is still closely correlated in countries with traditional production systems (FAO, 2006c; Gerber *et al.*, 2005). In the distribution of ruminant species (e.g. cattle, buffaloes, sheep, goats) feed and especially fodder resources have played an important role. The land area used for ruminant production is generally substantial. Ruminants have been herded where there are pasture resources, and only in exceptional cases have they been fed with harvested feed (e.g. draught animals or seasonally in cold areas). Herding ruminants involves daily or seasonal movements, over distances varying from hundreds of metres up to hundreds of kilometres in the case of large-scale transhumance or nomadism. Some or all of the humans relying on the herd are involved in the movement, sometimes keeping a geographical anchor area (e.g. village, *boma, territoire d'attache*).

In modern times, livestock production has developed from a resource-driven activity into one led mainly by demand. Traditional livestock production was based on the availability of local feed resources, in areas where disease constraints allowed this.

Modern livestock production is essentially driven by demand for livestock products (Delgado *et al.*, 1999), drawing on additional feed resources as required. As a result, the location of livestock production is undergoing important shifts. With the emergence of large economies such as China and India as new centres of demand and production (Steinfeld and Chilonda, 2006) these geographic shifts have accelerated globally over the last decades. The geography of livestock production and its changes are the keys to understanding livestock-environment interactions. For example, livestock waste does not pose an environmental problem in areas of sparse livestock density; on the contrary, it is a valuable input to crop activities and helps to maintain soil fertility. In contrast, in areas of high livestock density, the capacity of surrounding land or waters to absorb the waste is often exceeded and environmental damage ensues.

Access to markets, feed resources, infrastructure, prices for land, labour and transport and disease status affect the location of livestock production. In this chapter we will analyse the trends in livestock geography and the underlying determinants, to help understand and interpret the environmental consequences. We will examine first the overall extent of land devoted directly or indirectly to livestock production, and then the geographical distribution of the main stages and types of livestock production.

Land use intensification in the feed sector

The first main feature is livestock's demand for pasture and cropland, and the very substantial changes in area that have occurred in the past and continue to occur. Grazing land has expanded by a factor of six since 1800, and now covers roughly 35 million km^2, including large areas of continents where previously there had been little or no livestock grazing (North America, South America, Australia). In many areas, grazing has expanded to occupy virtually all the land that can be grazed and for which there is no other demand (Asner *et al.*, 2004). South America, Southeast Asia and Central Africa are the only parts of the world where there are still significant areas of forest that could be turned into grazing, but in the latter major investments in disease control would be needed. As described in Section 2.5, the expansion of pasture into forest ecosystems has dramatic environmental consequences.

More recent is the advent of grain-feeding to livestock, starting in the 1950s in North America, extending into Europe, the former Soviet Union and Japan in the 1960s and 1970s, now commonplace in much of East Asia, Latin America and West Asia. Grain-feeding is not widespread yet in most of sub-Saharan Africa and South Asia, but is rapidly increasing from a low base. This demand for feedgrains and other feed materials has greatly increased the arable land requirements of livestock production, from a very small area to about 34 percent of the total arable land today (see Section 2.3).

Both the long-term expansion of grazing land and the more recent expansion of arable land for feed will probably reach a maximum, followed by a future decrease. World population is expected on the UN's medium projection to grow to just over 9 billion in 2050, about 40 percent more than today, and to begin decreasing shortly thereafter (UN, 2005). Population growth will combine with changes in incomes and urbanization rates to determine global trends in demand for animal-derived food, though the details are, of course, uncertain. In some developed countries, demand growth is already slowing or declining. In emerging economies, the ongoing livestock revolution is also poised for a slow down, as the tremendous increases in per capita livestock consumption of the past two decades have already occurred, and population growth continues to slow.

In fact, growth rates of livestock production for all developing countries peaked in the 1990s at 5 percent per year, falling to an average of 3.5 percent for the 2001–2005 period. In Asia and the Pacific, where China drove the livestock revolution, average annual growth rates peaked in the 1980s at 6.4 percent, and have decreased since then to 6.1 percent in the 1990s and 4.1 percent over the 2001 to 2005 period. Production followed a similar pattern in West Asia and North Africa. Some regions may, however, not yet have reached their peak in production growth. Growth rates patterns are less clear in Latin America and may well further increase, pulled by export-oriented production in countries such as Argentina or Brazil. Consumption and production are still very low in Africa and will increase as economic growth allows. Finally, production growth is expected to be strong in transition countries, recovering to previous levels. Despite these areas of expansion, it is probable that the bulk of global growth in livestock production has already occurred and that further growth will take place at diminishing rates.

At the same time, intensification and the continued shift from ruminants to monogastrics (especially poultry) are continuously improving land-use efficiency, helping to reduce the land area used per unit of output. This is reinforced by the effect of increased feedcrop production efficiency, demonstrated by the continuing yield increases in all major feedcrops described above. By reducing post-harvest losses, advances in processing and distribution technology and practices also reduce the land required per unit of consumed products. The combined effect, in many developed countries, has been a decrease in the extent of grazing land, amounting to, for example, 20 percent since 1950 in the United States.

Two antagonist trends are thus at play: on the one hand production growth will further increase land demand by the sector, though at diminishing growth rates. On the other, continuous intensification will reduce the area of land used per unit of output. The relative strength of these two trends will determine the trend in total area used by livestock. It is suggested here that the global land requirements of the livestock sector will soon reach a maximum and then decrease. Grazing areas will start to decline first, followed by a reduction in land required for feed production. This overall trend is proposed as a model for understanding of livestock geography dynamics.

Locations shift in relation to markets and feed sources

The second major feature in livestock geography is livestock's changing spatial distribution: the geographical association with the feed base on the one hand, and with people and their needs for animal products on the other. At pre-industrial levels of development, monogastrics and ruminants follow different patterns of distribution. The distribution of monogastrics follows that of human settlements. When humans live predominantly in rural areas, so do monogastrics. In the early phases of industrialization, occurring today in many developing countries, humans rapidly urbanize, and so do monogastrics, usually in a peri-urban belt around consumption centres. This rural to peri-urban shift creates significant environmental problems and public health hazards. In a third phase, these problems are corrected by the gradual relocation of farms farther away from cities, once living standards, environmental awareness and institutional capacity permit. The same pattern applies for ruminants, but is less pronounced because their higher daily fibre requirements entail bulk movement of fodder, and the cost of this acts as a brake to the urbanization of livestock. Ruminant production, both meat and milk, tends to be much more rural-based throughout the different phases of development, even though important exceptions exist (for example, peri-urban milk production, such as observed in India, Pakistan and around most sub-Saharan cities).

The rapid urbanization of livestock, in particular monogastrics, and the subsequent gradual de-urbanization is a second distinct pattern taking place alongside the land-use intensification of the sector. Both patterns have immense implications for livestock's impact on the environment, and constitute the basic theme of this and the following chapters. We will use the expression "*livestock transition*" as a short form for these two patterns.

2.2 Geography of demand

On a global scale, the geographical distribution of the demand for animal-derived foods broadly follows that of human populations (Map 3, Annex 1). However, people have quite different demand patterns, depending on income and preferences. The rationale on which people select their food is complex, based on a number of objectives, and decisions are influenced by individual and societal capacity and preferences, as well as availability. Food preferences are undergoing rapid changes. While growing incomes in developing countries are increasing the intake of proteins and fats, some higher income segments in developed countries are cutting down on these components, for a number of reasons including health, ethics and an altered trust in the sector. On average, per capita consumption of animal-derived foods is highest among high-income groups, and growing fastest among lower- and middle-income groups in countries experiencing strong economic growth. The first group is

Table 2.4

Livestock and total dietary protein supply in 1980 and 2002

	Total protein supply from livestock		Total protein supply	
	1980	2002	1980	2002
	(............... g/person ....)			
Sub-Saharan Africa	10.4	9.3	53.9	55.1
Near East	18.2	18.1	76.3	80.5
Latin America and the Caribbean	27.5	34.1	69.8	77.0
Asia developing	7.0	16.2	53.4	68.9
Industrialized countries	50.8	56.1	95.8	106.4
World	20.0	24.3	66.9	75.3

Source: FAO (2006b).

mostly concentrated in OECD countries, while the latter is mostly located in rapidly growing economies, such as Southeast Asia, the coastal provinces of Brazil, China and parts of India. The two groups coincide geographically in urban centres in rapidly growing economies.

Table 2.4 provides an overview of the important changes that have occurred in the average protein intake of people in various world regions. People in industrialized countries currently derive more than 40 percent of their dietary protein intake from food of livestock origin (the figures do not include fish and other seafood), and little change has occurred between 1980 and 2002. Changes have been most dramatic in developing Asia, where total protein supply from livestock for human diets increased by 140 percent, followed by Latin America where per capita animal protein intake rose by 32 percent. In contrast, there has been a decline in consumption in sub-Saharan Africa, reflecting economic stagnation and a decline in incomes. Detailed consumption patterns are shown in Table 2, Annex 2. The increasing share of livestock products in the human diet in many developing countries is part of a dietary transition that has also included a higher intake of fats, fish, vegetables and fruit, at the expense of staple foods, such as cereals and tubers.

Two major features emerge from these trends. First, there is the creation of new growth poles in emerging economies, with Brazil, China and India now being global players. Meat production in the developing countries overtook that of developed countries around 1996. Their share of production is projected to rise to about two-thirds by the year 2030 (FAO, 2003a). In contrast, in developed countries both production and consumption are stagnating and in some places declining. Second is the development of demand hotspots – urban centres - with high consumption per capita, fast aggregate demand growth, and a shift towards more processed animal-derived foods. A certain homogenization of consumed products (e.g. chicken meat) is also observed, although local cultures still have strong influence.

2.3 Geography of livestock resources

Different livestock species have the capacity to utilize a wide variety of vegetative material. Usually, feedstuff is differentiated into roughage, such as grass from pastures and crop residues, and feed concentrates, such as grains or oilseeds. Household waste and agro-industrial by-products can also represent a large share of feed resources.

2.3.1 Pastures and fodder

Variations in conversion, management and productivity

Grasslands currently occupy around 40 percent of the total land area of the world (FAO, 2005a; White, Murray and Rohweder, 2000). Map 4 (Annex 1) shows the wide distribution of pastures. Except in bare areas (dry or cold deserts) and dense forest, pastures are present to some extent in all regions. They are dominant in Oceania (58 percent of the total area – 63 percent in Australia), whereas their spread is relatively limited in West Asia and North Africa (14 percent) and South Asia (15 percent). In terms of area, four regions have 7 million km^2 of grassland or more: North America, sub-Saharan Africa, Latin America and the Caribbean and the Commonwealth of Independent States (see Table 3, Annex 2).

As Table 2.5 shows, grasslands are increasingly fragmented and encroached upon by cropland and urban areas (White *et al*., 2000). Agriculture expansion, urbanization, industrial development, overgrazing and wildfires are the main factors leading to the reduction and degradation of grasslands that traditionally hosted extensive livestock production. The ecological effects of this conversion, on ecosystems, soil structure and water resources, can be substantial. There are, however, signs of an increasing appreciation of grassland ecosystems and the services they provide, such as biodiversity conservation, climate change mitigation, desertification prevention and recreation.

Permanent pastures are a type of human land use of grasslands, and are estimated to cover about 34.8 million km^2, or 26 percent of the total land area (FAO, 2006b). Management of pasture and harvested biomass for livestock varies greatly. On balance, although accurate estimates are difficult to make, biomass productivity of pastures is generally much lower than that of cultivated areas. A number of factors contribute to this trend. First, large pastures mainly occur in areas with marginal conditions for crop production (either temperature limited or moisture limited), which explain their low productivity in comparison to cropland. Second, in the arid and semi-arid rangelands, which form the majority of the world's grassland, intensification of the areas used as pasture is often technically and socio-economically difficult and unprofitable. Most of these areas already produce at their maximum potential. In addition, in much of Africa and Asia, pastures are traditionally common property areas that, as internal group discipline in the management of these areas eroded, became open access areas (see Box 2.2). Under such conditions any individual investor cannot capture the investments made and total investments levels will remain below the social optimum. Lack of infrastructure in these remote areas further contributes to the difficulty of successfully improving productivity through individual investments. In extensive systems, natural grasslands are thus only moderately managed.

However, where individual ownership prevails or traditional management and access rules are operative, their use is often carefully planned, adjusting grazing pressure seasonally, and mixing different livestock classes (e.g. breeding stock, young stock, milking stock, fattening stock) so as to reduce the risks of climate variability. In addition, techniques such as controlled burning and bush removal are practices that can

Table 2.5

Estimated remaining and converted grasslands

Continent and region	Percentage of				
	Remaining in grasslands	Converted to croplands	Converted to urban areas	Converted to other (e.g. forest)	Total converted
North America tallgrass prairies in the United States	9.4	71.2	18.7	0.7	90.6
South America cerrado woodland and savanna in Brazil, Paraguat and Bolivia	21.0	71.0	5.0	3.0	79.0
Asia Daurian Steppe in Mongolia, Russia and China	71.7	19.9	1.5	6.9	28.3
Africa Central and Eastern Mopane and Miombo in United Republic of Tanzania, Rwanda, Burundi, Dem. Rep. Congo, Zambia, Botswana, Zimbabwe and Mozambique.	73.3	19.1	0.4	7.2	26.7
Oceania Southwest Australian shrub lands and woodlands	56.7	37.2	1.8	4.4	43.4

Source: White, Murray and Rohweder (2000).

Box 2.2 The complex and weakening control of access to pastureland

Pastureland falls under a variety of property and access rights. Three types of land tenure are generally recognized, namely, private (an individual or a company), communal (a local community) and public (the state). Access rights can overlap with property rights, sometime resulting in a complex set of rules controlling the use of resources. Such discrepancies between access rules and the multiplicity of institutions responsible for their application often lead to conflicts among stakeholders claiming access to pastureland. In this regard, the Rural Code of Niger is an exemplar attempt to secure pastoralists' access to rangelands while maintaining such areas under a common property regime. The table below provides an overview of these rules and of the relative level of security they provide for the livestock keeper accessing the land resource. Access to water often adds another layer of access rights: in the dry lands, water plays a critical role as location of water resources are determinant to the use of pastures. Consequently, water rights are key to the actual access to arid and semi-arid pastureland. Holding no formal rights over land, pastoralists often do not get rights over water thereby suffering from a double disadvantage (Hodgson, 2004).

Table 2.6

Land ownership and access rights on pastoral land: possible combinations and resulting level of access security for the livestock keeper

	No overlapping access right	**Lease**	**Customary access rights[1]**	**Illegal intrusion or uncontrolled access**
Private	+++ Freehold	from ++ to +++ Depends on the duration of the leasing contract and the strength of the institution that guarantees the leasing contract.	0 to ++ Issues may arise from the conflicting overlap between customary access right and recent land titling policies.	0 to + Conflict
Communal	+++ Case of commonly/nationally owned herds		+ to +++ Customary access rights tend to loose strength and stability because of migrations and overlap with exogenous property and access right.	+ to ++ Depends on the relative strength of local communities/public administration and livestock keepers

Note: Level of stability in the access to the resource, from very high (+++) to very low (0)

[1] Customary access rights can take numerous forms. A common trait is their indentification of first and latecomers. They are thus quite vulnerable to strong migration fluxes, in which context they may exacerbate ethnic quarrels

Source: Chauveau, 2000; Médard 1998; Klopp, 2002.

improve pasture productivity, although they may also increase soil erosion and reduce tree and shrub cover. The low management level of extensive pasture is a major reason why such grasslands can provide a high level of environmental services such as biodiversity conservation.

For the purpose of this assessment, grasslands are grouped into three categories: extensive grasslands in marginal areas, extensive grasslands in high potential areas, and intensive pastures.

Box 2.2 (cont.)

Stability and security in accessing the pastoral resource are of utmost importance, as they are determinant to the management strategy the user will adopt. In particular, investments in practices and infrastructures improving pasture productivity may only be implemented if there is a sufficiently high probability to realize economic returns on the mid to long term. More recently, the existence of clear usage rights has shown to be indispensable to the attribution and remuneration of environmental services.

Table 2.7

Land use and land ownership in the United States

Acre	Cropland	Pasture	Forest	Other	Total
Federal	0	146	249	256	651
State and local	3	41	78	73	195
Indian	2	33	13	5	53
Private	455	371	397	141	1 364
Total	460	591	737	475	2 263
Relative percentages					
Federal	0	25	34	54	29
State and local	1	7	11	15	9
Indian	0	6	2	1	2
Private	99	63	54	30	60

Source: Anderson and Magleby (1997).

While detailed statistics are lacking, it is probably safe to say that most pasture land is private property, not common property and government land. Pasture are predominantly established on communal and public land in Africa (e.g. freehold land covers only about 5 percent of the land area in Botswana), South Asia (e.g. Commons, dominantly under pasture, account for around 20 percent of India's total land area), West Asia, China as well as Central Asia and Andean highlands. Furthermore, in Australia, most of the Crown Land - representing about 50 percent of the countries' area - is grazed under leases. In contrast, the majority of pasture land is titled under private ownership in Latin America and in the United States. Indeed, a survey on the United States shows that 63 percent of pastures are privately owned, while 25 percent belong to the Federal State and the rest to states and local communities (see Table 2.7). Finally, in Europe, pasture located in fertile low lands are generally privately owned, while marginal areas such as mountain rangelands and wetlands are usually public or communal, with traditional access rights.

Extensive pasture in marginal areas are defined here as having a net primary productivity of less than 1 200 grams of carbon per m^2/yr (Map 4, Annex 1; Table 4, Annex 2). This is the largest category by area (60 percent of all pastures), and is located mostly in dry lands and cold lands. This category is particularly dominant in developed countries, where it represents almost 80 percent of grasslands, while in developing countries it accounts for just under 50 percent of pastures. The contrast can be explained by differences in the opportunity cost of land: in developed countries, areas with good agro-ecological potential are generally used in more intensive forms than pasture. Grasslands in marginal areas are used extensively, either by mobile production systems (Africa, the CIS, South Asia and East Asia), or in large ranches (Oceania, North America). Using actual evapotranspiration (AET) as an indicator of vegetation climatic stress, Asner *et al.* (2004) show that in dry land biomes grazing systems tend to occupy the driest and climatologically most unstable regions, and in temperate biomes the most humid and/or cold parts. In terms of soils, the authors also show that grazing systems generally occupy the least fertile soils in the dry lands and the unfrozen soils of the boreal areas, along with both least fertile and moderately fertile soils in the tropical biomes. They conclude that the land frontier for further pasture expansion into marginal areas is exhausted.

Extensive pasture in high potential areas is defined as those with a net primary productivity of more than 1 200 g of carbon per m^2/y (Map 4, Annex 1; Table 4, Annex 2). Pastures in this category are predominantly found in tropical humid and subhumid climates, as well as in parts of Western Europe and the United States. Because biomass production is steady or seasonal, such pastures are predominantly fenced in and grazed throughout the year.

Intensive cultivated pasture production is found where climatic, economic and institutional conditions are favourable, and land is scarce. Such conditions are typically found in the EU, North America, Japan and the Republic of Korea. In the EU, meat and dairy production units rely to a large extent on temporary pastures (leys), and on the cultivation of forage crops for fresh and conserved feed. The most intensive pastures are found in southern England, Belgium, the Netherlands and parts of France and Germany. Forage systems are high-yield oriented, with regular use of high levels of mineral fertilizers combined with regular manure applications and mechanization. These intensively used pastures are a main source of nutrient loading and nitrate pollution in those countries. Cultivated grasslands are usually species-poor and are typically dominated by *Lolium* species (European Commission, 2004). Intensive forage production in some cases supplies processing industries, such as alfalfa dehydration and hay compaction. These industries (mostly in Canada and the United States) are highly export-oriented.

2.3.2 Feedcrops and crop residues

The feed use of primary food crop products such as cereals and pulses has increased rapidly over recent decades, responding to the growing demand for feed and the inability of traditional feed resources to supply the quantities and qualities required. The growing demand for food and feed has been met without an increase in prices. On the contrary, it was driven by a decrease in cereal prices. In real terms (at constant US$) international prices for grains have halved since 1961 (FAO, 2006b). Expanding supply at declining prices has been brought about mainly by intensification of the existing cropped area.

Cereals

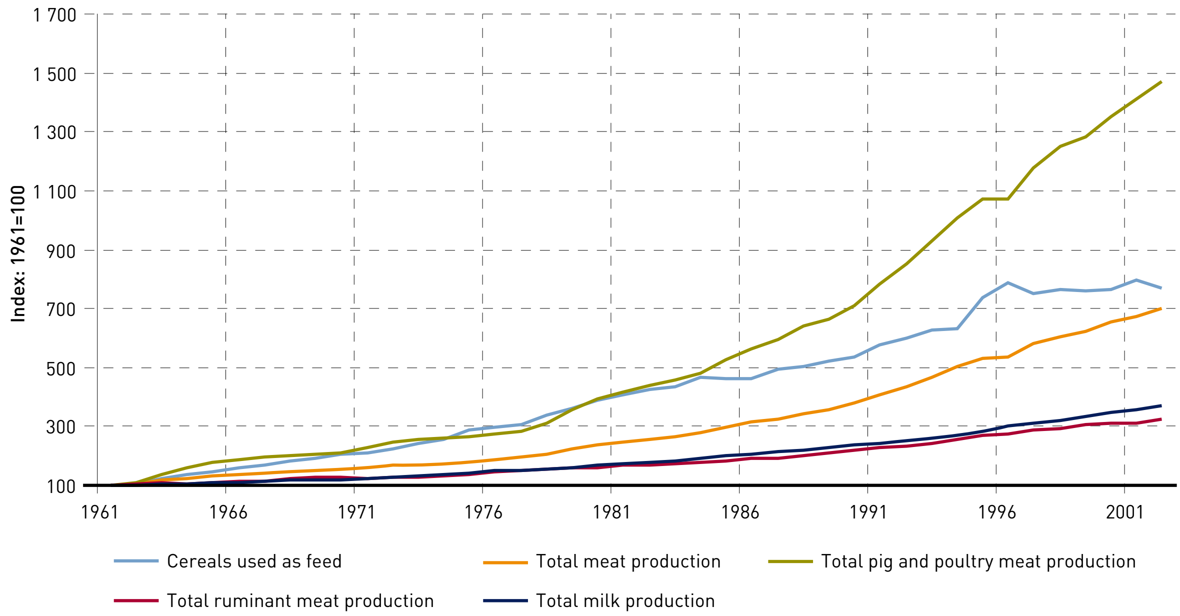
Expansion of feed use slows as feed conversion improves

Some 670 million tonnes of cereals were fed to livestock in 2002, representing a cropped area of around 211 million hectares. A variety of cereals are used as feed, mostly for monogastric species including pigs and poultry. For ruminants, cereals are usually used as a feed supplement. However, in the case of intensive production, such as feedlot or dairy production, they can represent the bulk of the feed basket.

Worldwide, the use of cereal as feed grew faster than total meat production until the mid-1980s. This trend was related to the intensification of the livestock sector in OECD countries, and the related increase in cereal-based animal feeding. During this period, the increasing share of cereals in the feed basket raised the meat production. After this period, meat production has grown faster than cereal use as feed. This can be explained by increasing feed conversion ratios achieved by a shift towards monogastric species, the intensification of livestock production based on high-yielding breeds and improved management practices. In addition, the reduction of subsidies to cereal production under the EU Common Agricultural Policy and economic regression in the ex-socialist countries of Central Europe have reduced the demand for feed grains.

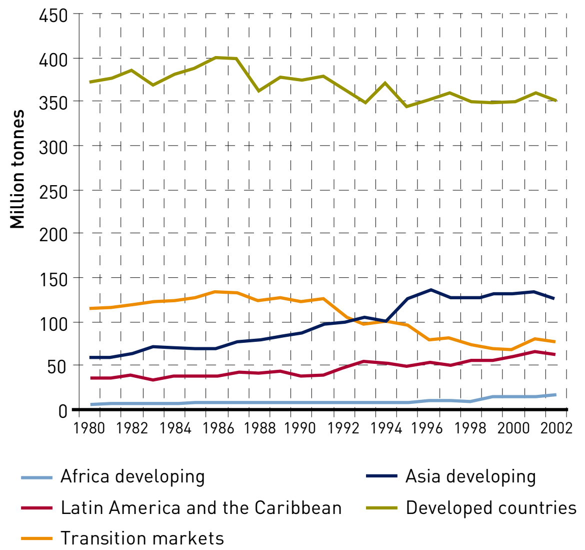
In developing countries, increased meat production has been coupled with increasing use of cereals for feed over the whole period (Figure 2.3). Recently, though, demand for cereal

Figure 2.3 **Comparative growth rates for production of selected animal products and feed grain use in developing countries**



Source: FAO (2006b).

Figure 2.4 **Regional trends in the use of feed grains**



Source: FAO (2006b).

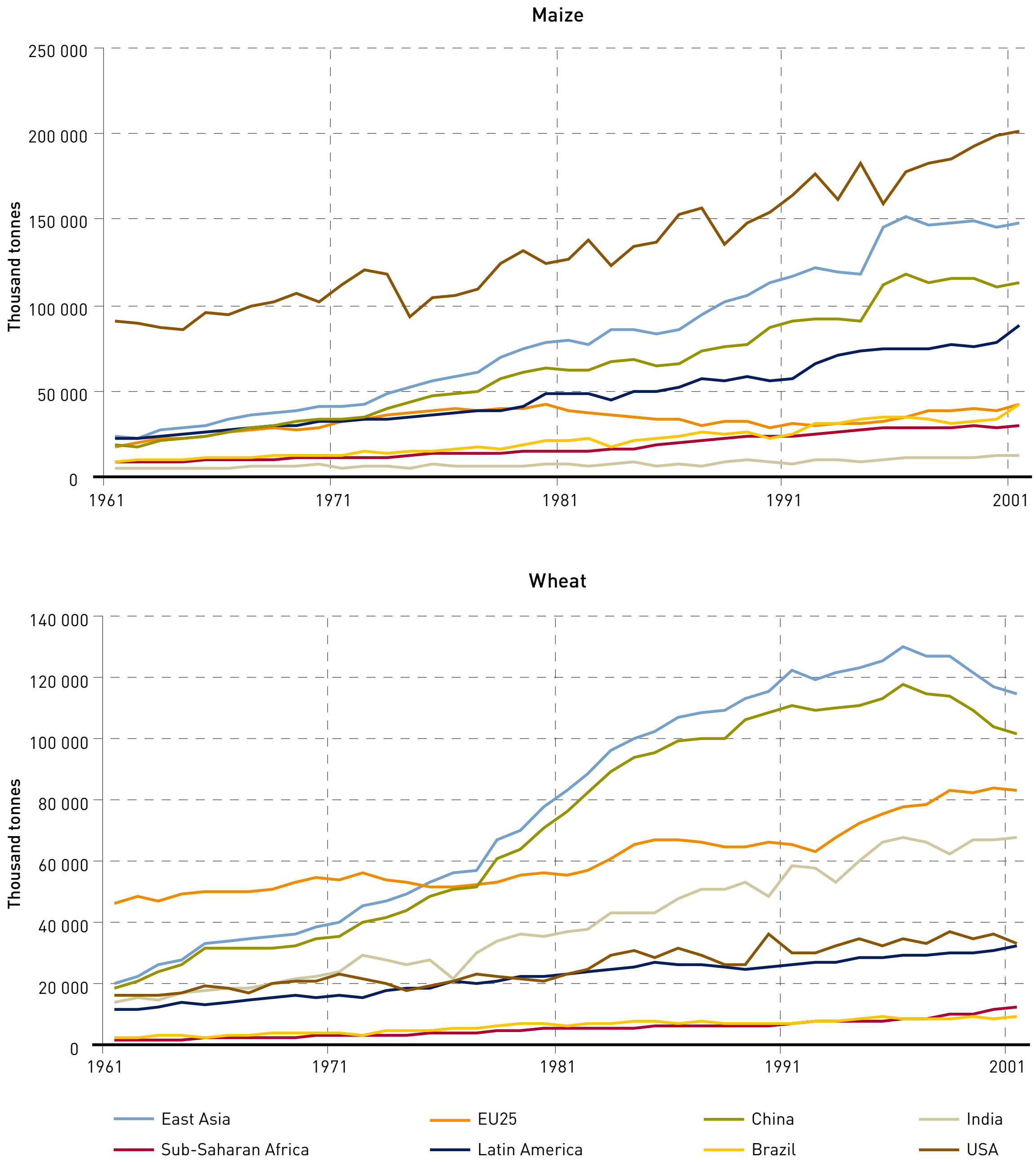
as feed has tended to stabilize, while total meat production has continued to grow, probably driven by highly intensive and monogastric-dominated developing countries, such as Brazil, China and Thailand.

Overall, since the late 1980s, feed demand for cereal has been relatively stable. Such stability, observed at an aggregated level, hides a marked geographical shift in demand, which occurred in the mid-1990s. Demand in the transition countries fell sharply, offset by increases in demand from Asian developing countries (Figure 2.4). At the same time, but more progressively, feed demand dwindled in industrialized countries and strengthened in the developing world.

Expressed as a share of total cereal production, volumes of cereal used as feed increased substantially in the 1960s, but remained fairly stable thereafter and even declined in the late 1990s.

Among the cereals, maize and barley are used mainly as feed – more than 60 percent of their total production over the 1961 to 2001 period. However, feed demand for cereals varies greatly across regions. Maize is the predominant feed cereal in Brazil and the United States, while wheat and barley are dominant in Canada and Europe. Southeast Asia relied on similar proportions of wheat until the early 1990s, since then,

Figure 2.5 **Feed demand for maize and wheat in selected regions and countries from 1961 to 2002**

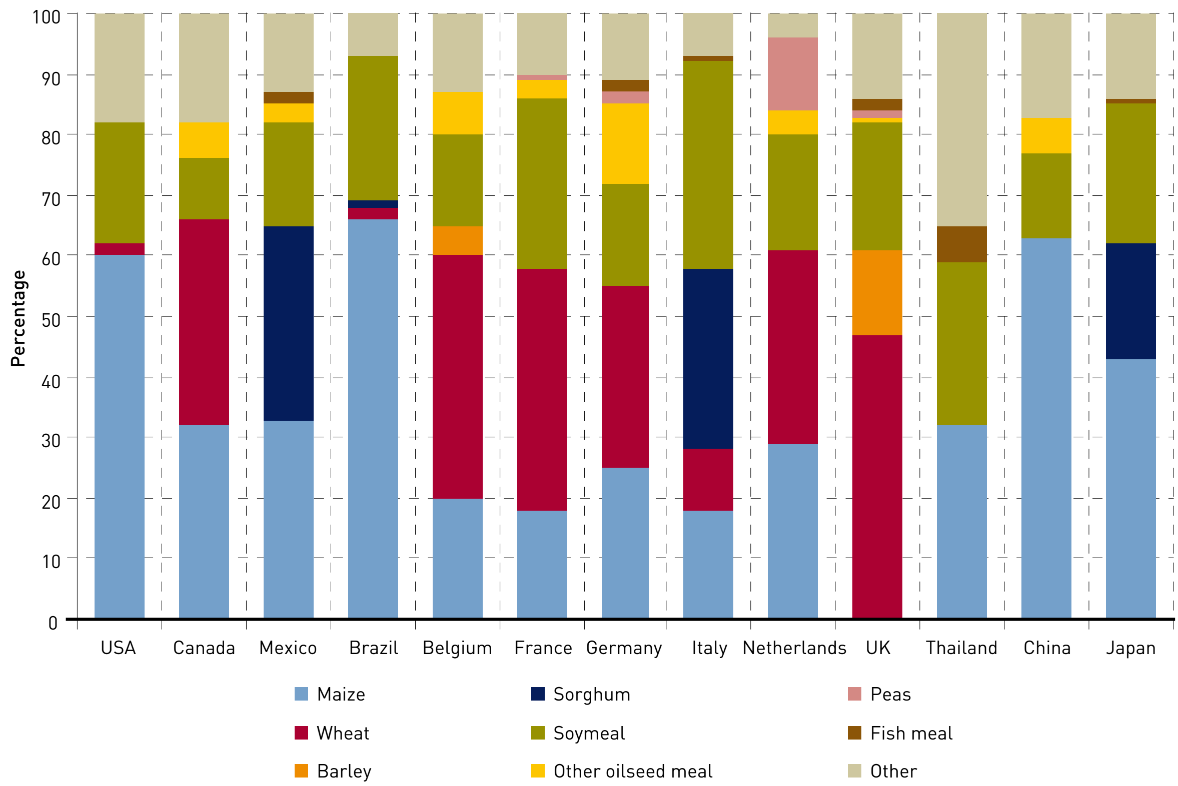


Source: FAO (2006b).

has progressively shifted to maize. These trends reflect the suitability for production of particular crops in these regions – wheat and barley being more adapted to temperate or cold climates than maize (Map 5, Map 6 and Map 7, Annex 1).

Different comparative advantages for producing feedgrains, along with trade conditions, translate into different feed rations at the livestock production level. There is a remarkable homogeneity in the total cereal component in feed rations across analysed countries (cereals represent for example about 60 percent of the weight of chicken feed – Figure 2.6). However, countries differ noticeably in the mix of various

Figure 2.6 **Relative composition of chicken feed ration in selected countries (by weight)**



Note: A large amount of rice is included in the "other" class for Thailand.
Source: Own calculations.

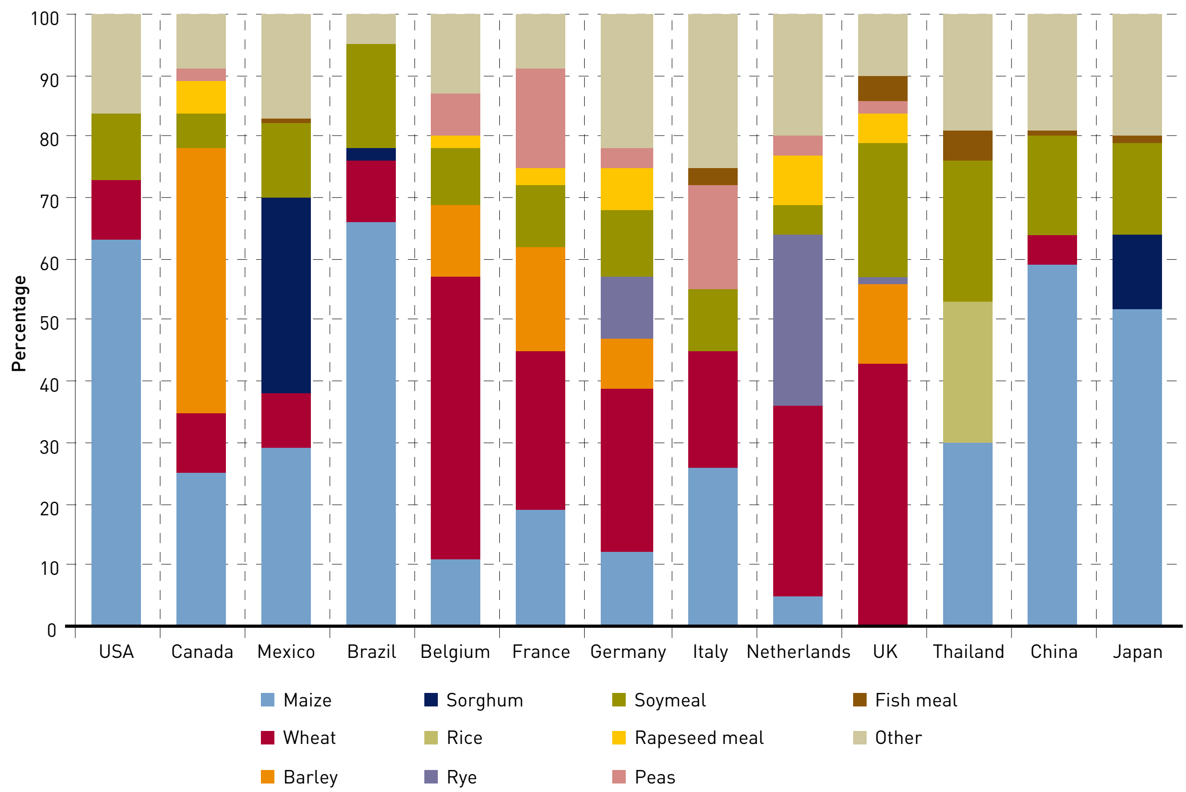
cereals. Maize dominates in chicken feed in Brazil, China and the United States and wheat in the EU. Similar trends are observed for pigs, with a more variable cereal content (60 to 80 percent) for the analysed countries (Figure 2.7).

Crop residues

A valuable but increasingly neglected resource

Crop residues are a by-product of crop agriculture. They are typically high in fibre content but low in other components and indigestibility. The role of crop residues is, therefore, usually one of supplementing basic caloric and fibre requirements, mostly in the diet of ruminants. The use of crop residues such as straw and stover as feed is still fundamental to farming systems that produce both crops and livestock. In these systems, livestock (particularly ruminants) convert residues into valuable food and non-food goods and services. Crop residues represent a large share in the feed basket, especially in tropical semi-arid and subhumid environments where most of the world's poor farmers live (Lenné, Fernandez-Rivera and Bümmel, 2003). Crop residues – as well as agro-industrial by-products – often play a critical role during periods when pastures are in low supply (Rihani, 2005). Devendra and Sevilla (2002) estimated that 672 million tonnes of cereal straws and 67 million tonnes of other crop residues are potentially available as feed in Asia. The actual use of rice straw as feed varies greatly, from over 70 percent of the available total in Bangladesh and Thailand to only 15 percent in South Korea. In other countries of Southeast Asia and in China, the share is estimated at between 25 and 30 percent.

Figure 2.7 **Relative composition of pig feed basket in selected countries (by weight)**



Note: A large amount of oats is included in the "other" class for Italy.
Source: Own calculations.

Despite its local importance in smallholder mixed farming systems, the use of crop residues as feed is in decline. A number of factors drive this trend, all are related to agricultural intensification. First, less crop residues are available per unit of crop produced, because of genetic selection aimed at reducing residues (e.g. dwarf cereals) and because of more effective harvesting machinery. Second, genetic selection, based on performance traits relating to the main food product, tends to reduce the quality of crop residues (Lenné, Fernandez-Rivera and Bümmel, 2003). Third, intensive livestock production requires feed of high quality, which typically cannot be provided by crop residues. In addition, crop residues have gained increasing importance as a source of energy and in furniture production.

Other feedcrops

After cereals, the second main category of feedcrop is roots and vegetables. About 45 million tonnes were fed to livestock in 2001 - mostly cassava, potatoes, sweet potatoes, cabbage and plantain. In addition, about 17 million tonnes of pulses (mainly peas and beans) were fed to livestock, representing an important share of protein intake in some places, e.g. France, Italy and the Netherlands. Pulse, root and vegetable feedcrops are estimated to span a total area of over 22 million hectares. Oil seeds can also directly be fed to livestock, although the large majority is processed and only by-products are used as feed. In 2001, feed demand for oil seeds totalled about 14 million tonnes, equivalent to a cropped area of 6.4 million hectares. The main oil seeds used as feed include soybeans, cottonseed, rapeseed and sunflower seed.

2.3.3 Agro-industrial by-products

As humans develop ever more sophisticated food chains, agro-industries are growing and so is the availability of associated by-products as sources of animal feed. An increasing share of human food is being processed, the number of stages of processing is growing, and processing plants are scaling up. All these factors raise the available amounts of by-products of reliable quality, so that gathering and processing them as feed becomes economically profitable.

Soybean

Feed demand drives a production boom

Soymeal, a by-product of the soybean oil industry, is a case in point. In oil extraction, soybeans yield 18 to 19 percent oil and 73 to 74 percent meal (Schnittker, 1997); the rest is waste. Only a small portion of the harvested beans is directly fed to animals (about 3 percent globally). However, more than 97 percent of the soymeal produced globally is fed to livestock. Soymeal is used primarily in the diet of monogastric species, particularly chickens and to a lesser extent pigs. Figure 2.8 shows the high fraction of soybeans processed by the oil industry, and the stable ratio between processed beans and resulting cakes over the last four decades. Worldwide, the feed demand for soymeal has skyrocketed over the past four decades, reaching 130 million tonnes in 2002 – see Figure 2.8. This far outstrips the second largest oilcake, made of rape and mustard seed, with 20.4 million tonnes of production in 2002.

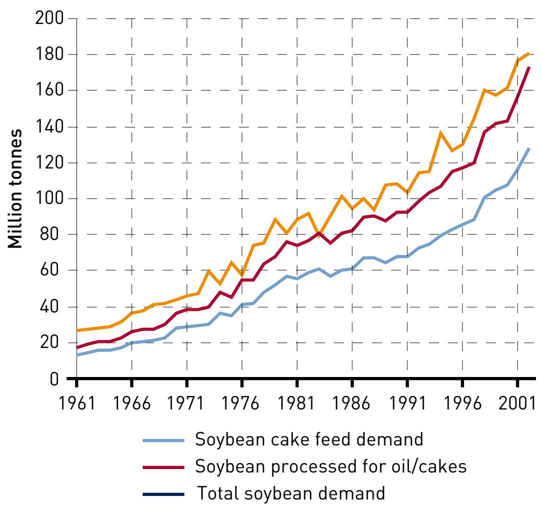
Growth of soymeal feed production took off in the mid-1970s and accelerated in the early 1990s, propelled by rapidly growing demand in developing countries. However, soymeal use per person is much higher in developed countries (50 kg per capita as opposed to 9 kg in developing countries). Over the past four decades, demand for soymeal has increased faster than total meat production, implying a net increase in the use of soymeal per unit of meat produced. This is true for ruminant as well as monogastric species. Part of this increase in use of soymeal by livestock is a consequence of the increasing demand for fishmeal in the fast expanding aquaculture sector, which, with a rather inflexible supply of fishmeal, forced the livestock sector to search for other protein substitutes in livestock feed. Aquaculture is more dependent on fishmeal (and fish oil) than terrestrial animals, and the share of fishmeal used by aquaculture grew from 8 percent in 1988 to about 35 percent in 2000 (Delgado *et al.*, 2003) and 45 percent in 2005 (World Bank, 2005a) despite efforts to reduce the proportion of such products in the fish feed ration. Another factor is the prohibition of using animal offal in animal feed to reduce the risk of mad-cow disease, which put more pressure on the production of vegetable protein for animal feed (see 2.3.4).

World soybean production tripled over the 1984 to 2004 period, half of this increase occurring in the last five years. Production is highly concentrated geographically. Eight countries provide 97 percent of world production; the top three countries (Argentina, Brazil and the United States), account for 39 percent, 26 percent and 17 percent respectively. These three countries also achieved the highest absolute growth in production over the past four decades.

Map 9 (Annex 1) provides an overview of areas where soybean is cropped for oil and meal production. The strong geographical concentration is clearly visible. Soybean processing and marketing have a high level of geographical concentration, specialization, vertical integration and economies of scale. Small producers – especially in developing countries – find it very difficult to compete, especially when faced with the requirements of rapidly expanding and highly efficient international trade. Recently, however, new countries started producing soybeans for export, achieving substantial production growth over the 1999 to 2004 period. These countries are in Latin American (e.g. Bolivia, Ecuador, Uruguay), the former Soviet bloc countries (e.g. Czech Republic, Kyrgyzstan, the Russian Federation and Ukraine) and Africa (e.g. Uganda). Of the largest soybean producers, the United States has the highest average yields: 2.6 tonnes per hectare.

Some of the smaller producers also achieve good results. Argentina and Brazil produce on average about 2.4 tonnes/ha, while China's yields are only 1.65 tonnes/ha. India is far behind with average yields of only 0.90 tonnes/ha (Schnittker, 1997). Over the past decade, the yield increase has been substantial, although most of the extraordinary growth in supply was the result of expansion of soybean harvested area – see Figure 2.2. Although the soy oil industry was initially the main driver of soybean production, feed demand is currently driving the expansion. Indeed, soymeal accounted for about two-thirds of the value of soybeans in recent years, with oil about one-third. This situation has developed over the past 30 to 40 years, as the demand for protein for terrestrial and aquatic animal feed increased rapidly and as the production of other oil-rich seeds such as palm oil, canola and sunflower weakened the demand for soy oil (Schnittker, 1997). This is confirmed by the analysis of feed baskets (Figures 2.6 and 2.7), which shows that soymeal is a major source of protein in all countries analysed. The contribution of other locally produced vegetable protein sources such as peas and other oil cakes is generally limited. The increasing demand for oilseeds for biofuels might change these trends (see 2.3.4).

Figure 2.8 **Global trends in demand for soybean and soybean cake from 1961 to 2002**



Source: FAO (2006b).

Other agro-industrial by-products

Other agro-industrial by-products are less widely commercialized and their use is confined to their regions of origin. They are often used during droughts or other periods of scarce feed supply to supplement pasture and crop residues (Rihani, 2005). In North Africa, their contribution to feed resources for small ruminants rises from 10 percent in favourable years to 23 percent in years with drought, when pasture and crop residues are short (Rihani, 2005). In this region, agro-industrial byproducts used for feed include brewery residues, citrus, tomato and date pulp, olive cakes, and sugarbeet molasses and pulp. In Japan, 30 percent of agro-industrial byproducts are recycled as feed after being dehydrated (Kawashima, 2006).

In contrast, food wastes from marketing and retailing are much less recycled as feed (5 to 9 percent, depending on the source), because their content and quality vary greatly and their geographical spread increases collection costs. The safety of food wastes is also questionable.

Household waste

The use of household waste as feed remains predominant among rural households in developing countries; though in OECD countries it is only sporadic. Food wastes are often collected from food processors in urban centres. Food wastes from individual households have been an important traditional feed resource, in particular for smallholder monogastric and dairy production. Indeed, the recycling of household wastes, as feed for monogastric species, explains the close spatial correlation between human populations and those of pigs and poultry prior to and during

Table 2.8

Supply and recycling of food by-products in Japan

	Supply of by-products per year	Share recycle as feed	Share recycle in other forms
	(thousand tonnes)	*(%)*	*(%)*
Food manufacturing industry	4 870	30	48
Food wholesaler/retailer	3 360	9	26
Food service industry	3 120	5	14
Total	**11 350**	**17**	**32**

Source: Kawashima (2006).

the early stages of industrialization. However, rising environmental and human health requirements usually bring an end to backyard production in urban and peri-urban areas, once rural areas are connected to urban centres adequately enough to provide sufficient and reliable supplies.

2.3.4 Future trends

Increasing feed demand

Today, feed production is estimated to use approximately 30 percent of the emerged land. Statistics on pasture add up to 34.8 million km^2 globally (26 percent of emerged land) while we estimate that about 4.7 million km^2 of cropland are currently dedicated to feed production (4 percent of emerged land or 33 percent of all cropland). The latter does not include crop residues but includes most agro-industrial by-products (see methodological note in Annex 3). In comparison, the shares of total meat output from grazing, mixed and intensive landless, are estimated at 8 percent, 46 percent and 45 percent respectively (see Section 2.4). The juxtaposition of these figures gives a sense of the strong intensity gradient along which livestock use land.

Livestock production is projected to increase and with it the demand for animal feed. FAO (2003a) estimates that feed demand for grain will increase by nearly one billion tonnes over the 1997/99 to 2030 period (at growth rates of 1.9 percent a year between 1997/99 and 2015, and 1.6 percent per annum thereafter). Most of this growth will be driven by developing countries, where the use of concentrate feeds is projected to grow faster than meat production. Feed use is expected to remain the most dynamic element driving the world cereal economy, accounting for a growing share of aggregate demand. Use of maize as feed is projected to rise from 625 to 964 million tonnes over the 2002 to 2030 period, with most of the growth occurring in developing countries (265 million tonnes), especially in Southeast Asia (133 million tonnes), Latin America (56 million tonnes) and to a lesser extent in sub-Saharan Africa (33 million tonnes). Projected feedcrop growth rates are higher than over the last 15 years. The projected increasing feed demand for cereals is the result of interacting trends.

First, the current recovery of economic decline in transition economies is expected to be sustained, and with it the growing demand for livestock products. Such demand will fuel production and thus feed demand to levels at least equal to those observed in the early 1990s. Feed demand for cereals is also expected to rise in the EU, boosted by decreasing prices induced by the common agricultural policy (CAP) reform process. The reforms proposed in 1992, and implemented in 1994 (Ray MacSharry reform), brought a 30 percent cut in the cereal intervention price, phased in over three years. These were followed by a further reduction in support prices for cereals, which were agreed to in March 1999 in the framework of Agenda 2000. In parallel, factors reducing demand are expected to weaken. Especially, the gain in feed efficiency is expected to dwindle.

In the past decades, the shift towards monogastric species, especially poultry, which has a higher feed conversion ratio than ruminants (typically 2 to 4 versus 7 kg of grain per kilogram of meat) (Rosegrant, Leach and Gerpucio, 1999); further gains in feed efficiency, from advanced feeding methods (multiple-stage feeding) and breeding, have allowed a substantial increase in feed efficiency, which has contributed to the counterbalancing of the soaring demand for feed. However, it is estimated that the shift towards monogastric species will be slower than over the last 20 years (FAO, 2003a) and room for feeding and breeding improvement also seems limited.

The role aquaculture will play in this process is uncertain. Products from fish fed on similar feed as livestock (e.g. tilapia) may be increasingly substituted for livestock products. Because of their substantially better feed conversion ratio than livestock[5] (typically 1.6 to 1.8 for tilapia), aquaculture may play the role poultry played in the past, depressing feed demand for cereals. Although possible, a significant shift to fish products would, however, require both the organization of supply chains and changes in consumers' preference and would thus probably only occur over a long period.

Although at a slower pace, the number of grazing animals will also increase, requiring more fodder. Tilman *et al*. (2001) estimate a net increase of 2 million km^2 of pasture by 2020 and of 5.4 million km^2 by 2050. While recognizing that pasture expansion will probably occur in Latin America and, to a lesser extent, sub-Saharan Africa, the authors of the current study consider that these figures may be overestimated.

The potential and actual production of vegetative feed resources varies substantially across the globe along with different ecological, economic, technical and policy contexts. The question of how feed supply can meet the demand of a burgeoning livestock sector is of relevance beyond its boundaries. Some aspects of this question are assessed below.

[5] Fish are cold-blooded, use less energy to perform vital functions and do not require the heavy bone structure and energy to move on land. Fish catabolism and reproduction is also more efficient.

Mixed cattle at pasture on a ranch in Obala – Cameroon 1969

Pastures: backs against the wall

Exploring options for pasture expansion, Asner *et al*. (2004) suggest that the expansion of grazing systems into marginal areas has already more or less reached the limits imposed by climate and soil factors. Any significant increase of grassland could, therefore, only take place in areas with high agro-ecological potential.

To see what land-use changes might result from pasture expansion, the current dominant land use in areas with high suitability for pasture but no current use as pasture are identified (see Map 10, Annex 1). Globally, forestry is the predominant current use of this land (nearly 70 percent) and in most of the continents, especially in sub-Saharan Africa (88 percent) and Latin America (87 percent). Cropland is the leading current use in West Asia and North Africa, Eastern Europe and South Asia. Urbanization is of local relevance only, except in Western Europe, where urban areas occupy 11 percent of the land suitable for pasture.

These results suggest that any significant increase of grassland into areas with high agro-ecological potential can, therefore, only occur at the expenses of cropland (which is highly improbable) or through the conversion of forests to pasture, as is currently happening in the humid tropics.

In reality, pasture will most probably keep on losing ground to cropland. This trend is already occurring in a number of places, and in particular in Asia and sub-Saharan Africa, fuelled by an increasing demand for grain. Urbanized areas will also encroach into pasture land, especially in areas with booming populations such as sub-Saharan Africa and Latin America. Encroachment by urban and cropland areas is particularly harmful to pasture-based systems, as it usually takes away the most productive land. This compromises the access to biomass during the dry season, when the less productive land cannot sustain the herd. This often results in overgrazing, increased losses during drought and conflicts between pastoralists and agriculturalists.

Pastures are on the increase in Africa and in Latin America where the land colonization process is still ongoing. The pace of pasture expansion into forests will depend mainly on macro- and microlevel policies in concerned areas. In OECD countries, the total pasture area will be stable or declining, as rangelands are converted to cropland, urban areas and natural ecosystems/recreational areas. Since the prospect of expansion on pastureland is limited, the intensification of pasture production on the most suitable land, and loss of marginal pastures, is likely to continue (Asner *et al*., 2004). It is indeed estimated that there is significant scope for increased grassland production, through improved pastures and enhanced management. In the subhumid areas of Africa, and especially in West Africa, Sumberg (2003) suggests that, on fertile soils with good accessibility, crops and livestock will be integrated, while the most remote areas will be progressively marginalized or even abandoned.

Climate change is also likely to alter grassland-based systems. The impact on natural grasslands will be greater than on cropland, where growing conditions can be more easily manipulated (e.g. by irrigation or wind protection). On dry lands, the impact is projected to be dramatic. Results from a case study in Mali by Butt *et al*. (2004) indicate that climate change could reduce forage yields by as much as 16 to 25 percent by 2030, while crop yields would be less affected, with a maximum of 9 to 17 percent reduction for sorghum. In contrast, pastures located in cold areas are expected to benefit from rising temperatures (FAO, 2006c). An opportunity for pasture expansion exists in transition countries, where extensive areas of abandoned grassland would be available for re-colonization at relatively limited environmental cost.

Croplands

Prospects for yield and land expansion jeopardized by degradation and climate change

Producing more feed will require increasing productivity, increasing production area, or a combination of both. There is a wide consensus that the potential to further raise the yield frontier in cereals and oilseeds is generally large; although yields may have peaked in some areas (e.g. the Ganges basin) (Pingali and Heisey, 1999; FAO, 2003a). In the case of major cereals, the yield frontier of maize would be easiest to shift, through technology transfer from industrialized nations. Pingali and Heisey (1999) estimate that this transfer is most likely to occur in China or other parts of Asia, where rapidly expanding demand for feed maize will make the crop increasingly profitable and where the private sector should be able to make the necessary investments. In contrast, growth in soybean yields may be slower (Purdue University, 2006). There is also remaining potential for expansion of cropland. Currently, arable land plus land under permanent crops is estimated to represent slightly over one-third of the land that is suitable for crop production (FAO, 2003a). It is, therefore, estimated that land expansion will continue to contribute to the growth of primary agricultural output.

The prospects vary considerably by region. The possibility of expanding cropland under grains and soybean is limited in South and Southeast Asia (Pingali and Heisey, 1999). It is more promising in most other continents, especially in Africa and Latin America. The contribution of arable land expansion to crop production over the 1997/99 to 2030 period is projected to be 33 percent in Latin America and the Caribbean, 27 percent in sub-Saharan Africa, 6 percent in South Asia and 5 percent in East Asia (FAO, 2003a). These figures reflect the extent of areas with high potential for cereal production (Map 11, Annex 1), and soybean production (Map 12, Annex 1).

Two major issues jeopardize this overall positive picture. First is the land degradation associated with intensifying and expanding crop production, and its consequences in terms of ecological damage and decreased productivity. Declining productivity trends observed lately in South Asia can be directly linked to the ecological consequences of intensive cropping, including the build-up of salinity, waterlogging, declining soil fertility, increased soil toxicity and increased pest populations (Pingali and Heisey, 1999). Expanding arable land into natural ecosystems also has dramatic ecological implications, including loss of biodiversity and of ecosystem services such as water regulation and erosion control. Issues of land degradation associated with intensive agriculture are further investigated in Section 2.5 below.

Second, although there seems to be enough production potential for the world taken as a whole, there are considerable local variations. Because of land scarcity and poor land suitability for cropping, local level land shortages are likely to arise (FAO, 2003a). The impact of climate change will also vary considerably by region. Climate change will affect the yields of vegetative resources for livestock production, mainly through changes in temperature, rainfall, CO_2 concentration, ultraviolet radiation and pest distribution. Indirect effects may also occur through the alteration of soil biology and chemistry. Some of these changes will be damaging, such as reduced yields in many areas; some may be beneficial, such as the "fertilizing effect" of increased CO_2 concentrations. The literature tends to agree that there may be a net reduction of yields aggregated at global level. However, North America, South America, Western Europe and Oceania are often listed among the regions for which climate change may bring increasing yields (Parry *et al.*, 2004).

Competitions and complementarities in the quest for feed biomass

Animals are not the sole users of crops, crop wastes and by-products. The foodcrop, aquaculture, forestry and energy sectors are competing users, thus indirectly competing with livestock for land resources. Direct competition between feed and food demand for cereal is estimated to be low on average. The elasticity of the livestock demand for cereals and oilseeds is much higher than elasticity of the human demand. Thus, when crop prices rise, the demand for meat, milk and eggs tends to decrease rapidly, releasing more of the cereal supply to human consumption. It can, therefore, be argued that the use of cereals by livestock represents a buffer, acting to protect food demand from fluctuations in production (Speedy, 2003). This buffering effect occurs also on a smaller scale, for example with sheep fattening in the Sahel. In a good year, the surplus grain crop is used for the household fattening of sheep, whereas in a bad year, it is exclusively used for human food. But the availability of using grain for animal feed in good years induces farmers to grow more than strictly needed, thus improving food security in a poor year.

FAO projections suggest that, despite regionally contrasted trends, the share of cereals globally used as feed is likely to increase by 2030, driving cereal production growth from 1.8 to 2.6 billion tonnes between 1999/01 and 2030. An increasing share of this feed use will be taken by the aquaculture industry, which is expected to grow at 4 to 6 percent per year to 2015, and 2 to 4 percent per year over the following 15 years (FAO, 1997).

Indeed, with feed conversion ratios better than those for livestock, aquaculture will become a significant competitor to monogastric species in regions such as Southeast Asia and sub-Saharan Africa.

The energy sector is another competitor. With the approaching depletion of fossil fuel resources and increasing efforts to mitigate climate change, green energies based on vegetal biomass are taking off. Today, ethanol produced from sugar cane accounts for 40 percent of the fuel sold in Brazil. Worldwide, fuel ethanol production increased from 20 billion litres in 2000 to 40 billion litres in 2005, and is expected to reach 65 billion litres in 2010 (Berg, 2004,) In 2005, the total area used for biofuel crop production in the EU was around 1.8 million hectares (EU, 2006). The average ethanol yield ranges between 3 000 litres/ha (based on maize) and 7 000 litres/ha (beet) (Berg, 2004). In the medium to long term, this land use may well compete with feed production. It is, however, foreseen that the "second generation" of bio-fuels will rely on a different biomass resource, shifting to the fermentation of lingo-cellulosic materials. If such prospects materialize, the biofuel sector may well become a strong competitor of the grass-based livestock production for the access to biomass.

Complementarities also exist. The potential complementarities between food and feed production at the level of crop residues and agro-industrial by-products are well known and to some extent achieved (e.g. oilseed meal). The further expansion of agro-industrial by-products and non-conventional feed resources may represent a major potential for increasing feed resources from primary crop production.

In contrast, food wastes are seldom recycled as feed. With a very low self-sufficiency for feed (24 percent), Japan is exploring ways of increasing recycling of food waste for feed. In addition to reducing feedstuff imports, the aim is to reduce environmental impacts currently associated with incineration or dumping in landfills. Kawashima (2006) proposes technical options for the sanitation and homogenization of food wastes, based on dehydration, heat treatment and silage.

In various contexts, food wastes and agro industrial by-products could contribute substantially to the feed supply, and by the same token release pressure on land. Their better recycling can help to improve self-sufficiency for feed and to improve animal productivity by supplementing diets. There is also an ecological interest in recycling the nutrients and energy embodied in food wastes and by-products, instead of disposing of them in environmentally damaging ways. However, food safety and ethical concerns do limit the potential for this practice, and must be adequately addressed.

Food safety and consumer preferences also shift feed requirements

The bovine spongiform encephalopathy (BSE) scare has shown the dramatic consequences of an ill-considered recycling of agro-industrial by-products (in this case meat and bone meal) as animal feed. The incident and its media coverage have also brought new livestock feeding practices to general public attention. This and similar events such as dioxin contamination of broiler meat in some EU countries have created widespread consumer distrust in the industrial livestock sector. Following the precautionary principle (UN, 1992), the EU set a ban on feeding meat-and-bone meal to all farm animals starting on 1 January 2001.

While the adoption of the precautionary principle should guarantee safer animal-derived foods, it may have a significant impact on feed requirements. The EU meat-and-bone meal ban is a dramatic example. Before the ban the amount of meat and bone meal consumed in the EU was about 2.5 million tonnes annually. Based on protein equivalency, this equates to 2.9 million tonnes of soymeal or to 3.7 million tonnes of soybeans (USDA/FAS, 2000). Largely because of the ban, EU soymeal imports increased by almost 3 million tonnes between 2001 and 2003, about 50 percent more than over the previous period of the same length. Soybean expansion and shipment creates environmental impacts in terms of biodiversity erosion, pollution and greenhouse gas emissions (see Chapter 3). Although soymeal is the main beneficiary of the meat-and-bone meal ban, corn gluten, field peas, rapeseed meal and sunflower seed meal are other potential substitutes. This example casts a dramatic light on the conflicting objectives associated with livestock production.

The need to address such tradeoffs is likely to become increasingly acute, and policy decisions in this area will be critical to the environmental and social sustainability of the sector. Another factor affecting the feed sector, and in particular the soybean market is consumer concern about genetically modified organisms (GMOs). Responding to consumer concerns, the EU has required that products containing GMOs be labelled so that consumers can identify them. In addition, the EU is pushing for GMO soybeans to be separated from other varieties, so that those purchasing them for feed or as ingredients can make a choice. This trend, if maintained, will impact producers' relative competitiveness as well as production practices. More generally, the use or banning of GMOs in animal feeds will have an impact on the crop species used, production practices, competitiveness of smallholders, yields and the future geographical distribution of their production areas.

2.4 Production systems: location economics at play

Production and processing systems are shaped by the requirements of linking demand with resources (feed, labour, water, etc.), given the available technology and capital. This has resulted in the diverse geographical trends of livestock and production systems that we currently observe. The pattern has changed over time, following human population dynamics (e.g. growth, movements), technical changes (e.g. domestication, cropping, transport) and cultural preferences.

These geographical shifts are still continuing, perhaps even accelerating, as a result of the rapid evolution driven by demand, resource scarcity, technology and global trade (see Chapter 1). The major changes in demand for animal products were reviewed in Section 2.2. They have resulted in a geographical redistribution of demand, with urban centres in rapidly growing economies emerging as consumption centres.

Resource availability influences livestock production costs, especially land and water resources. Previous sections have shown that in several regions of the world there is increasing competition for land and limited options for expanding the feed base, while in other regions there is still potential for expansion. In this section, we will first review the current geographical distribution of livestock and their production systems, in the light of the sector's history. We will then explore current spatial trends of landless and land-based production systems.

2.4.1 Historical trends and distribution patterns

Historically, transport and communication infrastructures were more limited than today. Products were not easily transported and technologies were not propagated rapidly. As a result, demand and resources had to be linked locally, mostly relying on locally available capital and technology mixes. Traditionally, livestock production was based on locally available feed resources, particularly those of limited or no alternative value, such as natural pasture and crop residues. In a context of less developed communication than nowadays, cultures and religions were less widespread and more specific to limited areas. They, therefore, influenced consumer preferences and production options in more diversified ways.

Livestock production systems

Production environments, intensities and goals vary greatly within and across countries. Animal agriculture systems correspond to agro-ecological opportunities and demand for livestock commodities. In general, the systems are adjusted to the prevailing biophysical and socio-cultural environment and, traditionally, since there were no external inputs they have been, for the most part, in sustainable equilibrium with such environments.

In many of these systems, the livestock element is interwoven with crop production, as in the rice/buffalo or cereal/cattle systems of Asia. Animal manure is often essential in maintaining soil fertility, and the role of animals in nutrient cycling is often an important motivation for keeping animals, particularly where this involves a transfer of nutrients from common property resources to private land. In other cases, mobile forms of livestock production have been developed to harness resources from semi-arid or mountainous, seasonally shifting or temporarily available pastures. Although many of these systems result from a long historical evolution, they are currently under pressure to adjust to rapidly evolving socio-economic conditions. Over recent decades, large intensive livestock production units, in particular for pig and poultry production have emerged in many developing regions in response to rapidly growing demand for livestock products.

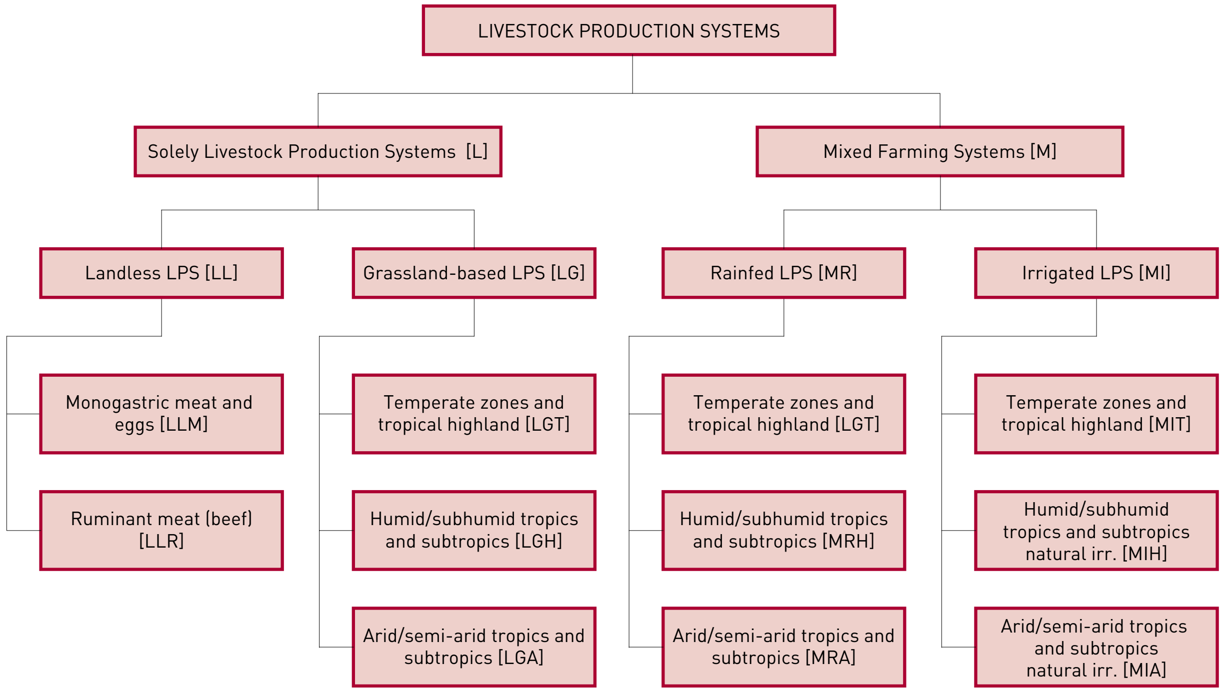
For clarity of analysis, it helps to classify the vast variety of individual situations into a limited number of distinct livestock production systems. Ideally the following criteria should be considered:

- degree of integration with crops;
- relation to land;
- agro-ecological zone;
- intensity of production;
- irrigation or rainfed; and
- type of product.

FAO (1996) has proposed a classification of eleven categories of livestock production systems (LPSs) based on different types of farming systems, relationship to land and agro-ecological zone (see Figure 2.9). They identify two main groups of LPSs:

- those solely based on animal production, where more than 90 percent of dry matter fed to animals comes from rangelands, pastures, annual forages and purchased feeds, and less than 10 percent of the total value of production comes from non-livestock farming activities; and
- those where cropping and livestock rearing are associated in mixed farming systems, where more than 10 percent of the dry matter fed to animals comes from crop by-products or stubble, or more than 10 percent of the total value of production comes from non-livestock farming activities.

Figure 2.9 **Classification of livestock production systems**



Source: FAO (1996).

Below the division between livestock-only and mixed farming, four broad groupings can be distinguished. Map 13 (Annex 1) shows the relative predominance of these four broad groups of livestock production systems around the world (Steinfeld, Wassenaar and Jutzi, 2006), while Tables 2.9 and 2.10 show their relative prevalence in livestock numbers and production data. Two of these broad groupings are among the livestock-only systems: landless LPSs, and grassland-based LPSs.

Landless LPSs are mostly intensive systems that buy in their feed from other enterprises. They are found mostly in Eastern North America, Europe, Southeast and East Asia. These are defined as systems in which less than 10 percent of the dry matter fed to animals is farm-produced, and in which annual average stocking rates are above ten livestock units per km^2 (on average at the census unit level). The landless category defined by FAO (1996) is split into landless ruminant and landless monogastric systems. The presence of landless or "industrial" LPSs is connected to both demand factors and supply determinants. They are prevalent in areas with high population density and purchasing power, in particular coastal areas in East Asia, Europe and North America, that are also connected to ocean ports for feed imports. In contrast, there are areas with ample feed supply such as the mid-western United States and interior parts of Argentina and Brazil, where industrial systems have been developed primarily using local surpluses of feed supplies. East and Southeast Asia strongly dominate industrial monogastric production in the developing regions. Southern Brazil is another industrial production hotspot of global importance. Regionally important centres of industrial production are found, for example, in Chile, Colombia, Mexico and Venezuela, as well as for chicken in the Near East, Nigeria and South Africa.

The other three major categories are land-based, with each category split into three

Table 2.9

Global livestock population and production in different production systems

Parameter	Livestock production system			
	Grazing	Rainfed mixed	Irrigated mixed	Landless/ industrial
Population (million head)				
Cattle and buffaloes	406.0	641.0	450.0	29.0
Sheep and goats	590.0	632.0	546.0	9.0
Production (million tonnes)				
Beef	14.6	29.3	12.9	3.9
Mutton	3.8	4.0	4.0	0.1
Pork	0.8	12.5	29.1	52.8
Poultry meat	1.2	8.0	11.7	52.8
Milk	71.5	319.2	203.7	–
Eggs	0.5	5.6	17.1	35.7

Note: Global averages 2001 to 2003.
Source: Own calculations.

depending on the agro-ecological zone: temperate and tropical highland; humid/subhumid tropics and subtropics; and arid/semi-arid tropics and subtropics

Grassland-based (or grazing) systems are livestock-only LPSs, often based on grazing of animals on seasonal, shifting or upland pastures, primarily found in the more marginal areas that are unfit for cropping because of low temperature, low rainfall or topography, and predominant in semi-arid and arid areas. They are defined as systems in which more than 10 percent of the dry matter fed to animals is farm-produced and in which annual average stocking rates are less than ten livestock units per hectare of agricultural land. These systems cover the largest land area and are currently estimated to occupy some 26 percent of the earth's ice-free land surface. This figure includes a large variety of agro-ecological contexts with very different levels of biomass productivity.

The other two types of land-based system practise mixed crop and livestock farming. Mixed systems are prevalent in bio-climatically more favoured ecosystems.

Rainfed mixed farming systems are mixed systems in which more than 90 percent of the value of non-livestock farm production comes from rainfed land use. Most mixed farming systems are rain-fed and are particularly present in semi-arid and subhumid areas of the tropics and in temperate zones.

Irrigated mixed farming systems are found throughout the world, but have generally limited spatial extent. Exceptions are eastern China, northern India and Pakistan, where mixed irrigated systems extend over large areas. They are defined as mixed systems in which more than 10 percent of the value of non-livestock farm production comes from irrigated land use.

Tables 2.9 and 2.10 show the distribution of production (ruminants and monogastrics) and of animal numbers (ruminants only) over the production system groups, both globally and for the developing regions. The 1.5 billion head of cattle and buffaloes, and the 1.7 billion sheep and goats, are fairly evenly distributed across the land-based systems. However, their average densities increase steeply from grazing systems to mixed irrigated systems, since the latter have far greater livestock-supporting capacities per unit area.

Table 2.10

Livestock population and production in different production systems in developing countries

Parameter	Livestock production system			
	Grazing	Rainfed mixed	Irrigated mixed	Landless/ industrial
Population (million head)				
Cattle and buffaloes	342.0	444.0	416.0	1.0
Sheep and goat	405.0	500.0	474.0	9.0
Production (million tonnes)				
Beef	9.8	11.5	9.4	0.2
Mutton	2.3	2.7	3.4	0.1
Pork	0.6	3.2	26.6	26.6
Poultry meat	0.8	3.6	9.7	25.2
Milk	43.8	69.2	130.8	0.0
Eggs	0.4	2.4	15.6	21.6

Source: Own calculations.

Monogastrics shift towards landless industrial systems, ruminants remain land-based

As yet, only a small fraction of the world's **ruminant** population is found in industrial feedlots, partly owing to the fact that even in intensive production environments feedlots are usually used only in the final stage of the animal's life cycle. The vast majority of large and small ruminant populations are found in the developing regions. Ruminant productivity varies considerably within each system, but overall productivity in developing countries' grazing and mixed systems is lower than in developed countries: globally, beef production per animal in grazing systems is 36 kg/head and year while the average for developing countries is 29 kg/head and year. By far the largest variation in intensity of production is found within the mixed rainfed system, the largest producer of ruminant products. Despite the fact that the developing regions house the vast majority of animals in this category, they account for less than half of the category's production globally. In fact, beef productivity in these regions averages 26 kg/head, as opposed to 46 kg/head at world level, and their milk production is only 22 percent of the world total. Across all four categories, developing regions account for half of the world's beef production, some 70 percent of mutton production and about 40 percent of milk production.

A sharply contrasting situation is found in the **monogastrics** sector. Currently more than half of the world's pork production originates from industrial systems and for poultry meat this share amounts to over 70 percent. About half of the industrial production originates from developing countries and, though reliable population figures are not available, variation in productivity between regions is probably much lower than for ruminants. However, huge differences in total production are found between the developing regions. The majority of the world's pork, poultry and egg production from irrigated mixed systems takes place in developing regions. Although substantial, production in Latin America is less than one-tenth of that in Asia, whereas production is almost absent in Africa and West Asia. The developed countries and Asia together account for over 95 percent of the world's industrial pork production .

Geographical distribution of main livestock species

The distribution of species can also be examined by agro-ecological zone (Table 2.11). Recent strong industrial growth in production of mono-

Table 2.11

Livestock population and production in different agro-ecological zones

Parameter	Agro-ecological zones		
	Arid and semi-arid tropics and sub-tropics	Humid and sub-humid tropics and sub-tropics	Temperate and tropical highlands
Population (million head)			
Cattle and buffaloes	515	603	381
Sheep and goat	810	405	552
Production (million tonnes)			
Beef	11.7	18.1	27.1
Mutton	4.5	2.3	5.1
Pork	4.7	19.4	18.4
Poultry meat	4.2	8.1	8.6
Milk	177.2	73.6	343.5
Eggs	4.65	10.2	8.3

Note: Global averages 2001 to 2003.
Source: Own calculations.

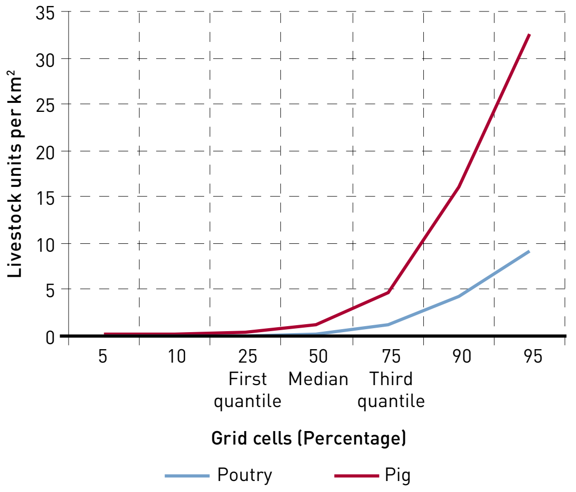
gastrics in the tropics and subtropics has led to production levels that are similar to that of temperate regions. The situation is very different for ruminant production, partly because of its land-based nature; production and productivity are much higher in the cooler climates. Small ruminant production in the (semi)arid (sub)tropics is a notable exception, explained by the large population and the relatively high productivity, the latter being the result of the species' fitness under harsh and marginal conditions. The relatively low productivity for milk in the more humid tropics relates to the strong dominance of mixed systems in these regions, where use of animals for draught power and other uses such as transport is still substantial.

Of all livestock species, poultry has the closest distribution pattern to human populations (see Map 16, Annex 1). This may seem surprising, as poultry is predominantly raised in intensive systems, but the reason is that intensive systems are widely spread. On a global average, three birds are found per hectare of agriculture land, with the highest concentrations found in Western Europe (7.5 birds/ha), East and Southeast Asia (4.4) and North America (4.3). China counts 6.9 birds per hectare of agriculture land. When related to human population, the highest poultry/person ratios are found in North America (6.7 birds per person), followed by Latin America at only 4.5 birds per person. This is consistent with high poultry exports from these two regions (see Table 14, Annex 2).

Historically, the distribution of pig populations was closely related to that of humans. The high concentration of the pig industry in specialized regions has lead to strong subnational concentrations (see Map 17, Annex 1). The tendency for pigs to be more concentrated than poultry in areas with high animal densities is also illustrated in Figure 2.10. This trend may result from the high environmental impact of pig production. The other striking feature of pig distribution is their relative absence from three regions (West Asia and North Africa, sub-Saharan Africa and South Asia) for cultural reasons – see Table 7, Annex 2. On the other hand, the highest pig densities in relation to agricultural land and human population are recorded in Europe and Southeast Asia.

Major **cattle** densities are found in India (with an average of more than one head of cattle per

Figure 2.10 **Comparative distribution of pig and poultry**



Source: Calculation based on Maps 16 and 17 (Annex 1).

hectare of agriculture land), northeastern China (mostly dairy), Northern Europe, Southern Brazil and the East African Highlands (see Map 18, Annex 1 and Table 8, Annex 2). Smaller concentrations are also found in the United States, Central America and Southern China. Although large concentrations are not recorded in Oceania, the region has more cattle than inhabitants, especially in Australia where the cattle population is about 50 percent greater than the human population. Average stock per agricultural land here is, however, among the lowest, in line with the extensive nature of cattle production.

Small ruminants are uncommon in the Americas, except for Uruguay and, to a lesser extent, Mexico and Northern Brazil (see Map 19, Annex 1 and Table 9, Annex 2). In contrast, high densities are found in South Asia and Western Europe (1.3 and 0.8 head per hectare of agricultural land respectively), and there are local concentrations in Australia, China, Northern Africa and African dry lands. As in the case of cattle, sub-Saharan Africa shows higher animal to human population ratios than the world average, which is explained by the heavy reliance on ruminants and the low productivity of animals.

Map 20 (Annex 1) shows global geographical trends of aggregated livestock distribution, expressed in terms of livestock units. We observe six major areas of livestock concentration: Central and Eastern United States, Central America, South Brazil and North Argentina, Western and Central Europe, India and China. Four areas have densely concentrated areas of a lesser extent: Eastern Africa, South Africa, Australia and New Zealand.

Recent distribution trends

Monogastrics expand faster than ruminants

The comparisons between two quantifications of the world livestock productions systems study by FAO, (1996) (averages for 1991–93 and for 2001–03) show that significant changes in resource endowments have brought about changes in the nature and extent of production systems. Cattle stocks are slightly up on the world level (5 percent), with a considerable increase in stock numbers for sub-Saharan Africa, Asia and Latin America. A strong drop in animal numbers (almost 50 percent) occurred in the Eastern European and CIS countries following geopolitical changes and the collapse of the Soviet Union.

World output rose by about 10 percent in the period of observation, with very strong differences at regional level. Cattle meat output almost doubled in Asia. In sub-Saharan Africa it increased by 30 percent, in Latin America by 40 percent, and in West Asia and North Africa by about 20 percent, albeit from a lower absolute level. The strongest cattle output increases occurred in mixed systems in the humid zones. At lower overall production levels (see Table 2.9 and 2.10) total meat production from small ruminants increased by about 10 percent, although the overall stock numbers for small ruminants remained fairly constant for the two reference periods. There were inter-regional shifts in distribution. Stock numbers increased considerably in sub-Saharan Africa and Asia, and strongly declined in Latin America, the OECD, and in particular in Eastern Europe and the CIS. The increases occurred mainly in mixed humid systems. The changes in monogastric animal production are more striking. Total pig meat output (the highest meat output per species in 2002) rose by 30 percent at world level, an increase accounted for almost entirely by Asia. Most regions showed increases in pig meat production, although for Eastern Europe and the CIS there was a drop of about 30 percent. Industrial pig meat production grew at about 3 percent per year. Strong increases also occurred in the humid and temperate mixed irrigated systems.

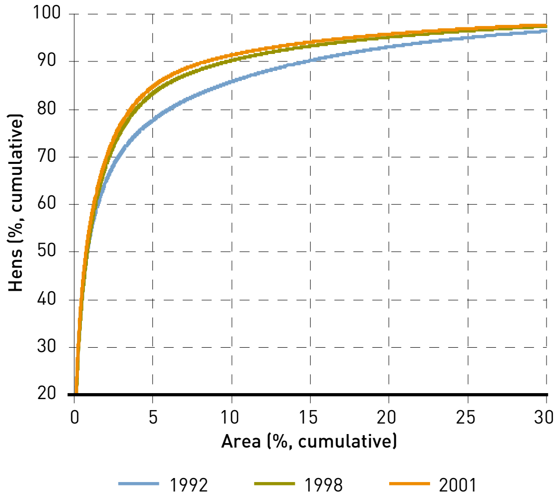
The total production of poultry meat grew by about 75 percent, the strongest expansion of all livestock products. Regional differences were pronounced, with an extremely strong expansion in Asia (about 150 percent increase, with a yearly growth rate of over 9 percent). The growth rates were generally positive, between 2 and 10 percent across regions, most of this resulting from expansion of industrial systems. Global production of table eggs grew by about 40 percent. Asia more than doubled its egg production in the period, to reach a share of about 50 percent of world production. The landless livestock production system grew by about 4 percent per year.

2.4.2 Geographical concentration

The industrialization of livestock production occurs where economic growth is taking place (see Chapter 1). Thus, new farming systems are dominant in industrialized countries and countries with rapid economic growth. A characteristic of such production systems is the segmentation of production stages (feed production, animal raising, slaughtering and processing) and the location of each segment where operating costs are minimized. In this process, animal farms tend to concentrate geographically into clusters.

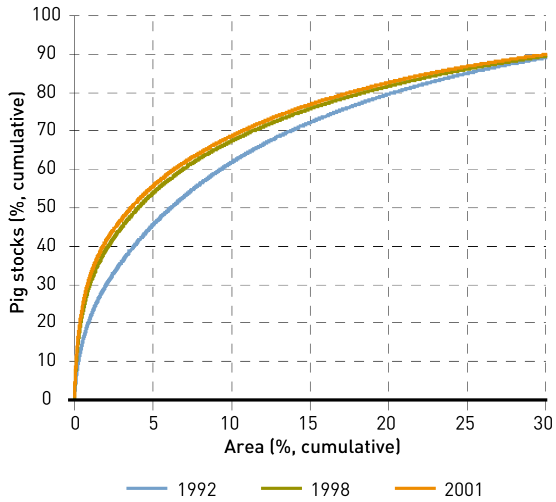
The trend of landless production systems towards clustering is ongoing in developed as well as developing economies. The analysis of the pig and poultry populations at municipal level in Brazil shows a more accentuated geographical concentration for hens than for pigs, and an increasing concentration for both species over the 1992 to 2001 period (see Figures 2.11 and 2.12). In 1992, 5 percent of the total country's area hosted 78 percent of the hen population, rising to 85 percent of the population

Figure 2.11 **Changes in geographical concentration of hens in Brazil from 1992 to 2001**



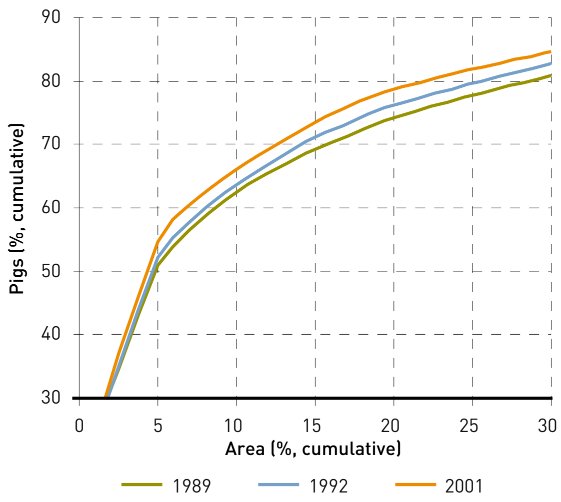
Source: Own calculations.

Figure 2.12 **Changes in geographical concentration of pigs in Brazil from 1992 to 2001**



Source: Own calculations.

Figure 2.13 **Changes in geographical concentration of pigs in France from 1989 to 2001**



Source: Own calculations.

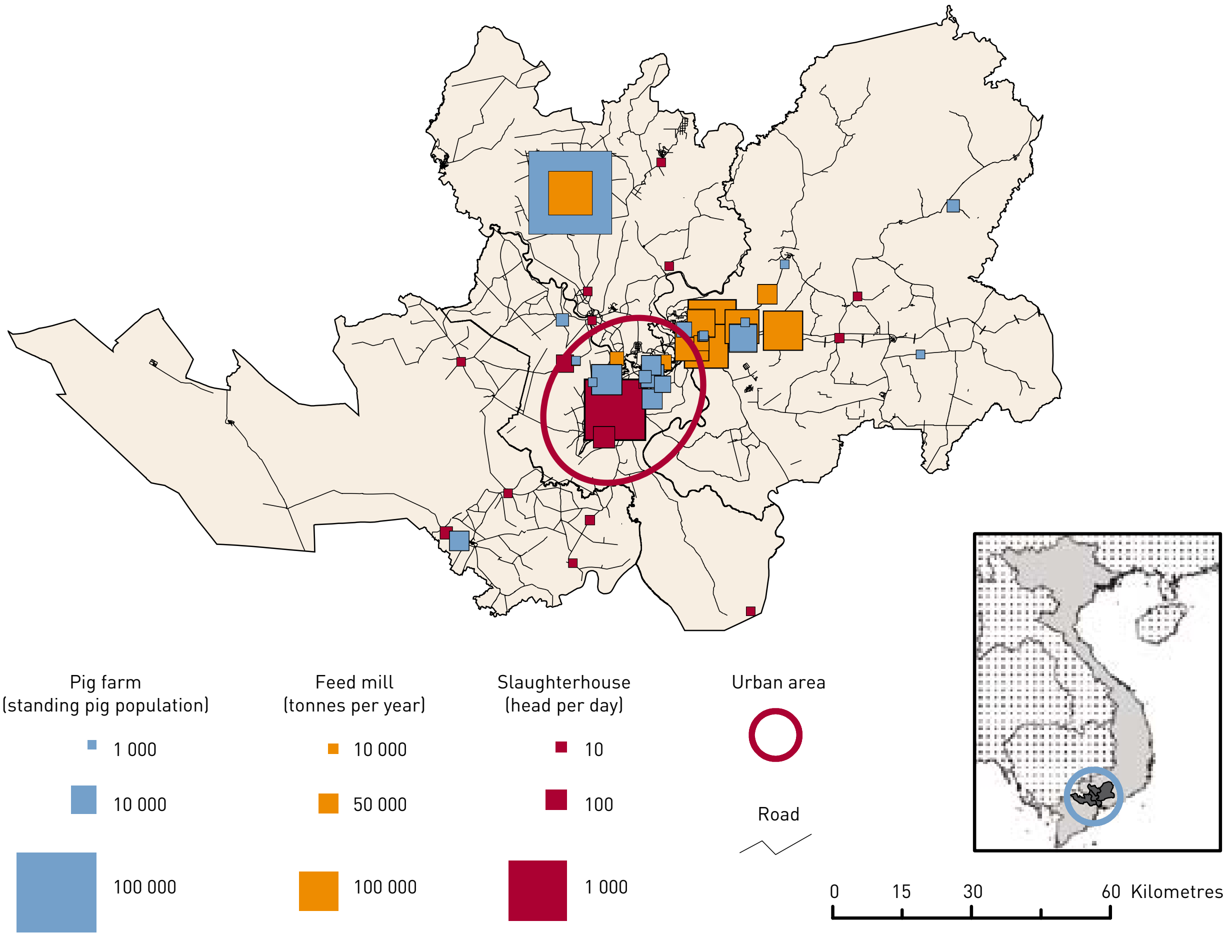
in 2001. The corresponding figures for pigs over the same period are 45 percent and 56 percent respectively. A similar analysis conducted for France and Thailand (see Figures 2.13 and 2.14) showed concurring results.

Landless production systems

A two-step move: rural to urban, urban to sources of feed

As developing countries industrialize, livestock production generally relocates in two stages (Gerber and Steinfeld, 2006). As soon as urbanization and economic growth translate rising population into "bulk" demand for animal food products, large-scale operators emerge. At the initial stage, these are located close to towns and cities. This occurs because livestock products

Map 2.1 **Location of industrial pig sector in southern Viet Nam (Dong Nai, Binh Duong, Ho Chi Minh city and Long An province)**



Source: Tran Thi Dan *et al.*, (2003).

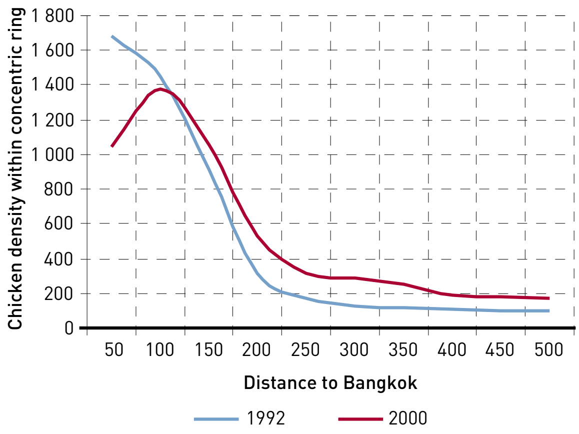
are among the most perishable products, and their conservation/transport without chilling and processing poses serious problems. Therefore, as long as transport infrastructures remain inadequate, livestock-derived foods have to be produced in the vicinity of demand. Map 2.1 illustrates how the intensive pig sector has located at the periphery of Ho Chi Minh City in Viet Nam. Most feed mills, pig farms and slaughterhouses are found within 40 km of the city centre.

In a second phase, transport infrastructure and technology develop sufficiently to make it technically and financially possible to keep livestock further away from demand centres. Livestock production then shifts away from urban areas, driven by a series of factors such as lower land and labour prices, access to feed, lower environmental standards, tax incentives and fewer disease problems. Following a similar trend, the poultry density in areas less than 100 km from Bangkok decreased between 1992 and 2000, with the largest decrease (40 percent) in the areas close to the city (less than 50 km). Poultry density increased in all areas further than 100 km away (see Figure 2.14). In this particular case, the geographical shift was further accelerated by tax incentives.

When pushed out of peri-urban areas, landless production systems tend to move closer to feed resources so as to minimize transport costs on the input side, since the feed used per head is bulkier than the livestock produced. The shift occurs either towards feed production areas (e.g. the United States corn belt, Mato Grosso in Brazil, Mexican El Bajio), or towards feed importing and processing areas (e.g. Chachoengsao Province of Thailand, Jeddah in Saudi Arabia).

In OECD countries, where industrialization of the livestock sector began from 1950 on, clusters formed in rural areas with surplus cereal supply. Here, livestock were initially produced as a means of diversification and value addition. In Europe, pig and poultry production clusters of this type include Brittany, the Po valley in Italy, Western Denmark and Flanders. The geography

Figure 2.14 **Changes in the peri-urban concentration of poultry from 1992 to 2000 in Thailand**



Source: Own calculations.

of these clusters was affected by the increasing use of imported feed. Those with good connection to ports strengthened (e.g. Brittany, western Denmark, Flanders) and new production areas appeared in the vicinity of major ports (Lower Saxony, Netherlands, Catalonia). Finally, a more recent type of feed-related production cluster is observed close to newly created feed processing plants establishing comprehensive animal production chains. Concentration close to feed processing plants is observed in Brazil by analysis of pig numbers and feedcrop production at *Municipio* level in Brazil. From 1992 to 2001, part of the pig population moved away from traditional feed production areas and concentrated around major feed mills in Mato Grosso.

Disease control strategies may, however, scatter production clusters. To limit the spread of diseases, large farms tend to scatter away from other large farms and small-scale units. A distance of a few kilometres is sufficient to prevent disease propagation. It is therefore probable that this trend will prevent the concentration of small- and large-scale farms, especially in peri-urban settings, but will most probably not alter the trend towards specialized areas, equipped with feed mills, slaughterhouses and animal health services.

Land-based systems: towards intensified systems

Fodder is bulky and its transportation expensive. Livestock raised in land-based systems are, therefore, bound to feed resource production areas. Previous sections have, however, shown that pasture expansion is likely to be limited, blocked on one side by lack of suitable land and on the other by competition from land uses with lower opportunity costs (e.g. agriculture, forestry, conservation).

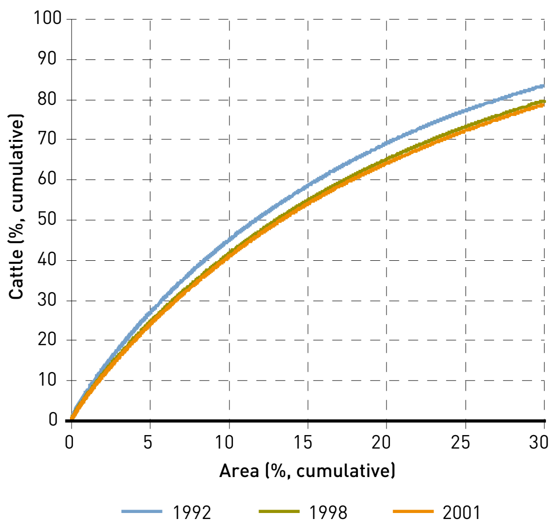
As a result, pushed by an increasing demand for beef and milk, part of the production shifts from land based towards intensified systems, such as feedlots and dairy plants (see Chapter 1), following the same geographical trend as intensive monogastric production.

Land-based systems also tend to expand into the remaining areas with good potential for pasture or where there are no strong land use competitors. These are predominantly found in Oceania and South America. Over 1983 to 2003, beef and milk production grew by 136 percent and 196 percent respectively in Oceania, and by 163 percent and 184 percent respectively in South America. For comparison, world production as a whole increased by 124 percent for the two products over the same period (FAO, 2006b).

Transporting chickens to poultry plant near Magee – United States

These overall trends are confirmed by local analysis. Cattle numbers per *Municipio* in Brazil in land-based livestock systems show a more even geographical spread of cattle (see Figure 2.15) than was observed for stock in landless, intensive systems. The expansion of pasture into the Amazon is further described in land degradation hotspots (Section 2.5 below).

Figure 2.15 **Changes in geographical concentration of cattle in Brazil from 1992 to 2001**



Source: Own calculations (2005).

2.4.3 Increasing reliance on transport

Trade and transport improvements increase transport of livestock products

The transport of livestock sector commodities has become increasingly economically affordable and technically possible. Technical changes in transport, such as the development of infrastructure, large-scale shipments of primary crop production or consolidation of long-distance cold chains, have played a determinant role in shaping change in the livestock sector.

Developments in transport have made it possible to bridge the geographical gap between urban demand for animal products and the land resources for their production. Increased trade and transport of animal products and feedstuff are also fundamental factors in the industrialization of the livestock sector. Because they operate on a large scale, with considerable volumes of inputs and outputs, landless industrial systems intrinsically rely on transport for supply of inputs (especially feed) and delivery of outputs. Furthermore, the low private costs of transport (which rarely factor in social and environmental costs) have strongly influenced the location economics of the various segments of the livestock commodity chain, from feed production and feed mill, to animal production, slaughtering and processing. Since the transport cost of connecting each segment is limited, other production costs play a greater role in determining location. Such parameters include cost of land, labour, services, health control, tax regimes and strictness of environmental policy. Although to a lesser extent than landless industrial systems, land-based production systems increasingly rely on transport, as they shift closer to available land resources and further away from consumption centres.

Worldwide, most livestock are produced for national consumption. However, animal products are increasingly traded, and a larger share of the global production enters trade nowadays than in the 1980s. The trend was particularly dynamic for poultry meat, where the internationally traded share rose from 6.5 percent in 1981–83 to 13.1 percent in 2001–03. In 2001–03, more than 12 percent of bovine meat, poultry meat, and milk produced worldwide were traded, and 8.2 percent of pig meat. All of these shares were significantly up on the 1981–83 average. Among feeds, trade in soymeal represented a higher share of production (24–25 percent) over the same periods, though showing little increase (see Table 2.12). For feedgrains the traded share of total production has also remained fairly constant. Trade increases were fostered by a number of policy measures and agreements aimed at easing international trade, including regional trade agreements, harmonization of standards and the inclusion of agriculture in the World Trade Organization (WTO) mandate.

Table 2.12

Trade as a share of total production for selected products

Product	1981–1983 average	2001–2003 average
	(...................... %	......................)
Bovine meat	9.4	13.0
Pig meat	5.2	8.2
Poultry meat	6.5	13.1
Milk equivalent	8.9	12.3
Soymeals[1]	24.3	25.4

[1] Soymeal trade over soybean production.
Source: FAO (2006b).

Feed trade: Americas dominate exports, China and EU dominate imports

As livestock production grows and intensifies, it depends less on locally available feed resources and more on feed concentrates that are traded domestically and internationally. Map 21 and 22 (Annex 1) display estimated spatial trends in feed surplus/deficit for pig and poultry, providing evidence of the sector's high reliance on trade. Feed trade and the related transfers of virtual water, nutrients and energy is a determinant factor of the sector's environmental impacts. Statistics on feedgrains are generally not separate from overall grain trade flows. However, major trends can be inferred from regional level trade flows, as shown in Table 10 of Annex 2 for maize. North and South America are the two regions with significant interregional exports. The maize that they export to Africa is predominantly used for food, while a large share of exports to Asia, EU and America supplies feed demand (Ke, 2004). Asian maize demand, driven by the feed sector, is predominantly supplied by North America, although imports from South America increased dramatically over the period. North America also exported large volumes of maize to South and Central America (2.8 and 9.2 million tonnes respectively (2001 to 2003 average). Both flows have increased strongly over the past 15 years. On the other hand South America dominates the EU market. Contrasted country profiles and strategies explain these trends. Exports from North and South America are driven by countries (e.g. Argentina, Canada, United States) with ample land resources and strong grain export policies. On the other hand, China, which is a major driver of Asian imports, compensates for its land shortage with imports.

The comparison of grain resources and grain requirements at the local level allow estimating domestic trade (see Map 21, Annex 1), although imports from international markets would most probably supply part of the demand in deficit areas.

About one-third of global soybean, soy oil and soymeal production is traded (29.3, 34.4 and 37.4 percent respectively). This proportion is significantly above that recorded for other agricultural commodities. Soymeal and soybeans account for 35 and 50 percent of the total value of soy-based trade, respectively (FAO, 2004a). The widespread consumption of soybeans is supplied by a few major exporting countries to a large number of importing countries (see Table 11 and Table 12, Annex 2 and Map 22, Annex 1). The United States is the largest soybean exporter (29 million tonnes), followed by Brazil (17 million tonnes). Among the top seven producers, China is the only one with decreasing exports over the period (see Table 11, Annex 2). Indeed, over the past 10 to 20 years China has gone from being a soybean exporter to being the world's largest importer of whole soybeans and a large importer of soymeal – with one-third of its soymeal consumption supplied by imports.

Countries import soybeans either raw, or processed into soy oil and/or soymeal, depending on domestic demand, which is also determined by the structure of the local processing industry. The United States exports about 35 percent of its raw soybeans, before processing. In contrast, Argentina and Brazil add value to most of their crop, process about 80 to 85 percent of their soybeans before export (Schnittker, 1997). For soymeal, South America dominates interregional trade, with the EU as first client and Asia as second (18.9 and 6.3 million tonnes respectively in 2002). The United States has a lesser role in soymeal interregional trade. In recent years, a number of importing countries, especially in the EU have shifted from the importation of soymeal to purchases of beans, which reflects efforts to promote processing at the local level. As a result, about six million tonnes of soymeal produced in the EU enter trade, mostly intraregional, but also towards Eastern Europe. There is also international trade in other fodder products, such as processed alfalfa and compressed hay bales. Exporting countries are predominantly Canada and the United States. Japan is by far the largest importer, followed by the Republic of Korea, and Taiwan Province of China.

Animal and derived products trade increases globally

Live animals and animal-derived products are traded in smaller volumes than feed, because of smaller demand volumes and greater private costs of transport per unit. Nevertheless, the growth of trade in animal products is outpacing the growth of feed trade and of animal production. This rapid growth is facilitated by weakening tariff barriers within the context of GATT, and by the preparation of codes and standards to regulate global trade. In parallel, the trend towards increased demand for processed products by households and catering further expanded the transport of animal products.

Trade in poultry meat has overtaken trade in beef over the past 15 years, with volume soaring from about 2 million tonnes in 1987 to 9 million tonnes in 2002, compared to beef's rise from 4.8 to 7.5 million tonnes over the same period. Except for Eastern Europe, all analysed regions became increasingly involved in trade (see Table 14, Annex 2). North America supplies about half of the interregional market (2.8 million tonnes per year on average, between 2001 and 2003), followed by South America (1.7 million tonnes) and the EU (900 000 tonnes). Brazil is the top exporting country. With relatively low feedgrain and labour costs and increasingly larger economies of scale, Brazil's production costs for whole eviscerated chicken are estimated to be the lowest of any major supplier (USDA-FAS, 2004). On the importer side, the picture is more diversified than for beef, with several regions playing important roles. Asia ranks number one, followed by the Baltic states and CIS, the EU, sub-Saharan Africa and Central America. Important and rapidly increasing regional level trade is taking place in Asia and the EU, both regions yielding local competitive advantages.

To assess transport of meat further, we calculated balances between primary production and demand for animal products at the local level. The results for poultry meat are shown on Map 23 (Annex 1). Production is similar to consumption on a majority of grid cells. A balanced situation (set as +/- 100 kg of meat per km^2) is generally found in land-based systems (compare with Map 13, Annex 1). Areas of highly positive balances (surplus) are associated with landless industrial systems (Map 14, Annex 1), whereas negative balances (deficit) usually coincide with high population densities and urban areas. The poultry exporting position of North and South America shows up here as a dominance of red (surplus) pixels in these two regions. The same analysis conducted for pig meat (Map 24, Annex 1) shows a similar coincidence of positive balances with industrial production areas. However, poultry and pig meat differ in the geographical spread of areas with negative and positive balances. Production areas are generally more scattered among consumption areas for poultry than for pigs. The three maps also show important domestic trade.

Beef is predominantly exported from Oceania and South America, taking advantage of their land-based cattle production systems (Table 13, Annex 2). North America is the main market for Oceania (903 thousand tonnes per year on average, between 2001 and 2003), but Asian imports from Oceania have dramatically increased in recent years (686 thousand tonnes per year on average, between 2001 and 2003, a 173 percent increase in 15 years). South American exports go mainly to the EU (390 thousand tonnes per year on average, between 2001 and 2003) and Asia (270 thousand tonnes), both volumes having roughly doubled over the past 15 years. The EU and North America also make large contributions to global bovine meat supply, based on more intensive production systems, especially in the United States. Most of the EU's trade is within the EU region, although the EU also supplied the Baltic states and CIS countries in 2002. North America predominantly supplies Asia, which is by far the biggest beef importer of all ten analysed regions, importing about 1.8 million tonnes of beef per year on average, between 2001 and 2003 (see Table 13, Annex 2). Asian imports, driven by China, are also the most dynamic, with a 114 percent increase over the 1987 to 2002 period. Asia responds to its soaring demand through interregional trade, but also by drawing upon a booming intraregional beef meat market. Interregional trade is also building up in Sub-Saharan Africa. Finally, Table 13 (Annex 2) illustrates the collapse of Eastern Europe over the period, with imports from North America, sub-Saharan Africa and the Baltic States and CIS that are close to zero. The estimated beef balances (Map 25, Annex 1) display the need for both domestic trade and international trade.

2.5 Hotspots of land degradation

As a major land user, the livestock sector has a substantial influence on land degradation mechanisms in a context of increasing pressure on land (see Box 2.3). With regard to land-based systems, two areas pose the most serious problems. There is the ongoing process of degradation of pastures, particularly in the arid and semi-arid environments of Africa and Asia, but also in subhumid zones of Latin America. There is also the issue of pasture expansion, and the conversion of forest land into pastures, particularly in Latin America.

Landless industrial systems are disconnected from the supporting land base. The separation of production from resources often creates pollution and soil degradation problems, both at feed production and animal operation levels. In parallel, feedcrop expansion into natural ecosystems creates land degradation.

In the following sections, we will review four major mechanisms of land degradation related to the livestock sector:

- expansion into natural ecosystems;
- rangeland degradation;
- contamination in peri-urban environments;
- pollution, soil degradation and productivity losses in feedcrop production areas.

We will assess the geographical extent of these problems, as well as their underlying biophysical process. Impacts on the global environment will simply be listed here. Implications on climate change, water depletion and biodiversity erosion will be further developed in later chapters.

2.5.1 Pastures and feedcrops still expanding into natural ecosystems

Crop and pasture expansion into natural ecosystems has contributed to livestock production growth, and will probably do so in the future under the "business as usual" scenario. Whatever the purpose, the destruction of natural habitats to establish agricultural land use means direct and significant biodiversity losses. The Millennium Ecosystem Assessment (MEA) lists land-use change as the leading cause of biodiversity loss (MEA, 2005a). The destruction of vegetative cover also leads to carbon release, fuelling climate change. In addition, deforestation affects water cycles, reducing infiltration and storage and increasing runoff by the removal of canopies and leaf litter, and through the reduced infiltration capacity of the soil as a result of reduced humus content (Ward and Robinson, 2000).

In OECD countries, the decision to plant soybeans or grain does not usually mean clearing natural habitat. Producers merely make a choice

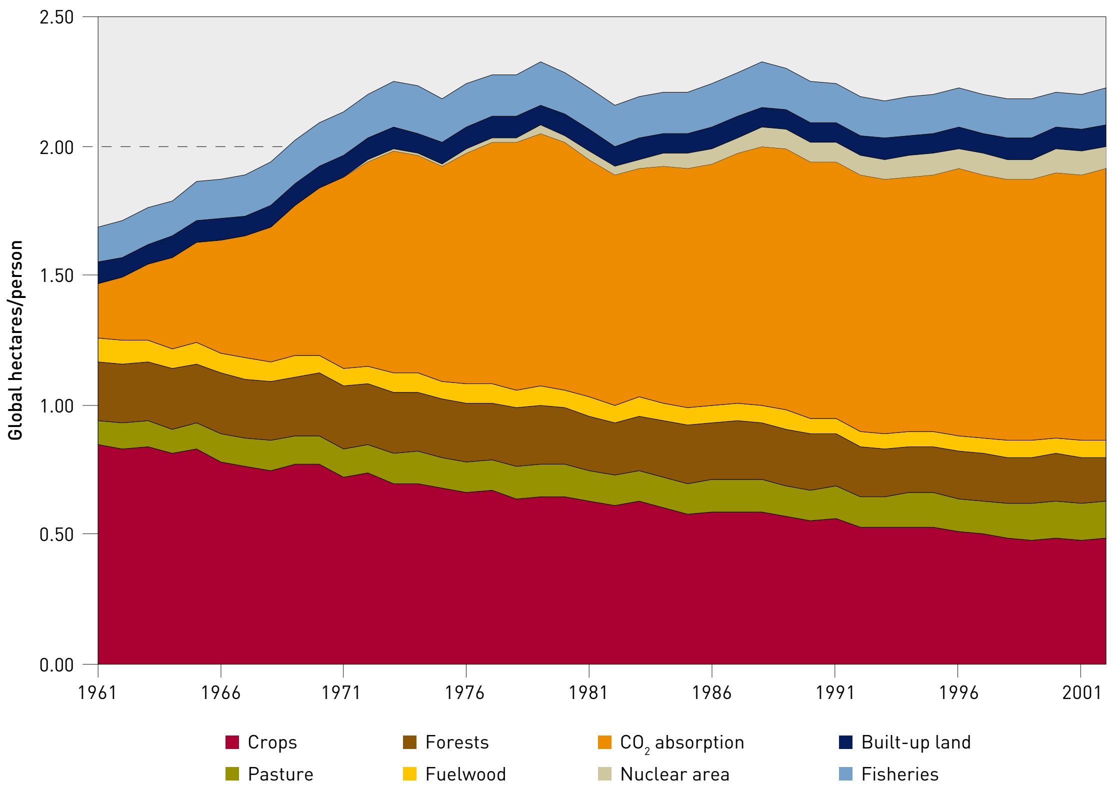
Illegal deforestation for soybean production in Novo Progresso, State of Pará – Brazil 2004

Box 2.3 **Ecological footprint**

To measure humanity's pressure on land and increasing competition for scarce resource, the Global Footprint Network defined an indicator called the ecological footprint. The ecological footprint measures how much land and water area a particular human population requires to produce the resources it consumes and to absorb its wastes, taking into account prevailing technology (Global Footprint Network). This indicator allows us to compare the use of resources with their availability. The Global Footprint Network estimates that global demand for land overtook global supply by the end of the 1980s. It is further estimated that humanity's ecological footprint is currently 20 percent larger than the entire planet can sustain. In other words, it would take one year and two months for the earth to regenerate the resources used by humanity in a single year.

Livestock-related activities contribute significantly to the ecological footprint, directly through land use for pasture and cropping, and also indirectly through the area needed to absorb CO_2 emissions (from fossil fuel use in livestock production) and ocean fisheries (related to fishmeal production for feed).

Figure 2.16 **Ecological footprint per person, by component**



Source: Global Footprint network (available at http://www.footprintnetwork.org).

between a number of crops, within an agricultural area that remains roughly stable. In many tropical countries, however, the cultivation of crops is often driving the process of converting extended areas of natural habitat to agriculture. This is the case in much of tropical Latin America, sub-Saharan Africa and Southeast Asia. Soybeans in particular are a driving force. Between 1994 and 2004, land area devoted to growing soybeans in Latin America more than doubled to 39 million ha, making it the largest area for a single crop, far above maize, which ranks second at 28 million hectares (FAO, 2006b). In 1996, there were only 1 800 hectares of soybeans in Rondônia in the western Amazon, but the area planted increased to 14 000 hectares in 1999. In the eastern Amazon in the state of Maranhão the area planted with soybeans increased from 89 100 to 140 000 hectares between 1996 and 1999 (Fearnside, 2001). The demand for feed, combined with other factors, has triggered increased production and exports of feed from countries like Brazil where land is relatively abundant.

The land area used for extensive grazing in the neotropics has increased continuously over the past decades and most of this has been at the expense of forests. Ranching-induced deforestation is one of the main causes of loss of unique plant and animal species in the tropical rainforests of Central America and South America as well as of carbon release into the atmosphere. Livestock production is projected to be the main land use replacing forest in the neotropics after clearing. Indeed, Wassenaar and colleagues (Wassenaar *et al.*, 2006) estimate that the expansion of pasture into forest is greater than that of cropland. For South America, Map 33B (Annex 1) indicates deforestation hotspots and areas with a more diffuse deforestation pattern. The full ecological and environmental consequences of such deforestation processes are not yet fully understood and deserve greater attention from the scientific community. This is a particularly acute issue, since the major potential for pasture expansion exists predominantly in areas currently under humid and subhumid forest. There is little evidence of the livestock sector being a major factor in deforestation in tropical Africa. Timber harvesting and fire seem to be the two main processes leading to deforestation. Cases of farming replacing forest are predominantly due to small-scale cropping, or to using secondary forest and scrub land for wood harvesting.

Main global environment concerns associated with feedcrop and pasture expansion into natural ecosystems include climate change, through biomass oxidation and carbon release into the atmosphere; water resources depletion through disruption of water cycles and; biodiversity erosion through habitat destruction. These issues will be reviewed in Chapter 3, 4 and 5, respectively.

2.5.2 Rangeland degradation: desertification and vegetation changes

Pasture degradation related to overgrazing by livestock is a frequent and well studied issue. Pasture degradation can potentially take place under all climates and farming systems, and is generally related to a mismatch between livestock density and the capacity of the pasture to be grazed and trampled. Mismanagement is common. Ideally the land/livestock ratio should be continuously adjusted to the conditions of the pasture, especially in dry climates where biomass production is erratic, yet such adjustment is rarely practiced. This is particularly the case in the arid and semi-arid communal grazing areas of the Sahel and Central Asia. In these areas, increasing population and encroachment of arable farming on grazing lands, have severely restricted the mobility and flexibility of the herds, which enabled this adjustment. Pasture degradation results in a series of environment problems, including soil erosion, degradation of vegetation, carbon release from organic matter decomposition, loss of biodiversity owing to habitat changes and impaired water cycles.

Concentrated "hoof action" by livestock – in areas such as stream banks, trails, watering points, salting and feeding sites – causes compaction of wet soils (whether vegetated or exposed) and mechanically disrupts dry and exposed soils. The effects of trampling depend on soil texture – soils with greater fractions of silt and clay are more easily compacted than sandy soils. Compacted and/or impermeable soils can have decreased infiltration rates, and therefore increased volume and velocity of runoff. Soils loosened by livestock during the dry season are a source of sediments at the beginning of the new rainy season. In riparian areas the destabilization of streambanks by livestock activities contributes locally to a high discharge of eroded material. Furthermore, livestock can overgraze vegetation, disrupting its role of trapping and stabilizing soil, and aggravating erosion and pollution. Ruminant species have distinct grazing habits and thus different aptitude to cause overgrazing. For instance, goats being able to graze residual biomass and ligneous species have also the greatest capacity to sap grasslands' resilience. (Mwendera and Mohamed Saleem, 1997; Sundquist, 2003; Redmon, 1999; Engels, 2001; Folliott, 2001; Bellows, 2001; Mosley *et al.*, 1997; Clark Conservation District, 2004).

Asner *et al.* (2004) suggest three types of ecosystem degradation syndromes related to grazing:

- desertification (in arid climates);
- increased woody plant cover in semi-arid, subtropical rangelands; and
- deforestation (in humid climates).

The role of livestock in the deforestation process has been reviewed in Section 2.1 above. Asner and colleagues describe three major elements of desertification: increased bare soil surface area; decreased cover of herbaceous species; and increased cover of woody shrubs and shrub clusters.

The overarching pattern is one of increased spatial heterogeneity of vegetation cover and of soil conditions (e.g. organic matter, nutrients, soil moisture).

Woody encroachment has been well documented in semi-arid, subtropical rangelands of the world. There are hotspots in North and South America, Africa, Australia and elsewhere, where woody vegetation cover has increased significantly during the past few decades. Among the causes are overgrazing of herbaceous species, suppression of fires, atmospheric CO_2 enrichment and nitrogen deposition (Asner *et al.*, 2004; van Auken, 2000; Archer, Schimel and Holland, 1995).

The extent of grassland degradation in arid and semi-arid climates is a serious source of concern and debate, as its quantification is complex. There is a lack of reliable and easily measurable land quality indicators, ecosystems also fluctuate, and the annual vegetation of these arid areas has shown to be highly resilient. For example, after a decade of desertification in the Sahel, there is now evidence of increasing seasonal greenness over large areas for the period 1982 to 2003. While rainfall emerges as the dominant causative factor for the increase in vegetation greenness, there is evidence of another causative factor, hypothetically a human-induced change superimposed on the climate trend. The notion of human induced irreversible degradation of the Sahelian rangelands is thus challenged (Herrmann, Anyamba and Tucker, 2005). On the other hand, desert is rapidly gaining on pasture in northwestern China (Yang *et al.*, 2005). Diverse estimates exist for the extent of desertification. According to the Global Assessment of Human and Induced Soil Degradation methodology, the land area affected by desertification is 1.1 billion ha, which is similar to UNEP estimates (UNEP, 1997). According to UNEP (1991), when rangelands with degraded vegetation are added (2.6 billion ha), the share of dry lands that are degraded is 69.5 percent. According to Oldeman and Van Lynden (1998), the degraded areas for light, moderate and severe degradation are 4.9, 5.0 and 1.4 billion hectares, respectively. How-

Soil erosion in the Solo River basin – Indonesia 1971

ever, these studies do not take into account of vegetation degradation. Map 27 (Annex 1) shows the location of grasslands established on weak soils in harsh climates, which face significant risks of degradation if ill-managed.

In addition, there is the risk of pasture degradation in humid to temperate climates. When stocking rates are too high, the removal of nutrients (especially nitrogen and phosphorus) via livestock products and via soil degradation processes may be higher than the inputs, and soils are "mined". In the long run, this results in pasture degradation, evidenced by productivity decline (Bouman, Plant and Nieuwenhuyse, 1999). With decreasing soil fertility, weeds and undesired grass species compete more strongly for light and nutrients. More herbicides and manual labour are needed to control them, which has a negative impact on biodiversity and on farmers' income (Myers and Robbins, 1991). Pasture degradation is a widespread issue: half of the 9 million hectares of pasture in Central America is estimated to be degraded (Szott *et al*., 2000). Pasture degradation can be even more acute locally. For example Jansen *et al*. (1997) estimated that over 70 percent of the pastures in the Northern Atlantic zone of Costa Rica are in an advanced stage of degradation, with overgrazing and lack of sufficient N input identified as principal causes.

Main global environment concerns associated with rangeland degradation include climate change, through soil organic matter oxidation and carbon release into the atmosphere; water resources depletion through reduction of groundwater replenishment and biodiversity erosion, through habitat destruction. These issues will be further assessed in Chapter 3, 4 and 5, respectively.

2.5.3 Contamination in peri-urban environments

The ongoing geographical concentration of livestock production systems was described previously, first in peri-urban settings, then close to feed production and processing. In parallel, animal-derived food processing also locates in peri-urban areas, where the costs of transport, water, energy and services are minimized. The geographical concentration of livestock, in areas with little or no agricultural land, leads to high impacts on the environment (water, soil, air and biodiversity), mainly related to manure and waste water mismanagement. Nutrient overloads can result from several forms of mismanagement, including overfertilization of crops, overfeeding of fish ponds and improper waste disposal of agricultural (e.g. livestock) or agro-industrial wastes. Nutrient overloads coming from crop–livestock systems mainly occur when the nutrients present in manure are not properly removed or recycled. The major effects of animal waste mismanagement on the environment have been summarized by Menzi (2001) as follows:

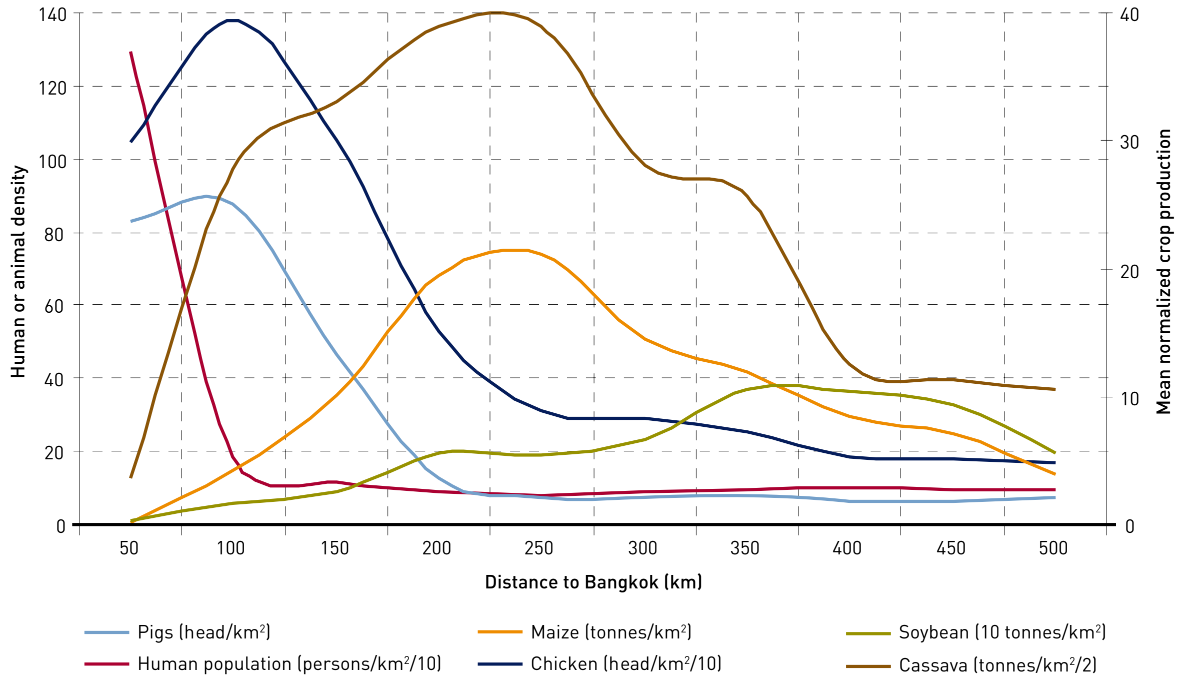
- **Eutrophication of surface water** (deteriorating water quality, algae growth, damage to fish, etc.) owing to input of organic substances and nutrients when excreta or wastewater from livestock production get into streams through discharge, runoff or overflow of lagoons. Surface water pollution threatens aquatic ecosystems and the quality of drinking-water taken from streams. Nitrogen and phosphorus are both nutrients often associated with accelerated eutrophication of surface water (Correll, 1999; Zhang *et al.*, 2003). However, phosphorus is often the limiting factor to the development of blue-green algae, which are able to utilize atmospheric N_2. Therefore, phosphorus management is often identified as a key strategy to limit surface water eutrophication from agricultural sources (Mainstone and Parr, 2002; Daniel *et al.*, 1994).
- **Leaching of nitrate and possible transfer of pathogens to groundwater** from manure-storage facilities or from fields on which high doses of manure have been applied. Nitrate leaching and pathogen transfer are particular threats for drinking water quality.
- **Excess accumulation of nutrients in the soil** when high doses of manure are applied. This can threaten soil fertility owing to unbalanced or even noxious nutrient concentrations.
- **Natural areas such as wetlands and mangrove swamps are directly impacted by water pollution** often leading to biodiversity losses.

Results from LEAD studies show that in most Asian contexts, the recycling of animal manure on crops or in fish ponds (including sanitation costs) is a less expensive option than manure treatment as nutrients are removed using biochemical processes (Livestock waste management in East Asia project – LWMEA) (see Box 2.4). When production or processing units are located in peri-urban settings, far from crops and fishponds (see Figure 2.17), high transport costs make recycling practices financially unprofitable. Production units also often face high land prices and therefore tend to avoid building adequately sized treatment facilities. The result is often a direct discharge of animal manure into urban waterways, with dramatic consequences on their nutrient, drug and hormone residues and organic matter load. Manure products with high value (e.g. chicken litter, cattle dung) are, however, often marketed out of the peri-urban area.

There are also a number of animal diseases that are associated with increasing intensity of production and concentration of animals in a limited space. Many of these zoonotic diseases pose a threat to human health. Industrial and intensive forms of animal production may be a

Farms in Prune – India, situated in proximity to apartment buildings

Figure 2.17 **Spatial distribution of humans, livestock and feed crops around Bangkok, 2001**



Source: Own calculations.

breeding ground for emerging diseases (Nipah virus, BSE), with public health consequences. Intra- and interspecies contamination risks are especially high in the peri-urban environment where high densities of humans and livestock coincide (see Figure 2.17).

As a result of economies of scale, industrial livestock production generates substantially lower income per unit of output than smallholder farms and benefits go to fewer producers. Furthermore, economic returns and spillover effects occur in the, generally, already better-off urban areas. The shift towards such production has thus, on balance, a largely negative effect on rural development (de Haan *et al.*, 2001).

Main global environment concerns associated with contamination in peri-urban environments include climate change through gaseous emissions from animal waste management, water resources depletion through pollution of surface and groundwater, and biodiversity erosion through water and soil pollution. These issues will be further assessed in Chapter 3, 4 and 5, respectively.

2.5.4 Intensive feedcrop agriculture

Crop yield improvement from intensification often has substantial environmental costs (Pingali and Heisey,1999; Tilman *et al.*, 2001). Agricultural intensification can have negative consequences at various levels:

- local: increased erosion, lower soil fertility, and reduced biodiversity;
- regional: pollution of ground water and eutrophication of rivers and lakes; and
- global: impacts on atmospheric constituents, climate and ocean waters.

Biological consequences at the agro-ecosystem level

A key aspect of intensive agriculture is the high specialization of production, often leading to monoculture with tight control of unwanted "weed" species. The reduced diversity of the plant community affects the pest complex as

Box 2.4 Livestock waste management in East Asia

Nowhere have the rapid growth of livestock production, and its impact on the environment, been more evident than in parts of Asia. During the decade of the 1990s alone, production of pigs and poultry almost doubled in China, Thailand and Viet Nam. By 2001, these three countries alone accounted for more than half the pigs and one-third of the chickens in the entire world.

Not surprisingly, these same countries have also experienced rapid increases in pollution associated with concentrations of intensive livestock production. Pig and poultry operations concentrated in coastal areas of China, Viet Nam and Thailand are emerging as the major source of nutrient pollution of the South China Sea. Along much of the densely populated coast, the pig density exceeds 100 animals per km^2 and agricultural lands are overloaded with huge nutrient surpluses (see Map 4.1, Chapter 4). Run-off is severely degrading seawater and sediment quality in one of the world's most biologically diverse shallow-water marine areas, causing "red tides" and threatening fragile coastal, marine habitats including mangroves, coral reefs and sea grasses.

The related booms in production and pollution have kindled plans for one of the most comprehensive efforts to forge an effective policy response – the Livestock Waste Management in East Asia Project (LWMEAP) – which has been prepared with the governments of China, Thailand and Viet Nam by FAO and the inter-institutional Livestock, Environment and Development Initiative (LEAD – www.lead.virtualcentre.org), under a grant from The Global Environment Facility. The project addresses environmental threats by developing policies to balance the location of livestock production operations with land resources and to encourage the use of manure and other nutrients by crop farmers. It will also set up pilot farms to demonstrate good manure management techniques.

Pollutants from all three countries threaten the South China Sea. But the nature of livestock operations differs markedly among the countries. In Thailand, three-quarters of pigs are now produced on large, industrial farms with more than 500 animals. In Viet Nam, on the other hand, very small producers with just three or four pigs account for 95 percent of production. While half of the pigs in Guangdong are still produced in operations with fewer than 100 animals, large-scale industrial operations are growing rapidly. Almost one-quarter of the pigs in Guangdong are produced on farms with more than 3 000 animals.

The LWMEAP project outlines policies at both the national and local levels. At the national level, the project stresses the need for inter-agency cooperation to develop effective and realistic regulations on environmental monitoring and manure management and to undertake spatial planning for the location of future livestock development to create the conditions for better recycling of effluents. As a key tool for shaping and implementing policy at the local level, LWMEAP provides support to the development of codes of practice adapted to the specific contexts.

Source: FAO (2004d).

well as soil invertebrates and micro-organisms, which in turn affects plant growth and health. The low diversity of monocultural agricultural systems typically results in greater crop losses from insect pests that are less diverse but more abundant (Tonhasca and Byrne, 1994; Matson *et al.*, 1997). The immediate reaction is to increase pesticide applications. As a result, pesticide diffusion along wildlife food chains and pesticide resistance has become an acute problem worldwide.

The effects of monoculture on the soil biotic community are less evident, as is effect of these changes on agro-ecosystems. Studies of key organisms however show that reduction in diversity of soil biota under agricultural practice may substantially alter the decomposition process and nutrient availability in the soil (Matson *et al.*, 1999).

Changes in natural resources

Organic matter is a critical component of soils. It provides the substrate for nutrient release, and plays a critical role in soil structure, increasing water holding capacity and reducing erosion. For intensive cropland in temperate zone agriculture, soil organic matter losses are most rapid during the first 25 years of cultivation, with typical losses of 50 percent of the original C. In tropical soils, however, such losses may occur within five years after conversion (Matson *et al.*, 1999). In addition to local impacts, the large amounts of CO_2 released in decomposition of organic matter greatly contribute to climate change.

Increasing yields also require more water. Irrigated land expanded at the rate of 2 percent per year between 1961 and 1991, and at 1 percent per year during the past decade (FAO, 2006b – see Table 1, Annex 2). This trend has dramatic consequences on the water resources. Over-pumping is a serious concern in many regions, especially where feedcrop species are cultivated outside their suitable agro-ecozone (e.g. maize in most parts of Europe), and the use of non-renewable water resources (fossil water) is frequent. Irrigation often takes place in a context of water scarcity, and this is expected to worsen as competition for withdrawals increases with human population growth, development and climate change.

Habitat deterioration

Intensification of agricultural production has been accompanied by large increases in global nitrogen (N) and phosphorus (P) fertilization. Chemical fertilizer consumption grew at 4.6 percent per year over the 1961 to 1991 period, though it stabilized thereafter (FAO, 2006b – see Table 1, Annex 2). The stabilization of fertilizer consumption at the global level results from the balance of consumption, increasing in developing countries and decreasing in developed countries.

The uptake of fertilizer nutrients by crops is limited. A significant share of P is carried away by runoff, while Matson *et al.* (1999) estimate that about 40 to 60 percent of the N that is applied to crops is left in the soil or lost by leaching. The leaching of nitrate from soils to water systems leads to increased concentrations in drinking water and contamination of ground and surface water systems, which threaten human health and natural ecosystems. In particular, eutrophication of waterways and coastal areas kills aquatic organisms and eventually causes biodiversity losses.

N fertilization, both chemical and organic, also leads to increased emissions of gases such as nitrogen oxides (NO_x), nitrous oxide (N_2O) and ammonia (NH_3). Klimont (2001) found that emissions of ammonia in China increased from 9.7 Tg in 1990 to 11.7 Tg in 1995 and are projected to rise to nearly 20 Tg NH_3 in 2030. The largest single source of emissions is the use of urea and ammonium bicarbonate - the key fertilizers in China.

Nitrogen oxide and ammonia may be transported and deposited to downwind ecosystems. This deposition can lead to soil acidification, eutrophication of natural ecosystems and shifts in species diversity, with effects on predator and parasite systems (Galloway *et al.*,1995). N deposition, mostly related to agriculture, is expected to increase dramatically over coming decades. The emission of nitrous oxides also impacts global climate, contributing to global warming - indeed the global warming potential of N_2O is 310 times greater than for carbon dioxide.

Finally, intensive agriculture land use impacts wildlife habitats. Monoculture areas offer little food or shelter to wildlife. Wild fauna is thus mostly absent from such intensive cropland.

Box 2.5 Livestock production systems and erosion in the United States

Soil erosion is regarded as one of the most important environmental problems in the United States. In the last 200 years, the United States has probably lost at least one-third of its topsoil (Barrow, 1991). Although erosion rates declined between 1991 and 2000, average erosion rates in 2001, at 12.5 tonnes per hectare per year (see Table 2.13), were still above the established sustainable soil loss rate of 11 tonnes per hectare per year (Barrow, 1991).

The rate and severity of erosion is site specific and depends largely on local conditions and soil types. However, the link with livestock production is compelling. About 7 percent of the agricultural land (2001) in the United States is devoted to the production of animal feed. Livestock production can be said to be directly or indirectly responsible for a significant proportion of the soil erosion in the United States. A careful assessment of erosion on crop and pasture lands suggests that livestock are the major contributor to soil erosion on agricultural lands, accounting for 55 percent of the total soil mass eroded every year (Table 2.13). Of this eroded mass, around 40 percent will end up in water resources. The rest will be deposited on other land sites.

Nevertheless considering the major importance of the role of agriculture land in water contamination by sediments in the United States, we can reasonably assume that livestock production systems are the major source of sediment contamination of freshwater resources.

Table 2.13

Contribution of livestock to soil erosion on agricultural lands in the United States

Erosion on cropped land	
Total erosion on cropped land *(million tonnes/year)*	1 620.8
Average water and wind cumulated erosion rate *(tonnes/ha/year)*	12.5
Total arable land for feed production *(million ha)*	51.6
Total erosion associated with feed production on cropped land *(million tonnes/year)*	**648.3**
As percentage of total erosion on cropped land	40
Erosion on pastureland	
Average water and wind cumulated erosion rate *(tonnes/ha/year)*	2
Total pastureland *(million ha)*	234
Total erosion on pastureland *(million tonnes/year)*	**524.2**
Erosion on agricultural land (crop and pasture)	
Total erosion from Agricultural land *(million tonnes/year)*	2 145.0
Total erosion associated with livestock production *(million tonnes/year)*	**1 172.5**
As percentage of total erosion on agricultural land	**55**

Source: USDA/NASS (2001); FAO (2006b).

Furthermore, intensively cropped parcels often represent a barrier to wildlife movements, leading to ecosystem fragmentation. As a consequence, Pingali and Heisey (1999) suggest that meeting the long-term demand requirements for food, and in particular cereals will require more than a shift in the yield frontier. It will also require fundamental changes in the way fertilizers and pesticides are used and soil is managed. To sustain cereal productivity growth while conserving the resource base demands that production increases should be achieved with less than proportionate increases in chemical inputs. Recent advances in fertilizer and pesticide formulae, as well as in technology and techniques for their efficient use, may help in meeting these objectives (Pingali and Heisey, 1999).

Soil erosion

Erosion rates greatly vary depending on local conditions and it is often difficult to compare local data. Erosion rates are influenced by several factors including soil structure, landscape morphology, vegetation cover, rainfall and wind levels, land use and land management including method, timing and frequency of cultivation (Stoate *et al*., 2001) (see Box 2.5). As the worst erosion is usually caused by runoff water, erosion tends to increase as infiltration decreases. Any activity that modifies significantly the infiltration process has an impact on the erosion process.

Croplands, especially under intensive agriculture, are generally more prone to erosion than other land uses. Major factors that contribute to increased erosion rates within croplands include:

- removal of the natural vegetation that binds the soil, protects it from the wind and improves infiltration;
- inappropriate cultivation practices;
- the mechanical impact of heavy agricultural machines; and
- depletion of the natural soil fertility.

Barrow (1991) reviewed the magnitude of erosion from cropland in various countries. As the methodologies used for assessing the erosion process are not standardized it is difficult to compare the different measures. He noted that erosion levels can be extremely severe in some cases resulting in the loss of more than 500 tonnes of soil per hectare per year (observed in Ecuador and Côte d'Ivoire). As a reference, a loss of 50 tonnes per hectare per year amounts to a loss of depth of about 3 mm/yr off a soil profile. This is enough to affect agriculture in quite a short time if the top soil is shallow. There is little agreement in the literature on permissible rates of erosion but erosion levels of 0.1 to 0.2 mm per year are often considered as acceptable (Barrow, 1991).

Main global environment concerns associated with intensive feedcrop agriculture include climate change, through gaseous emissions from fertilizer applications and the decomposition of organic matter in the soil, depletion of water resources through pollution and withdrawals, and erosion of biodiversity through habitat destruction and water and soil pollution. These issues will be reviewed in Chapter 3, 4 and 5, respectively.

2.6 Conclusions

Today, the livestock sector is a major land user, spanning more than 3.9 billion hectares, representing about 30 percent of the world's surface land area. The intensity with which the sector uses land is however extremely variable. Of the 3.9 billion hectares, 0.5 are crops, generally intensively managed (Section 2.3); 1.4 are pasture with relatively high productivity and; the remaining 2.0 billion hectares are extensive pastures with relatively low productivity (Table 4, Annex 2). The sector is the first agricultural land user, accounting for about 78 percent of agricultural land and as much as 33 percent of the cropland. Despite the fact that intensive, "landless" systems have been responsible for most of the sector's growth, the influence the sector has on the cropland is still substantial, and environmental issues associated to livestock production could not be comprehensively apprehended without including the crop sector in our analysis.

As the livestock sector develops, however, its land-size requirements grow and the sector undergoes a geographical transition involving changes in land-use intensity and geographical distribution patterns.

Intensification slows the spread of livestock-related land use

The first aspect of this transition is land-use intensification. It relates to feed supply, the main purpose for which the sector uses land (either directly as pasture or indirectly as feedcrops).

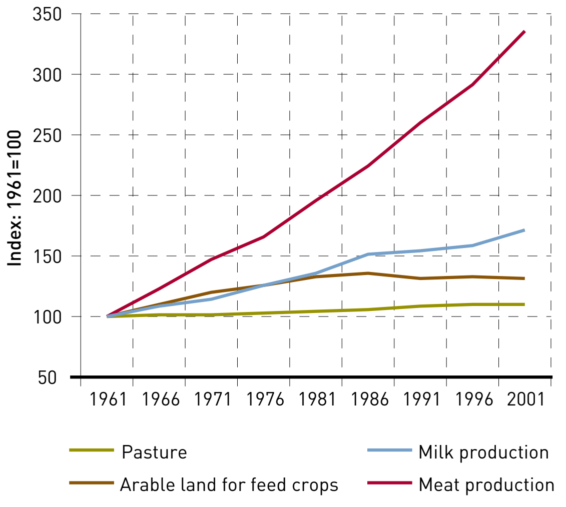
Feedcrops and cultivated pastures intensify in areas with developed transport infrastructure, strong institutions and high agro-ecological suitability. Figure 2.18 shows the marked difference in growth rates between the global areas dedicated to pasture and feed production, compared to the meat and milk outputs of the sector. This increasing productivity is the consequence of strong intensification of the sector on a global scale. The shift from ruminant species to monogastric species fed on improved diets plays a critical role in this process.

The growth in demand for livestock products will probably still play a dominant role over the next decades and lead to a net increase in the area dedicated to livestock, despite the intensification trend. Extensive pastures and feedcrop production will expand into natural habitats with low opportunity cost. It is, however, likely that the bulk of pasture and feedcrop spread has already occurred, and that the intensification process will soon overcome the trend for area expansion, leading to an eventual net decrease in the area under pasture and feedcrops.

There are regional variations to these global trends. In the EU (Figure 2.19) and more generally in OECD countries, the growth of meat and milk production happened at the same time as a reduction in the area dedicated to pasture and feedcrops. This was predominantly achieved through improved feed-conversion ratios, but part of the reduction in local feedcrop area was also compensated by feed imports, in particular from South America. Indeed, the comparable trends in South America (Figure 2.20) show a relatively stronger growth of feedcrop areas. Rapid development of a regional intensive livestock sector fuelled the feed production industry but exports were responsible for extra growth. Feedcrops grew especially rapidly in the 1970s and late 1990s, when first developed countries and then developing countries engaged in livestock industrialization and started importing protein feed.

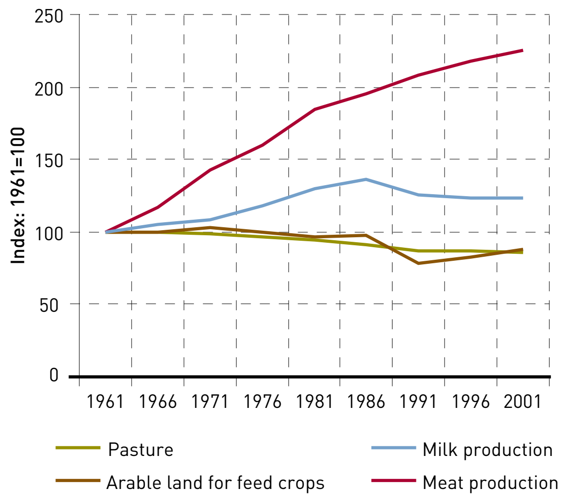
This is for example currently under way in East and Southeast Asia (Figure 2.21), where production has grown dramatically faster than the area under feedcrops and pasture (which has remained stable). This difference in growth rates has been achieved by importing feed resources,

Figure 2.18 **Global trends in land-use area for livestock production and total production of meat and milk**



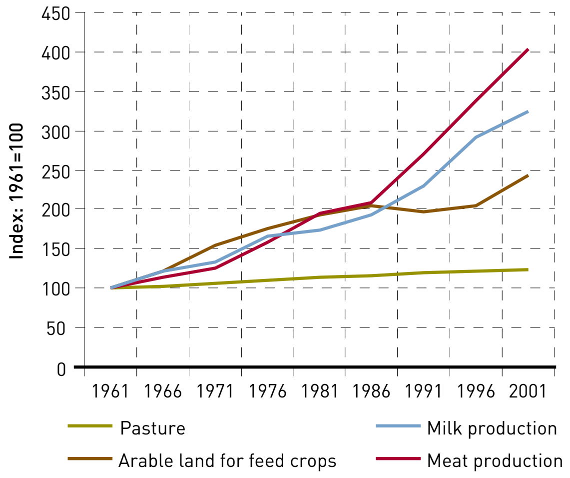
Source: FAO (2006b).

Figure 2.19 **Trends in land-use area for livestock production and local supply of meat and milk – EU-15**



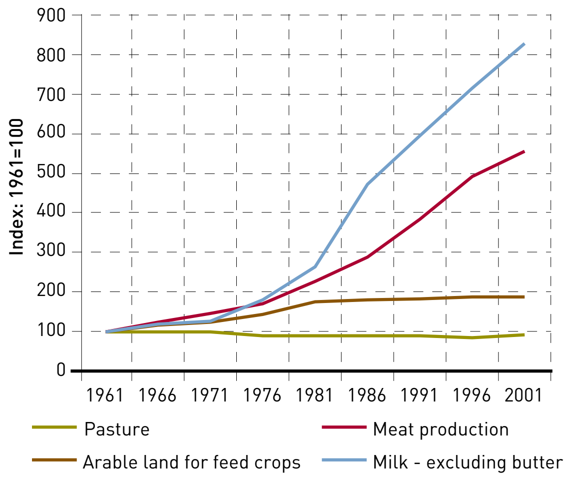
Source: FAO (2006b).

Figure 2.20 **Trends in land-use area for livestock production and local supply of meat and milk – South America**



Source: FAO (2006b).

Figure 2.21 **Trends in land-use area for livestock production and local supply of meat and milk – East and Southeast Asia (excluding China)**



Source: FAO (2006b).

and also through a rapid intensification of the livestock industry involving breed improvement, improved animal husbandry and a shift to poultry (the methodology developed to estimate land use by livestock, as well as complementary results are presented in Annex 3.1).

Production shifts to areas of feed resources or lower costs

The second feature of livestock's geographical transition lies in the changing spatial distribution of production. Production and consumption no longer coincide, as most consumption is located in urban centres, far from the feed resources. The livestock sector has adapted to this new configuration by splitting up the commodity chain and locating each specialized production or processing segment where production costs are minimized. With the development of transport infrastructure, shipment of animal products is becoming relatively cheap in comparison with other production costs. The trend towards more processed foods further contributes to reducing transport costs. Livestock production, therefore, moves closer to feed resources, or to places where the policy context (tax regime, labour standards, environmental standards), as well as access to services or disease conditions, minimize production costs. In essence, livestock are thus moving from a "default land user" strategy (i.e. as the only way to harness biomass from marginal lands, residues and interstitial areas) to an "active land user" strategy (i.e. competing with other sectors for the establishment of feed-crops, intensive pasture and production units).

Paying the environmental price

This process leads to efficiency gains in the use of resources. However, it usually develops within a context of environmental and social externalities that are mostly not addressed, and inadequate pricing of resources on the basis of private rather than social costs. As a consequence, changes in livestock geography are associated with substantial environmental impacts. For example, the private costs of transport are distortedly low and do not reflect social costs. The expansion and intensification of crop agriculture is associated with profound land degradation problems. The continuous expansion of agriculture into natural ecosystems causes climate change and biodiversity loss. The disconnection of livestock production from its feed base creates inadequate conditions for good waste management practices, which often cause soil and water pollution as well as greenhouse gas emissions.

On current trends, the ecological footprint of the livestock sector will increase because of expansion of land use and land degradation. Confronting the global environmental challenges of land use will require assessing and managing the inherent trade-offs between meeting the current demand for animal-derived foods, and maintaining the capacity of ecosystems to provide goods and services in the future (Foley *et al.*, 2005). Ultimately, reaching a sustainable balance will require adequate pricing of natural resources, the internalization of externalities and the preservation of key ecosystems.