Chapter 14

Sustainability Concerns of Livestock-Based Livelihoods in the Andes

Carlos Leon-Velarde[1], Roberto Quiroz[2], Percy Zorogastúa[2] and Mario Tapia[2]
International Livestock Research Institute, Ethiopia
International Potato Center, Peru

Introduction

Mountains account for 20% of the world's landscape and are home to at least 15% of the earth's people. Mountains are also home to the poorest of the poor. Some of the poorest mountain people live in Latin America in the Andes of Ecuador, Peru, and Bolivia; a sizeable number live in remote mountain areas of the Hindu Kush-Himalayas. In these areas, there are grave social, economic, and biological concerns for humankind.

The Andean region in South America is a wide mountainous area covering approximately 1.4 million sq.km. Most of the estimated population of more than 113 million depend on agriculture for their livelihood. The majority of the farming systems in the high Andes are mixed crop-livestock systems. Livestock production plays an important role in the sustainability of these heterogeneous farming systems and is less susceptible to widespread climatic risks than crops. Animals take on a number of different and important roles within the mixed system: food supply, feed bank, work, source of energy in the system, source of fertiliser, and link to local markets. Livestock production is intrinsically associated with environmental quality. Production of crops and pasture on hillsides is directly associated with soil erosion and affects the supply and quality of the water used downstream; when the soil is covered by grass soil erosion is less than with crops alone.

This paper describes how the challenge of the constraints faced in the Andes can be met by adopting a holistic approach. The region includes several countries and ecosystems so that participation by a group or consortium of institutions is seen as necessary for an integral approach. Horizontal characterisation of agro-ecosystems (across the region) rather than a localised analysis is necessary in order to work towards sustainable use of the natural resources across the Andean region. In the consortium approach of CONDESAN (Consortium for Sustainable Development of the Andean Ecoregion), different institutions across the Andean region from both the government and private sectors are linked together to promote sustainable food production.

South America and the Andean Region

The area in South America denominated in a broad sense as the Andes covers around two million square kilometres and includes territory in seven countries. It extends from the northern coast of Venezuela and Colombia (latitude 11°N) to Argentina (55°S). It can be divided into two main areas: the Andean region and the Southern Cone. The latter comprises mainly Argentina, Uruguay, and Chile. The major part of the Andes lies in Ecuador, Peru, Bolivia, Colombia, and to a minor extent, Venezuela.

The Andean region is a mountainous area whose altitude ranges from 2,000 to more than 4,500 masl with variations in form and width. About 71% of the area lies between 2,000 and 4,000 masl, about 16% between 4,000 and 4,500m, and 13% above 4,500m In Colombia, the Andean region is 100 to 300 km wide and includes three mountain chains separated by the Cauca Valley and the Magdalena river. These chains are united in Ecuador to form the Loja node at the start of a higher and homogeneous mountainous chain, 150 to 200 km wide, which runs through the country. This mountain chain continues in Peru forming the Pasco node, and linked by the Vilcanota node, before it reaches the large and wide area of the Altiplano that spans part of Peru and Bolivia.

The population of South America is around 370 million (FAO 1994) and is expected to reach 490 million by 2025. It is expected that the increase will be in urban areas only, and that the rural population will remain at the current level. The average population density in the main Andean countries (Colombia, Ecuador, Peru, and Bolivia) is estimated to be 39.3 per sq.km, with higher densities at the lower altitudes, and is expected to increase to 56.7 per sq.km by the year 2010. Population growth means that the pressure on rural areas to produce more food will increase. Food demands will not be satisfied unless there is a drastic change in the use of natural resources through application of more appropriate policies and technologies. Changes are also needed to improve parameters such as infant and adult nutrition, health and sanitary conditions, and education. Urban dwellers cannot expect that a mass of ill-nourished, powerless, and illiterate peasants and farmers, historically disenfranchised and currently disadvantaged by inappropriate policies, will be able to produce enough food in a sustainable way. Current trends indicate that, although total food production in the region has increased in the past twenty years, food per capita has remained constant. It is essential that food per capita at least remains at the present level of calories and protein intake, which for the vast majority of people is already well below the recommended levels.

Poverty is increasing in the region, and if this continues it can be expected to lead to a greater degree of malnutrition, which will have an irreversible affect on the human capital of the region. In the 1980s, about 55 million people were already suffering from malnutrition (Janssen 1991). This critical situation is aggravated by the ongoing degradation of the natural resources used for agriculture, which will lead to decreased yields. For example, soil erosion in the Peruvian Andes is proceeding at a rate well above the five tonnes per ha threshold value (Quiroz et al. 1995). This indicates that current management practices are not sustainable. Table 14.1 shows some selected socioeconomic indicators for the Andean region and the Southern Cone.

Eco-geographic areas

In the Andes the concept of region overlaps well with the concepts of ecoregion, biome, area of life, bioregion, and biotic province, among other classifications. The Andean region has diverse sub-ecoregional zones each with specific characteristics of climate and cultural and socioeconomic conditions. Such zones include the Bolivian Altiplano and the savannas of Bogota. At each ecological level, the altitude, rain, and temperature define the predominance of forage species and agricultural crops. The temperature range is restricted by the longitude and modified by the altitude. Precipitation and moisture vary greatly and define a mosaic of soils in relatively small areas. The combined characteristics of rainfall and altitude define three main eco-

Table 14.1: Selected economic and other human welfare indicators in the main regions of the Andes and the Southern Cone

Indicator	Andean region	Southern cone
National Gross Product (US$$10^6$)	123,855	479,204
Income per capita (US$/year)	1,158	2,132
Urban population[1] (%) 1990	65.5	74.4
Proj. 2030	78.6	81.0
Poverty incidence (%)	53.6	37.4
Human development index (HDI)[1]	0.66	0.81
Agricultural land distribution[2]	0.74	0.86
Calories consumption per capita (cal/day)[3]	2,369	2,784
Protein consumption per capita (g/day)	57.9	79.8

[1] HDI includes life expectancy, education, and health; [2] Gini coefficient; [3] 1 calorie = 4.1868 joules

geographic areas known as the Green Andes, the Central area, and the Altiplano or Yellow Andes (Tapia 1996).

- *Green Andes* — This area covers the parts of the mountains of Colombia, Ecuador, and northern Peru that lie between 3,800 and 4,400 masl. Annual precipitation is more than 1,000 mm and the area is characterised by intense mists and the absence of arboreal species. There is an abundance of grass, which is used as a feed resource.
- *Central Andes* — This is the most extensive area. It includes almost the entire Andes. In the tropical area it rises to 4,200 m; to the north and to the south to 3,000 m. The climate is cold and crops are mainly frost tolerant species such as the bitter potato and the kañiwa. Livestóck raising is based on native grasses.
- *Yellow Andes* — This area lies between 15° and 27° S. It is a highland area ranging from 2,800 to 4,800m, containing a plateau known as the Altiplano and bordered by the western and eastern mountain ranges. It includes the lakes Titicaca and Poopo (Peru and Bolivia, respectively). The low parts of this area are favourable for agriculture. The high areas are characterised by extensive livestock production.

In addition to these is the Pre-Puñena province. This area is part of north Argentina and Chile. It is characterised by slopes and dry areas between 1,000 and 3,400m with a limited area devoted to agriculture.

Several characteristics differentiate the Andean region from other mountainous parts of the world (Gastó 1993), in particular the very steep slopes and extreme climatic variations associated with considerable regional diversity. The region faces severe problems of poverty and resource degradation which have no simple solutions. Traditional small farmers within communities have developed specific and traditional agricultural systems appropriate for the local conditions. However, high population density and urban development are producing imbalances in sustainable agricultural production and the well-being of farmers in the region. Marginal conditions and limited access to resources are the main reasons for the failure of previous development efforts.

Biological, Economic, and Social Indicators

Table 14.2 shows some major macroeconomic indicators for the main countries of the Andean region.

The annual growth rate of the population in the countries of the Andean region ranges between 2.2 and 2.7%. The projected population for the year 2010 is about 43% higher than at present. The trend of rural to urban migration is in the order of 15%. This means that measures are required to ensure sustained food production

Table 14.2: Major macroeconomic indicators in the countries of the Andean region[1]

Macro economic indicators	Andean region			
	Ecuador	Peru	Bolivia	Colombia
Population				
Total (millions) 1990	10.3	21.6	7.3	33.0
Projected in 2010 (millions)	15.5	31.0	11.1	42.9
Average annual growth rate % (1970-90)	2.7	2.4	2.6	2.2
Density (inhabitants/km2)				
- 1970	21.0	10.3	3.9	18.8
- 1990	36.1	16.8	6.7	29.0
Distribution (%)				
- Urban				
1970	39.5	58.1	38.2	57.5
1990	54.7	69.3	51.5	73.1
- Rural				
1970	60.5	41.9	61.8	42.5
1990	45.3	30.7	48.5	26.9
Economy				
EAP[1] (%)	32.7	35.2	31.1	30.8
Agricultural exports ($million)				
- 1970	175	177	121	598
- 1990	778	287	205	2,385
Agricultural GNP (% of total)	17.4	14.1	21.2	22.3
Debt increase (%)	4.5	4.5	6.4	3.6
Social				
Life expectancy (years)				
- 1970	61	56	51	64
- 1990	66	64	61	69
Illiterate (%)	14.2	14.9	22.5	13.3
Consumption				
- Protein (g)				
1970	51	62	50	51
1990	53	60	56	55
- Energy (Mcal)				
1970	1.9	2.3	1.8	2.2
1990	2.5	2.3	2.1	2.5
Agriculture				
Deforestation, average annual				
- 1970	1.2	0.3	0.4	0.5
- 1990	2.6	0.4	0.1	0.6

Source: IICA 1994

[1]Economically active population

and to increase labour occupation. Agricultural exports are expected to grow by 2%, which is less than the recommended level of 4% (McCalla 1994). Adding value to products by processing could increase the value of exports and benefit farmers, but a large proportion of the rural and urban poor might not be able to buy value-added products. This tradeoff requires further analysis.

Various studies indicate that the governments and the international community need to maintain or renew their commitment to agricultural growth (Winograd 1995).

This means that an effort must be made to develop adequate policies and cost-effective investments in agricultural research, extension, and the management of soil and water to alleviate the pressure on food production. Similarly, investments should be made in human capital and rural infrastructure.

The dramatic changes in socioeconomic and environmental issues around the world, and especially in the Andean region, have created new challenges and opportunities for research and economic development in the region. One key constraint to the sustainable development of the Andean region at the specific eco-regional level is the lack of local capacity to analyse and understand the complexity of the world agricultural situation, and to develop with the local population a productive and sustainable approach to using their resources in a market-oriented fashion.

Development of the Andean region has become necessary and important at national and international level because it is the core area that provides the basis for livelihoods and the natural resources, in particular water, for a large region. Almost 80% of the water supplied to the Amazon basin comes from the Andes. Problems within the Andes, particularly in the Altiplano, such as salinisation, soil erosion, and destruction of waterways can have major impacts downstream.

The Development of Livestock Production Systems in the Andean Region

Mountain specificities

Research towards the development of sustainable production systems in the Andes, must take into account the specific features that characterise the region. These are summarised in the box in terms of the special characteristics of all mountain areas, the 'mountain specificities', described by Jodha (1990), as they apply to the Andean region.

Grassland resources

It is important to have some knowledge of the existing types of grassland and their present state when considering the development of livestock systems. Table 14.3 shows the main grasslands' associations found in the Andean region, together with an indication of their present stocking rate (sheep per ha per year). The stocking rate is given in sheep units because some areas ('bofedales' and 'tolar') are not commonly grazed by cattle. Restoring grasses and shrubs in degraded pastures is a necessary prerequisite for restoring the balance of the biodiversity of plants (Paladines 1995).

MOUNTAIN SPECIFICITY	THE ANDEAN SITUATION
Fragility	The Andean region is a naturally fragile environment. There is intensive use of the natural resources.
Marginality	In general, decision-makers pay little attention to the living conditions and expectations of Andean producers.
Inaccessibility	Access to goods and services and opportunities for marketing are limited, which poses difficulties that restrict the sustainable development of the region.
Diversity	As a result of the wide diversity in climate and topography, the region contains a broad diversity of environments and resources, many of which have been used in forms of multiple production.
Adaptation Mechanisms	The extreme conditions in the mountains have generated traditional practices and management forms for the agricultural systems.
Niche	The combination of biodiversity and specific environments provides mountain areas with a potential comparative advantage for certain activities and the production of certain products.

Table 14.3: **Andean grassland associations - current carrying capacity and ecological situation**

Main grassland areas	Stocking rate, sheep units[1]	Ecological situation
Chillliguar rangelands (*Festuca dolichophylla*)	2 – 6	Partially overgrazed, palatable species disappearing
Bofedales: spring-fed, year-round-irrigated rangelands in the Puna	3 – 4	Seasonal use
Pajonal: middle and short bunch grasses of the Puna	0.5 - 1.5	Mostly overgrazed
Tolar, shrubs (*Parastrephia, Bacharis*)	0.5 - 1.2	Process of deforestation
Paramo rangelands	0.5 - 1.0	Partially overgrazed

[1]Sheep units: 35 kg head per ha per year.
Sources: Tapia 1996; Paladines 1995

Crop-livestock production systems

Considerable differences are found both among and within different agroecological zones in the crop-livestock production systems that are employed, as a result of differences in water availability, risk of frost, slope, and access to markets and market demands. The main features of these different systems are summarised in Table 14.4, and discussed in more detail below.

Table 14.4: **The major mixed crop-livestock production systems in the Andes**

Agro-ecological zone	a. Altitude (m) b. Rainfall (mm) c. Slope (%)	Crops grown, livestock kept	Livestock products	Feeding system
Inter-Andean Valleys	a. 200 - 2700 b. 250 - 700 c. 5 - 40	Maize, faba beans, rye grass, white clover, alfalfa Cows	Milk, cheese	Grazing, protected forage, agricultural by-products, commercial feed concentrates
Hillsides	a. 2700 - 3500 b. 500 - 800 c. 20 - 90	Maize, wheat, barley, potatoes, other root and tuber crops Triple-purpose cattle, sheep, goats	Milk, cheese, weaned and mature animals, wool, dung	Grazing, crop residues, protected forage
Suni	a. 3400 - 4000 b. 500 - 600 c. 0 - 80	Potatoes, oats, barley, wheat, quinoa, faba beans Sheep, camelids, triple-purpose cattle	Milk, cheese, wool, fibre, weaned and mature animals, dung	Grazing, crop residues, protected forage
Jalca	a. 3400 - 4000 b. 700 - 1300 c. 30 - 90	Potatoes, barley, oats Sheep, triple-purpose cattle	Milk, cheese, wool, weaned and mature animals, dung	Grazing, crop residues, protected forage
Puna	a. 3800 - 4500 b. 600 - 1200 c. 20 - 60	Bitter potatoes, quinoa, kañihua, cereals Sheep, camelids, triple-purpose cattle	Wool, fibre, weaned and mature animals, milk, cheese, dung	Grazing, crop residues, protected forage

Source: Tapia 1996 (modified from Quiroz et al. 1991)

Livestock production in the Andes is based on grazing of pasture, supplemented with crop residues, particularly stovers, or agricultural by-products and, in certain cases, with improved feed resources. Thus rangelands constitute the main feed resource for mixed systems with ruminant species. Native species dominate the grasslands across the region (Leon-Velarde and Izquierdo-Cadena 1993). The species found in both native and introduced pasture vary greatly according to agro-ecological zone. There is considerable scope for improved pasture management and forage conservation techniques, combined with better use of agricultural by-products, to contribute to livestock development.

Weather conditions in the inter-Andean valleys are similar to those in temperate areas. Although they are favourable for milk production, the available feed resources are not used optimally at present. The availability and quality of feed resources in the four other zones – hillsides, suni, jalca, and puna – are quite different to those in the inter-Andean valleys. Seasonality is more evident in both the quantity and quality of forage. Crop residues are a buffer during the dry season, which may last from four to six months (Quiroz et al. 1991). In general, animals not only constitute the main source of income, they are also the 'savings account' of most rural households (PISA 1993). This highlights the importance of using crop residues to reduce mortality rates. Crop residues and by-products are fed mainly to large ruminants, but, after a good harvest, they are also given to small ones. With the introduction of new types of pasture such as rye grass, alfalfa, and white clover, practices are changing. Cattle and sheep are now favoured, with lower-quality feedstuffs being left to camelids, which are more able to digest them (San Martin and Bryant 1987).

Although local National Agricultural Research Stations and universities have a history of research on feed resources, most investigations have been conducted at specific sites (research stations, peasant communities, and farming systems). The impact of research on feed resources has been limited and localised. The main constraints to the adoption of research results are the heterogeneity of the region, as determined by factors such as altitude, climate, soils, quality and quantity of feed resources, and ethnic background; lack of any methodology for integrating research results into technological alternatives to solve the different problems encountered; and inappropriate incorporation of socioeconomic aspects into the technology development and transfer process. There is still considerable potential for increasing sustainable crop-livestock productivity and household income if these constraints are taken into account during the design phase of research and development programmes. What is needed is an integrated research and development approach oriented to meet market demands.

Nearly all of the existing technologies have been generated with the single objective of increasing crop-livestock productivity. They should now be tested to see whether they can be used both to increase production efficiency and to enhance the natural resource base. This requires careful analysis of the farming systems and the natural resource base, and an in-depth understanding of the crop-livestock systems in mountain areas and the interaction of farmers with the environment. This interaction must be looked at not only at the farm level – the scale often used to generate and validate technology for crop-livestock production – but on larger scales, so that the impact on the environment can be adequately assessed. Production systems and ecosystems need to be documented with an emphasis on both determining vulnerable areas and on the potential contribution of crop-livestock production systems to solving the problem of feeding an increasing population without causing deterioration of the natural resources.

Agro-pastoral production systems

The pastoral production systems in the Andean region have developed as a result of environmental factors, type of forage, size of holdings, and land tenure, as well as existing policies. Livestock, especially ruminants, play an important role in most highland areas (Li Pun and Paladines 1993). The principal feed source is natural grass, especially at high altitude where there are severe restrictions to growing agricultural crops. The most important species are camelids, cattle, and sheep. They play several roles: as assets; animal traction; source of meat, fibre, and wool; and a source of cash income. Livestock production and the management of grasses are important factors in the economy of Andean farmers, but they have received little interest or support for research and the use of new technologies (Li Pun and Sere 1993).

Livestock Productivity

The main types of animals kept in the Andean region, and their average productivity, are summarised in Table 14.5.

In general, the production of milk, meat, and wool are declining as a result of poor management and inputs. The productivity is also affected by low nutrition, parasite

Table 14.5: **The main animal production systems in the Andean region: species, feeding practices, and productivity**

Species	Type	Feeding practice	Livestock	Production
Cattle[1]				
Milk	I	Forage/concentrate	Holstein-Brown Swiss	1,880-3,600 kg
	SI	Forage/residues	Crossbreeds	800-2,100 kg (210-310 days, milking 2x per day)
	Ex	Grazing (dual purpose)	Creole	600-1,200 kg
Meat				
Calf-cow	Ex	Grazing/residues	Creole	220-320 kg per head
Fattening	SI	Concentrate/forage	Creole, crossbreeds	280-370 kg per head
Sheep[2]	Ex	Grazing/forages	Corridale, others	3.8-5.2 kg wool 10.2-21.8 kg meat/head
	Ex	Grazing/residues	Creole, crossbreeds	1.8-3.6 kg wool 13-15 kg meat/head
Alpacas[2]	Ex	Grazing/residues	Huacaya, Suri	1.1-3.6 kg fleece 26.4-31.4 kg meat/head
Swine	I	Concentrate/residues	Duroc, Landrace, Yorkshire	65-92 kg per head
	Ex	Grazing/residues	Creole, crossbreeds	45-70 kg per head
Goats	Ex	Grazing/residues	Anglo-Nubian, crossbreeds	11-15 kg per head
Poultry[3]	I	Concentrates	Hybrid	150-190 eggs 0.8-1.2 kg meat/head
	Ex	Household	Creole, crossbreeds	20-130 eggs 0.8-1.4 kg meat/head

Source: PRODASA/CIP 1996
I = Intensive; SI = Semi-intensive; Ex = Extensive;
[1]milk is total per lactation; [2]wool/fleece is per head per year; [3]eggs are total per year

infestation and infectious diseases, and the lack of adequate breeding and selection. Research results indicate that there are considerable possibilities for improving the levels of animal production in the Andean region.

The main production and productivity parameters for the four countries in the Andean region separately are shown in Table 14.6. Cattle play an important role. Colombia has the largest population of cattle and the greatest total production of meat and milk. Peru has more sheep than the other countries, although still many less than in Argentina and Uruguay. Peru and Bolivia have similar-sized populations and similar production levels of goats. Pigs and poultry are considered to be 'short-term' food production, but these animals compete for food grains with people and more research is needed on alternative feed resources for them.

Alpacas have a unique comparative advantage in the production of fibre. Although only three per cent of the total volume of fibre is marketed at an international level, the demand is high and the fleece commands a competitive price. Moreover, alpaca and llama meat constitute the main source of protein for the inhabitants of the Altiplano. Improvement in the traditional processing practices for alpaca meat, and selection and breeding of alpacas for good fibre, are key challenges for future research (Leon-Velarde and Guerrero 1999).

Table 14.6: **Production and productivity parameters of the main animal species found in crop-livestock production systems in the Andean region**

Species	Ecuador		Peru		Bolivia		Colombia	
	1971-89	1992	1971-89	1992	1971-89	1992	1971-89	1992
Cattle (m)	3.0	4.8	4.3	3.9	4.5	5.8	24.1	25.3
Meat total (1000t)	79	143	87	105	100	132	607	651
kg/head	167	184	123	152	171	163	183	210
Milk total (1000 t)	924	1550	796	795	71	120	2,187	4,476
kg/head	1,446	2,084	1,298	1,407	1,396	1,412	965	994
Sheep (m)	1.5	1.6	13.8	11.9	8.9	7.5	6.0	4.6
Meat total (1000 t)	3	3	21	19	20	12	9	10
kg/head	14	14	14	14	11	9	15	14
Wool (1000 t)	1.2	1.1	5.5	4.6	4.8	3.9	1.0	1.0
Alpacas (m)	----		2.8	3.1	0.2	0.2	----	
Llamas (m)	-----		0.7	0.8	1.5	1.7	----	
Goats (m)	0.3	3.4	1.7	1.8	1.4	1.5	0.6	1.0
Meat total (1000t)	1	2	9	9	5	5	4	4
kg/head	15	15	12	12	11	11	16 –	16
Milk (1000 t)	2	3	19	19	14	11	10 -	12
Pigs (m)	3.4	2.5	2.2	2.4	1.6	2.3	2.0	2.6
Meat total (1000t)	58	87	72	91	47	68	98	134
kg/head	45	45	60	61	50	50	62	69
Poultry (m)	33	57	40	60	17	33	30	62

Source: Data from FAO 1996; IICA 1994
m = millions; t= tonnes

Figure 14.1 shows the average levels of livestock production in the Altiplano– separately for lead farmers and for communities as a whole. Most Altiplano farmers are producing at levels below their potential. With existing technologies, lead farmers have shown that it is possible to increase milk, wool, and fibre production, increase animal birth rates and average weight, and reduce mortality rates, which are seen as an indicator of inadequate management. In order to increase production overall, it will first be necessary to analyse the sociocultural factors involved, as well as the impact of existing policies, access to credit, and land tenure, and consider ways to improve these.

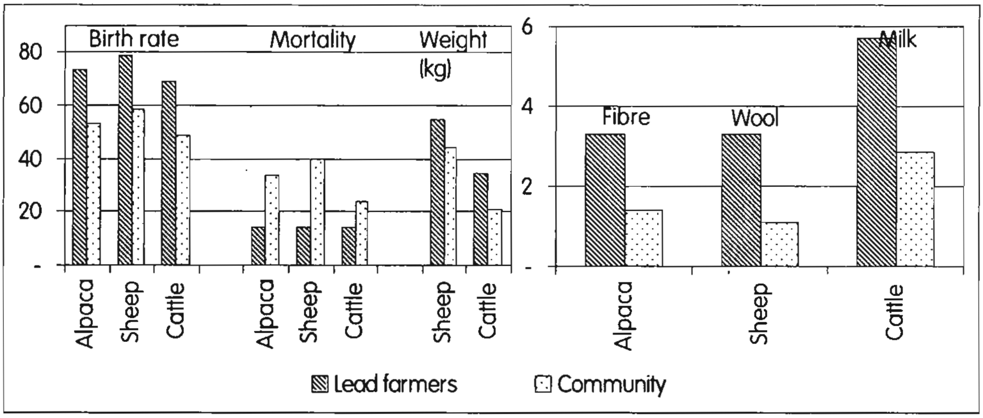

Figure 14.1: **Current potential of livestock production in the Altiplano**

The sources of income and expenses for a typical small farmer family in Puno, Peru, are shown in Table 14.7. At the level of the household economy, livestock are a source of protein, energy, shelter, fertiliser, draught power, and savings. The gross margin at the level of the producers is very low, however. In general, the animal production contributes around 73% of income and crops 27%. However, 20% of the animal production and 80% of crop production are used for family consumption (PISA 1993).

Most Andean producers are grouped into communities. They have access to both private and communal land. Usually the community has rules for the management of crops and animals: there is an established crop rotation and grazing management system. The crop cycle is 'potato→quinoa→barley (for forage)→fallow for three to four years'. Animals graze the native grass on fallow plots, facilitating nutrient recycling through animal excreta. Use of better quality cover plants at this time could contribute to improving the soil fertility and animal production. Recent studies (PRODASA/CIP 1996) indicate that livestock systems have an average income of US $ 1,130 per year with a capital of US$ 8,150, and US $ 876 per year with a capital of US$ 4,000. For cropping systems, the average income is about US$678 per

Table 14.7: **Sources of income and expenses for a small farmer family in the community of Santa Maria, Ilave, Puno, Peru (1992)**[1]		
Subsystem	US$ per year	per cent
Income		
Crops (potatoes, quinoa, oca, barley, others)	214	21.4
Livestock production	458	45.8
Processing (handicrafts, animal products, jerk meat)	107	10.7
Migration and trading	60	6.0
External support (food aid, others)	162	16.1
Total gross income	*1001*	
Expenses		
Own consumption of products	393	44.4
Food and supplies	110	12.4
External support (food aid and others)	162	18.3
Other cash expenses	220	24.9
Total gross expenses	*885*	
Gross margin	**116**	
[1] Adapted from PISA 1993; PRODASA 1993		

year with a capital of US$ 3,800. Farming families in the Andes participate in a range of activities, including growing crops and raising livestock, handicrafts, and work outside the farm, which help them diversify their sources of income and manage the risk. Livestock help reduce the climatic and economic risks from frosts and drought.

Communities in the Andean Altiplano include a large number of families. Studies show that communities have an average gross margin of some US$ 67,000 per year, which represents an annual gross margin of US $ 1,015 per year per family. Adequate land-tenure policies that facilitate growth of production need to be developed and introduced.

Modelling the Sustainability of Crop-livestock Production Systems

Agricultural scientists appear to agree about the importance of sustainability as an objective for research. However, in order to make the concept operational it is first necessary to have a method for quantifying sustainability. 'Sustainability' has been defined or characterised in a surprising number of different ways (IFPRI 1990), and no agreement has yet been reached on appropriate methods for measuring it. The common denominator is measurement of a trend over time. Table 14.8 shows some indicators of sustainability used in the analysis of crop-livestock production systems in the Andes.

Model simulations can be used to integrate mainly biophysical, biological, and economic components, including the social component, as an integral part of management. Simulation is an important method for developing possible scenarios

Table 14.8: Main parameters and indicators considered in the analysis of a crop-livestock production systems[1]

Parameter/ components	Sub-System components: Crops	Rangelands	Forest
Soil properties	- Organic carbon content - Nutrient content - Cation exchange capacity - Erosion rate	- Salinity - Organic carbon content - Nutrient content	- Nutrient content
Water quality and quantity	- Salinity - Seasonality - Pollutant concentrations	- Precipitation patterns - Pollutant concentrations	- Seasonality - Evapo-transpiration fluxes - Pollutant concentrations - Base flow
Biological diversity	- Species' richness and diversity of indicator groups - Population size of base species - Crop diversity - Diversity of pests and soil organisms	- Species' richness and diversity of indicator groups - Population size of base species - Forage diversity	- Species' richness and diversity of indicator groups - Population size of keystone species - Forage diversity
Production of goods and services	- Crop productivity (output/input) - Crop genetic reserves	- Stocking density - Forage productivity	- Yield of wood and non-timber products
Energy and nutrient flows	- Parent rock - Nutrient mobilisation - Nutrient (fertiliser) input fluxes - Energy efficiency and quality	- Nutrient mobilisation	- Primary productivity - Nutrient mobilisation
Landscape: composition and patterns	- Field size - Land-use conversion rate	- Grazing gradients - Land-use conversion rate	- Spatial variation of vegetation types - Land-use conversion rate
Atmospheric composition	- Acid precipitation - UV-B irradiation - Troposphere ozone concentration - Carbon dioxide concentration	- Acid precipitation - UV-B irradiation - Troposphere ozone concentration	- Acid precipitation - UV-B irradiation - Troposphere ozone concentration - Carbon dioxide concentration
Climate	- Mean temperature and variability - Mean precipitation and variability	- Mean temperature and variability - Mean precipitation and variability	- Mean temperature and variability - Mean precipitation and variability

[1]Does not include wildlife/unexploited land, freshwater fisheries, wetlands/groundwater, coastal resources, or marine fisheries

Such scenarios can help improve the basis for taking political decisions on the use of land resources and introduce the concept of bio-economic sustainability.

Figure 14.2 shows different schematic representations of sustainability calculated using a linear and a non-linear model. In both cases only a single variable (biological response) was considered, and at present it is only possible to try to plot changes in each variable separately over time. Nevertheless, to have a real measure of sustainability it is necessary to develop a combination of variables in a composite index. This is a challenge for the future. When looking at sustainability against time, it is necessary to consider the trend at a particular hierarchical level, for example related to a farm or a region, and look at the inputs and outputs at that level. At farm level the classical variable is the production expressed either as kg per ha or as income per ha. A recommended indicator at regional level is the continuity of supply of a given product. The main concern in the simulation models is the availability of information in relation to the technical point of intervention. Model d (in Figure 15.2 (B)) does not have a biological explanation; but with a technical intervention becomes model b.

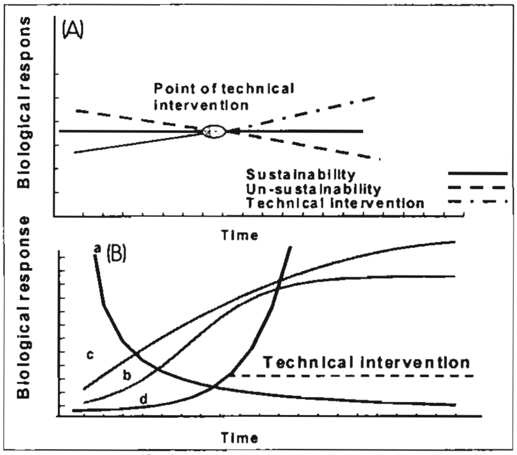

Figure 14.2: **Schematic representation of sustainability calculated using linear (A) and non-linear (B) models**

The possible effect of technical intervention can be analysed using models and simulation. Figure 14.3 shows the change in production (gross income) with time following a technical intervention in an alpaca production system using a simulation model. (This is line 'b' in Figure 14.2A) Three phases can be discerned – Phase I, technical intervention; Phase II, response to technical intervention; and Phase III, asymptotic of maximum potential –

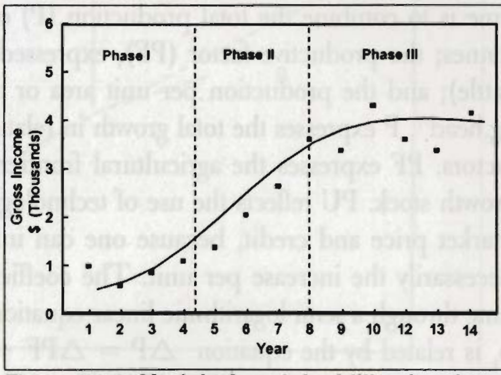

Figure 14.3: **Model of sustainability showing the change in gross income of an alpaca production system over time**

before sustainable production over time is reached (Leon-Velarde and Quiroz 1994, 1999). Note that time is a constraint in relation to technology, as well as an exogenous factor that farmers cannot control. Consequently, many of these systems remain in the 'status quo'.

The total factor productivity (Harrington 1992) indicates a measure of sustainability in relation to output over inputs. Likewise, it is related to the production trend per capita (C), expressed as kg.ha per inhabitant. This implies the use of the production per unit area (Y) as kg per ha, the cropping area (ha) and the population density (inhabitants per ha). In this form the equation is C = Y (A/P). This equation differentiated with respect to time and expressed in percentage change becomes:

$$(dC/dt)/C = (dY/dt)/Y + (dA/dt)/A - (dp/dt)/P;$$

where

(dC/dt)/C is the per cent change of the per capita production in a short space of time.

For example, if the production growth is 3.5% per year, the crop area is being reduced at 0.4% and the population growth is 2.5%; the production per capita will increase by 3.5 +(-0.4) – 2.5 = 0.6 % per year. This does not reflect any technical intervention because time is not considered in the equation, but any reduction can be interpreted as an unsustainable system.

Phase I, technical intervention; Phase II, response to technical intervention; Phase III, asymptotic of maximum potential

One way to integrate bioeconomic information to show sustainability and impact over time is to combine the total production (P) of a particular area expressed in kg, l, or tonnes; the productive factor (PF), expressed in number (ha, milking cows, head of cattle); and the production per unit area or animal (PU) expressed in $t.ha^{-1}$, $kg.ha^{-1}$, $kg.head^{-1}$. P expresses the total growth in relation to technology and credit among other factors. PF expresses the agricultural frontier including expansion of area or animal growth stock. PU reflects the use of technology. In some cases it is difficult to separate market price and credit, because one can influence the agricultural frontier but not necessarily the increase per unit. The coefficients of each variable are obtained over time through a semi logarithmic linear equation ($\ln Y = b_0 + b_1X$), thus the coefficient b_1 is related by the equation $\triangle P = \triangle PF + \triangle PU$. The results of a typical analysis are shown in Figure 14.4, which displays the annual growth rates of four commodities (potato, wheat, alpaca fibre and milk) in the Altiplano of Peru between 1970 and 1988. For wheat, both the area planted (PF) and the production per unit area (PU) showed growth rates, and the total production increased accordingly. There was a reduction in the area planted with potatoes (PF) and even though the production per unit area increased (PU) the overall effect was a reduction in total production. With both milk and alpaca the production factor (number of animals) increased, but the production per head went down, resulting in overall negative growth rates and indicating a lack of technology (Ccama 1990).

Analysis of total production in relation to the production factors and productivity also enables the influence of exogenous factors to be seen. This is illustrated in Figure 14.5, which shows the evolution of milk production from 1970 to 1988 (Ccama 1990). The first part (1970-1980) shows a negative trend, whereas after 1980 the trend is reversed. Assuming that this positive trend is maintained, it is possible to extrapolate the line and identify the point at which milk production will reach the level it was at before 1970 (the Agrarian reform). At the given rate of growth the level would be reached by 2006, 36 years after

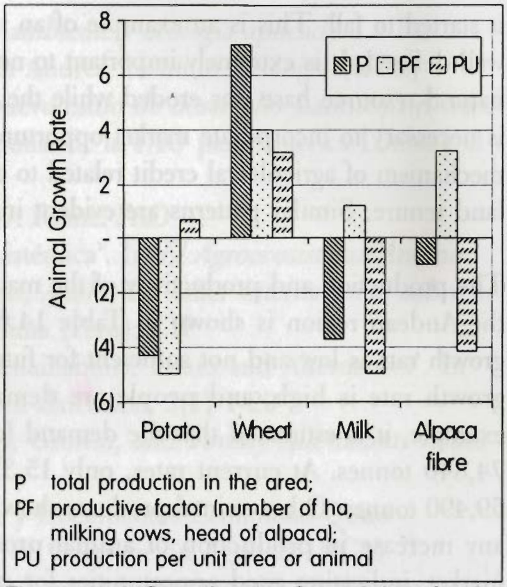

Figure 14. 4: **Growth rates for potato, wheat, milk, and alpaca fibre in the Altiplano, Peru (1970-1988)**

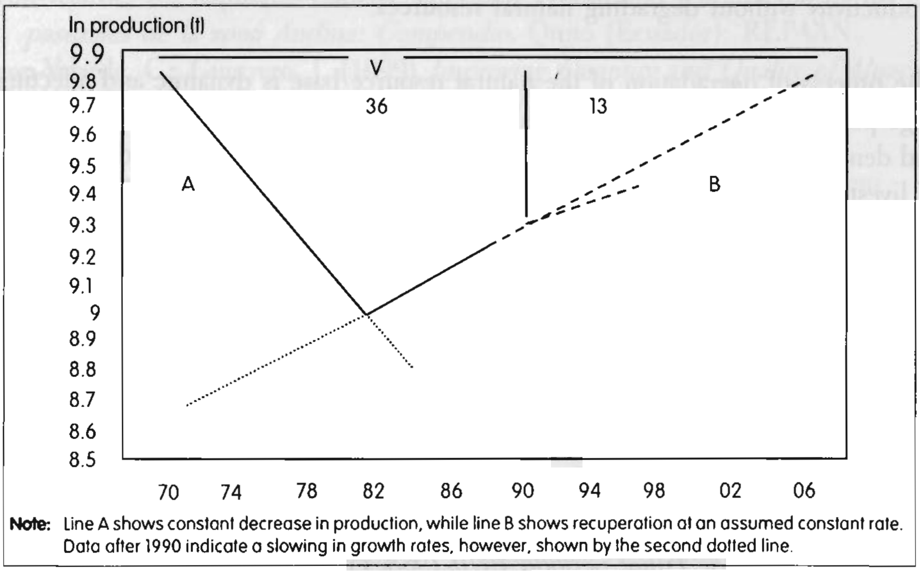

Figure 14.5: **Graphical representation of the influence of exogenous decisions on milk production in the Altiplano of Peru**

it started to fall. This is an example of an impact produced by policies that are not well defined. It is extremely important to note, however, that during the 36 years the natural resource base was eroded while the human population increased. Further, it is necessary to incorporate market opportunities based on demand and, as well as a mechanism of agricultural credit related to operational size, technical assistance, and land tenure. Similar patterns are evident in other countries of the Andean region.

The production and productivity of the main animal species in the four countries of the Andean region is shown in Table 14.6. Some indicators are positive, but the growth rate is low and not sufficient for future demands to be met. The population growth rate is high, and people are demanding more food at lower prices. For example, it is estimated that the demand for meat in Lima (Peru) in 2005 will be 74,840 tonnes. At current rates, only 15,350 tonnes will be available, a deficit of 59,490 tonnes. Other animal products show a similar trend. Thus it seems likely that any increase in production of animal products can be absorbed by the regional market, indicating good opportunities for crop-livestock systems in the region.

Conclusions

It is difficult to offer clear solutions to the issues raised in this document because the biophysical and socioeconomic conditions are changing rapidly. However, technical intervention and accumulated knowledge about crop-livestock systems can be used at specific sites. A wide range of appropriate methods and procedures will need to be used as tools to support decision-making in order to improve production and productivity without degrading natural resources.

The process of degradation of the natural resource base is dynamic and affecting a large part of the Andean region. The population in large urban cities is increasing and demanding more services and food. Although both the number and productivity of livestock are growing, the actual rates are not enough to cover the additional demand for meat and milk. Thus it seems likely that more products will have be imported, unless the necessary adjustments are made in land tenure, size of operational holdings, use of appropriate technology, and other factors. Partial or complete processing in situ of products with a clear market demand is highly recommended. Research will play an essential role in all these processes.

References

Ccama, F. (1990) *La estructura y evolucion de la produccion agropecuaria en el departamento de Puno: periodo 1970-1988.* Puno (Peru): Proyecto de Investigacion de Sistemas Agropecuarios Andinos (PISA) de Morales, C.B. (1995) *Bolivia; medio ambiente y ecología aplicada.* La Paz (Bolivia): Universidad Mayor de San Andrés, Instituto Ecología (GTZ)

FAO (1994) *La política agrícola en el nuevo estilo de desarrollo Latinoamericano.* Santiago (Chile): FAO, Oficina Regional de la FAO para America Latina y el Caribe

FAO (1996) *Food Balance Sheets,* p. 497. Rome: FAO

Gastó, J. (1993) 'Aproximación agroecosistémica'. In *El Agroecosistema Andino: Problemas, Limitaciones, Perspectivas, Anales del taller internacional sobre el agroecosistema Andino,* pp 31-49. Lima (Peru): CIP

Harrington, L.W. (1992) 'Measuring Sustainability: Issues and Alternatives'. In *Journal for Farming Systems Research-Extension,* 3(1) 1-20

IFPRI (1990) *Agricultural Sustainability, Growth, and Poverty Alleviation: Issues and Policies.* Washington: IFPRI

IICA (1994) *Los Andes en Cifras,* Serie y Documentos Economía. Quito (Ecuador): Instituto Interamericano de Cooperación Agrícola (IICA)

Janssen, W. (1991) 'Economic Trends in Latin America and the Caribbean: Implications for Agriculture and the Generation of Agricultural Technology'. In *CIAT in the 1990s and Beyond: A Strategic Plan,* Supplement, pp. 1-13. Cali (Colombia): CIAT

Jodha, N.S. (1990) *Some Conceptual Issues of Livestock Farming in the Mountains,* MFS Discussion Paper Series No. 4. Kathmandu: ICIMOD

León-Velarde, C.; Quiroz, R. (1994) *Análisis de sistemas agropecuarios: Uso de métodos bio-matemáticos.* La Paz (Bolivia): CIRNMA (EFI-GRAF)

León-Velarde, C.; Izquierdo-Cadena, F. (1993) *Producción y utilización de los pastizales de la zona Andina: Compendio.* Quito (Ecuador): REPAAN

Leon-Velarde, C.; Guerrero, J. (1999) *Improving Quantity and Quality of Alpaca Fiber Using a Simulation Model for Breeding Strategies.* Lima: CIP, SAAD-III

León-Velarde, C.U.; Quiroz, R. (1999) 'Selecting Optimum Ranges of Technological Alternatives by Using Response Surface Designs in System Analysis'. In *CIP Program Report 1997-98,* pp 387-393. Lima (Peru): CIP

Li Pun H.; Sere C. (1993) 'Animal Production Systems Research in Developing Countries: Overview and Perspectives'. In *Proceedings of the 7th World Conference on Animal Production,* pp 329-348. Edmonton (Canada): University of Alberta

Li Pun, H.H.; Paladines O. (1993) 'El Rol de las Pasturas y la Ganaderia en la Sostenibilidad de los Sistemas de Produccion Andina'. En *El Agroecosistema Andino: problemas, limitaciones, perspectivas.* Lima (Peru): CIP

McCalla, A.F. (1994) *Agriculture and Food Needs to 2025: Why We Should Be Concerned,* Consultative Group on International Agricultural Research, International Centers Week. Washington DC: CGIAR

Paladines, O. (1995) *Red de Pastizales Andinos (REPAAN) Annual Report 1995.* Quito: FUNDAGRO, Proyecto REPAAN

PISA (1993) *Proyecto de Investigacion de Sistemas Agropecuarios Andinos (PISA) Informe Final.* Puno (Peru): Instituto Nacional de Investigaciones Agropecuarias (INIA)

PRODASA (1993) *Proyecto de Desarrollo Agropecuario Sostenido en el Altiplano (PRODASA) Informe Annual 1993.* Annual Report submitted to CIP-INIA/CONDESAN, Puno, Peru

PRODASA/CIP (1996) *Proyecto de Desarrollo Agropecuario Sostenido en el Altiplano (PRODASA) Informe Final 1993-1995.* Project final report submitted to CIP-INIA/CONDESAN, Puno, Peru

Quiroz, R.A.; Pezo, D.A.; Rearte, D.H.; San Martin, F. (1997) 'Dynamics of Feed Resources in Mixed Farming Systems of Latin America'. In Renard, C. (ed) *Crop residues in Sustainable Mixed Crop-livestock Farming Systems.* London: CAB International

Quiroz, R.; Mamani, G.; Revilla, R.; Guerra, C.; Sánchez, J.; Gonzalez, M.; Pari, G. (1991) 'Perspectivas de investigación pecuaria para el desarrollo de las comunidades de Puno.' In Arguelles, L. and Estrada, R.D. (eds) *Perspectivas de la investigación agropecuaria para el Altiplano*, pp 357-406. Lima (Perú): CIID – PISA

Quiroz, R.; Estrada, R.D.; Leon-Velarde, C.U.; Zandstra, H.G. (1995) 'Facing the Challenge of the Andean Zone: the Role of Modeling in Developing Sustainable Management of Natural Resources'. In Bouma J.; Kuyvenhoven A.; Bouman B.A.M.; Luyten, J.C.; Zandstra, H.G. (eds) *Ecoregional Approaches for Sustainable Land Use and Food Production,* Proceedings of a Symposium on Eco-regional Approaches in Agricultural Research, 12-16 December 1994, pp 13-31. The Hague: ISNAR

San Martin, F.; Bryant, F.C. (1987) *Nutrición de los Camélidos Sudamericanos: Estado de nuestro conocimiento,* Technical Report T-9-505. Lubbock (USA): Texas Technical University (TTU), College of Agricultural Sciences

Tapia, M.E. (1996) *Ecodesarrollo en los Andes altos.* Lima: Fundación Friedrich Ebert

Winograd, M. (1995) *Indicadores ambientales para Latinoamerica y el Caribe: hacia la sustentabilidad en el uso de tierras,* en colaboracion con Proyecto IICA/GTZ, Organizacion de los Estados Americanos, Instituto de Recursos Mundiales. San Jose (Costa Rica): IICA