Small Ruminant Production Techniques

ILRI Training Manual 3

International Livestock Research Institute

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Foreword

The International Livestock Research Institute (ILRI) trains research scientists from national research systems (NARS) in sub-Saharan Africa. As part of this training, ILRI has conducted several training courses on small ruminant production techniques. The knowledge and skills learned in the courses enabled the participants to conduct research using an integrated approach to resolving constraints to increasing small ruminant productivity in smallholder farming systems.

This manual has been developed from the training courses and is intended for research scientists who are actively involved in research on small ruminants, or soon will be. The manual is designed for multiple users, including participants in courses on small ruminants or individuals who desire to learn on their own.

Many individuals have contributed to the preparation of this manual. As a training materials specialist, Dr H. Ibrahim wrote the first draft of the modules from the latest course materials as well as material available with ILRI's Information Services. The modules were then reviewed by ILRI scientists involved in teaching the course. A sample of former ILRI trainees were surveyed to obtain feedback. The manual was internally reviewed by Dr S. Lebbie, Co-ordinator of the Small Ruminant Network associated with ILRI, and externally by Dr L. Reynolds, Animal Scientist, Consultant, UK.

This manual emphasises an integrated approach to research on small ruminants. The manual starts with describing small ruminants in various agro-ecological zones in sub-Saharan Africa with emphasis on the prevailing production systems. The user is then introduced to the concepts and methodologies of farming systems research to better understand the needs of the smallholder farmer. The core of the manual presents knowledge and skills in the disciplines of reproduction, diseases, genetics, biometry, economics and communication. The manual ends by stressing the importance of transferring research results to farmers and the role of researchers in this vital process.

Even though this manual was written to stand on its own, it is part of ILRI's series of training material on small ruminants. This material includes audio-tutorial modules, slide series and posters. We view them as complementary to each other.

ILRI is grateful to the European Union for funding the production of this manual through its financial support to the Small Ruminant Network (SRNET).

Dr M.E. Smalley

Director, Strengthening Partnerships with National Agricultural Research Systems

ILRI

About the Manual

This manual is part of ILRI's effort to provide training materials for use in courses or self-teaching. The manual aims at providing an overview of small ruminant research knowledge and methods to help young scientists in Africa improve the situation in this vital area. Eleven modules cover the topics in an integrated approach to improving small ruminant productivity in sub-Saharan Africa.

The first module gives an overview of the role of small ruminants in production systems in relation to agro-ecological zones in sub-Saharan Africa. This is followed by the description of farming systems approaches. The core of the manual covers reproduction, diseases, breeding and genetics, nutrition, economics, biometry and communication. The reader is then exposed to approaches for writing protocols for funding research. The last module covers the role of researchers in transferring research results to the farmers. Relevant reading materials support each module.

Each module is designed such that the performance objectives are placed at the beginning to facilitate learning. The body of the module includes text, illustrations, reference and reading materials. Exercises are placed at the end of each module to stimulate the user for further learning. Topics that further illustrate the main concepts in the body of the module are placed in boxes.

Many individuals have contributed to the preparation of this manual. Dr H. Ibrahim prepared the modules and the following ILRI staff contributed to them:

- Dr S. Lebbie reviewed modules 1, 2 and 9
- Dr E. Mukasa-Mugerwa wrote and reviewed module 3
- Dr S. Tembely wrote and reviewed module 4
- Dr C. Valentine Yapi wrote and reviewed module 5
- Dr N. Ummuna reviewed module 6
- Dr B. Shapiro reviewed module 7
- Dr J. Rowlands wrote and reviewed module 8
- Mr P. Neate and Ms A. Nyamu reviewed module 10
- Drs M. Mohamed-Saleem and M. Jabbar reviewed module 11

Scientists in NARS are encouraged to use the manual in their training courses. It is hoped that users find the manual useful.

Habib Ibrahim

Training Materials Specialist

ILRI

Module 1: An overview of small ruminant production in Africa

1.1 Performance objectives

Module 1 is intended to enable you to:

1. Describe the effect of agro-ecological zones in sub-Saharan Africa on small ruminant production.
2. Describe the major small ruminant production systems in sub-Saharan Africa.
3. Describe the distribution of small ruminants in sub-Saharan Africa by zone and region.
4. List the special attributes of small ruminants.
5. List constraints to productivity of small ruminants in sub-Saharan Africa.
6. List the opportunities for improving small ruminant productivity.

1.2 Agro-ecological zones in sub-Saharan Africa

1.2.1 Agro-ecological zones

Sub-Saharan Africa can be divided into five agro-ecological zones: desert, arid, semi-arid, subhumid, humid and the cool highlands (Figure 1). These zones vary in climate, natural resources and human population density. This classification is based on amount and distribution of rainfall, effect of altitude on temperature and length of annual plant growing period. The parameters defining the zones (rainfall and plant growth days) and percentage area across the different regions of sub-Saharan Africa are shown in Table 1.1. In this module we will focus on small ruminant production in the arid, semi-arid, subhumid and humid zones where most of these animals are raised. However, since natural resources and human and livestock populations vary from one zone to another, special sections will be devoted to the effect of population pressure on crop–livestock integration.

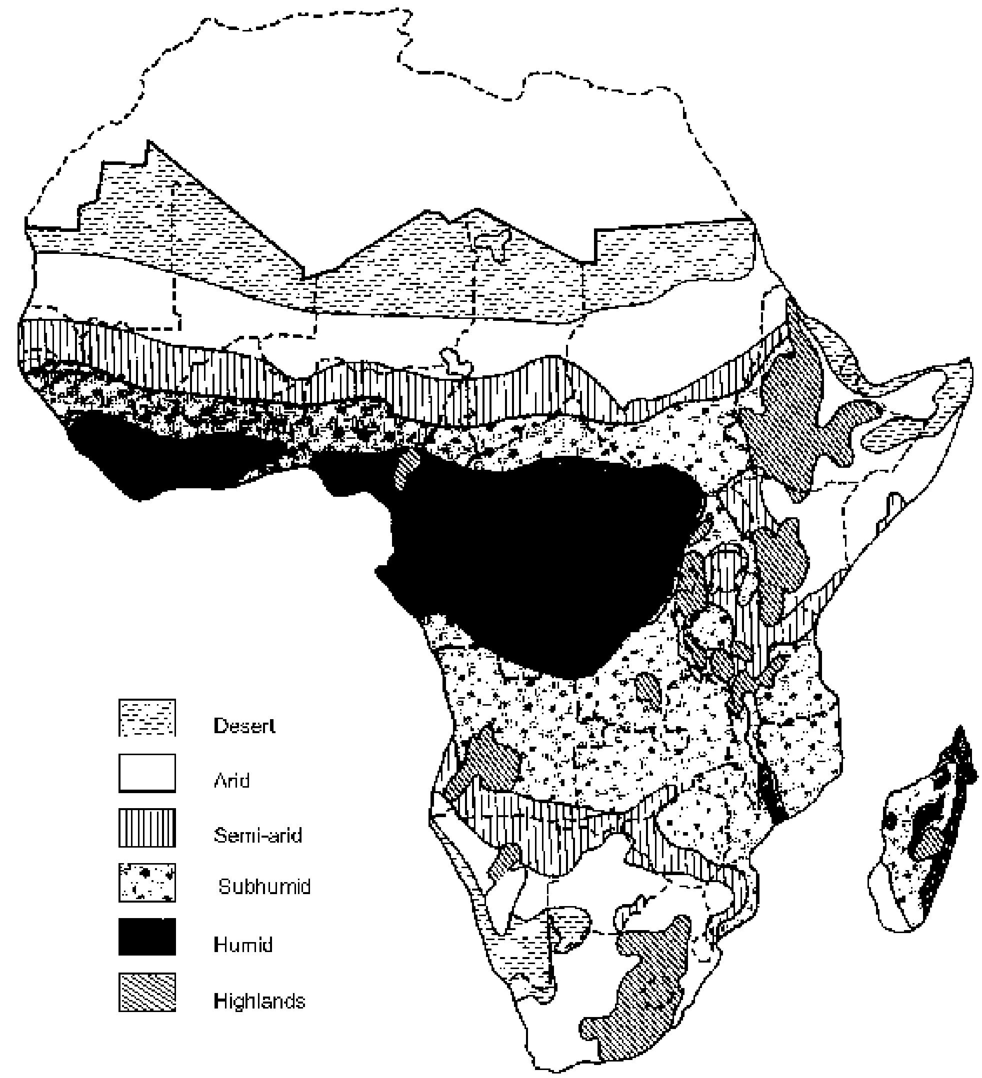

Figure 1.1. *Sub-Saharan Africa: Main agro-ecological zones.*

Arid zone

The arid zone receives 0 to 500 mm of rainfall annually which sustains plant life for less than 90 plant growth days (Table 1.1). The small amount of rainfall and its erratic distribution prevent cropping in most years; some cropping takes place in oases or irrigated areas. Plant cover consists of short annual grasses, legumes, scattered shrubs and trees. Farmers use most of the trees and shrubs for fuel. The arid zone occupies 36% of the area of sub-Saharan Africa, most of which is in West and East Africa. Opportunities for livestock development are limited but existing techniques could be improved upon if not to increase productivity, to at least sustain it.

Table 1.1. *Agro-ecological zones of sub-Saharan Africa.*

			Area (%)					
Zone	Definition	Rainfall range (mm)	West Africa	Central Africa	Eastern Africa	Southern Africa	Area of zone (%)	Total area ($\times 10^6$ km^2)
Arid	<90 pgd	0–500	54	1	52	20	36	7.7
Semi-arid	90–180 pgd	500–1000	20	7	18	34	18	4.0
Subhumid	180–270 pgd	1000–1500	16	29	16	38	22	4.8
Humid	>270 pgd	1500+	10	59	2	7	19	4.1
Highlands[a]	20°C	n.a.	0	4	12	1	5	1.0
Total			100	100	100	100	100	
Total area ($\times 10^6$ km^2			7.3	5.3	5.8	3.2		21.6

n.a. = data not available; pgd = plant growth days.

a. Defined as areas at 1500 m altitude within the semi-arid, subhumid, and humid zones where the mean daily temperature during the growing period is less than 20°C.

Source: ILCA (1987) after Jahnke (1982).

Semi-arid zone

The semi-arid zone receives 500 to 1000 mm of rainfall annually which sustains 90 to 180 plant growing days. The lower rainfall areas of this zone are used for grazing. Cropping and crop–livestock systems dominate the areas with higher rainfall. Farmers grow millet, sorghum, groundnut, maize and cowpeas. This zone occupies 18% of the area of sub-Saharan Africa and is found in all regions except central Africa.

Subhumid zone

The subhumid zone receives 1000 to 1500 mm of rain annually which sustains plants for 180 to 270 plant growing days. Food and cash crops are grown, including cassava, yams, maize, fruits, vegetables, rice, millet, groundnut, cowpeas and cotton. Some of these crops are used to make feeds such as cotton seed cakes and the residues of other crops are available for livestock feeding. In some areas of this zone farmers grow soyabean and leguminous forage crops. This zone occupies 22% of sub-Saharan Africa, mainly in southern and central Africa.

Humid zone

The humid zone receives more than 1500 mm of rainfall annually which sustains plants for 270 to 365 plant growing days. This zone consists of rain forest and derived savannahs. The soils have high levels of iron and aluminium and low levels of phosphorus. Therefore the organic matter content is low, and the soils are fragile and easily degraded when the vegetative cover is lost. The zone occupies 19% of sub-Saharan Africa, mostly in central and West Africa. This zone contains relatively few livestock and has limited potential for livestock development, particularly because of the threat of the trypanosomosis-transmitting tsetse fly.

Highlands zone

The cool highlands zone includes areas above 1500 m altitude that have a mean daily temperature of less than 20°C. This zone represents 5% of the total area of sub-Saharan Africa, most of which lies in eastern Africa; half of this zone is in Ethiopia. The soils are deep fertile Vertisols and Nitosols.The zone receives bimodal rainfall (1000 mm annually) and there are two growing seasons. Farmers grow forages and animal traction assumes more importance as the population pressure encourages crop–livestock integration. The cool highlands are a high potential area for crop–livestock integration.

1.2.2 Population pressure and natural resources

The human population in sub-Saharan Africa currently is increasing by 3.1% a year (Table 1.2). The projections (Table 1.2) indicate a decrease in growth rate after the year 2010 but it will still be relatively high by the year 2025. Based on projections of population increases and limited land availability, McIntire et al (1992) hypothesised that population pressures on agricultural land in sub-Saharan Africa will drive agriculture toward intensification.

One form of intensification due to population pressure is the evolution of crop–livestock systems.

Table 1.2. *Human population projections for sub-Saharan Africa, 1990–2025.*

Year	Human population (millions)	Annual growth rate (% 5-year period)
1990	498	–
1995	580	3.1
2000	676	3.1
2005	784	3.0
2010	902	2.8
2015	1,028	2.6
2020	1,159	2.4
2025	1,294	2.2

This system will be more economically efficient and sustainable than other systems when the following conditions prevail:

- traditional production methods, with low input technology, are used
- inputs are scarce
- markets are poorly developed.

The following scenarios may develop under different population pressures and land resources:

Scenario 1. Low population pressure + low animal disease stress symbol → Herding

Scenario 2. High population pressure → Crop–livestock systems

Scenario 3. Very high population pressure + urbanisation → Specialised systems

The first scenario results from using fallow periods rather than manure to restore the fertility of the cropping land. Labour requirements for the fallow system are low. The second scenario develops as population pressure makes increased food availability essential and therefore cropping is intensified. Continuous cropping leads to a decline in fertility and hence the need to introduce animals into the system to provide manure. Since pasture and fallow are no longer options for feeding livestock, crop residues start to play a more important role. The third scenario evolves when urban centres become the high population centres and markets and technologies are developed (fertilisers replacing manure, tractors replacing animal traction, concentrates replacing crop residues). As the population continues to increase, the efficiency of crop–livestock systems plateaus and attaining a higher level of productivity requires the use of higher input technologies. The demand for animal products becomes higher as the incomes of city dwellers increase. This leads to specialisation such as market-oriented peri-urban dairy production and livestock fattening, especially of ruminants. The demands of urban dwellers may also lead to specialised cropping such as vegetables, forages and cash crops. The evolution of crop–livestock integration is more complex than presented here. Each of the above scenarios can be further elaborated once you impose agro-ecological zones as factors.

1.3 Major production systems in sub-Saharan Africa

Livestock production systems in sub-Saharan Africa can be divided into two major types, namely traditional and modern (Table 1.3). They can be distinguished mainly through the three production factors, land, labour and capital.

Table 1.3. *A classification of small ruminant production types and systems in sub-Saharan Africa.*

Type	System	Management	Main production factors	Nutrient source
Traditional	Pastoral	Nomadic/ semi-sedentary	Land	Range
	Agropastoral	Transhumant/ sedentary	Land/labour	Range/crop by-products
	Agricultural	Sedentary	Land/labour	Crop by-products/ household waste/ forage
	Urban/peri-urban	Sedentary	Labour	Household waste/ feed
Modern	Ranching	Sedentary	Land/capital	Range/forage
	Feedlot	Sedentary	Capital/labour	Feed/storage
	Station	Sedentary	Land/labour/ capital	Range/forage/feed

1.3.1 Traditional types of livestock production systems

The traditional livestock production systems can be sub-divided into four: pastoral, agropastoral, agricultural and urban/peri-urban (Table 1.3). The production systems are segregated according to the following factors:

- degree of dependence on livestock products (of household or production unit) for income or food
- type of agriculture practised in association with livestock
- mobility and duration of movement.

Based on the above criteria, the characteristics of these production systems are discussed below.

Pastoral system

- More than 50% of household income (production unit) comes from livestock/livestock products.
- In pure arid areas there is little or no cropping activity; further south of the Sahara rainfed agriculture is practised.
- Livestock owners/helpers travel long distances year-round looking for forage and water along specific orbits (in oases frequency of movement is reduced and a little agriculture is practised, i.e. semi-sedentary).

Agropastoral system

- Between 10 and 50% of household income comes from livestock/livestock products.
- In semi-arid regions agriculture is practised together with management of livestock.
- The system is either transhumant or sedentary (limited movement). Transhumance refers to the whole system moving periodically, e.g. migration to the wetter fringes of the arid and semi-arid zones in the south during the dry season and returning in the wet season.

Agricultural systems

- Less than 10% of household income is derived from livestock/livestock products.
- Livestock production is secondary to crop production.
- The system is sedentary.

Urban/peri-urban

- Involves fattening of small ruminants to sell during festivities or to city dwellers.
- The operators are usually wage earners in the city who invest cash in sheep and goats for short-term profit.

The system is sedentary with cut-and-carry feeding for fattening (it can be natural grass cut and sold to urban dwellers or specialisation in forage marketing may emerge).

Land assumes more importance in the pastoral system whereas labour is more important in agropastoral, agricultural and urban systems. Depending on the extent of cropping, hired labour is needed to supplement family labour. As intensification increases, labour becomes more important than land. The urban system is capital intensive since farmers invest cash to buy sheep and goats to fatten for sale during peak demand. In this system, the high wages for labour are the main constraint to cutting and carrying forage to zero grazing livestock. In the pastoral system the small ruminants obtain their feed from rangeland. In agropastoral systems rangeland is used but crop residues assume importance. Crop residues, household waste and forages are used for feeding small ruminants in the agricultural systems. Urban systems provide sheep and goats with household waste, grain and protein concentrates if the number of animals is large or use a lot of labour to cut and carry grass to the animals.

1.3.2 Modern types of livestock production systems

The modern livestock production systems can be divided into the ranching, feedlot and station systems (Table 1.3). These production systems are characterised by high inputs and are all sedentary. Land is important and expensive in the ranching system while the feedlot system is capital intensive and is characterised by the use of large amounts of feed. Sometimes in the feedlot system, cut-and-carry forages are used to provide feed and this activity requires labour.

1.3.3 Management within livestock production systems

Management within livestock production systems is governed by the various objectives and strategies of the farmers. Table 1.4 shows details of ownership pattern for a few ethnic groups in Kenya and Chad. The objectives of the use of goats and sheep within ethnic groups in a few countries in sub-Saharan Africa are shown in Table 1.5. It is clear that farmers favour multiple uses of small ruminants over a single use, especially for goats.

Table 1.4. *Livestock owning in agropastoral and pastoral societies in Kenya and Chad.*

Country	Kenya		Chad		
Tribe	Maasai	Karapokot	Zioud	Salamat	Gondeye-Tchein
Production system	Pastoral	Agropastoral	Pastoral	Agropastoral	Agropastoral
Average holdings (head/household)					
Cattle	157.3	11.8	36.4	133.3	2.1
Sheep	44.0	5.4	43.5	2.0	1.3
Goats	83.1	13.6	45.0	46.3	4.7

Management is affected by the amount of rainfall (Table 1.6). The common features for the arid, semi-arid and highland areas are:

- as moisture increases, there is movement from nomadism to fattening strategies
- as we move from dry to wet zones, we move from free grazing to more confinement of animals
- the flock sizes decrease as we move to less harsh environments
- sheep are more predominant in the arid zone whereas goats and sheep predominate in the semi-arid zone; sheep ranching is predominant in the Kenya highlands and is highly commercial.

Farmers follow a range of strategies to ensure the best use of existing resources within an ecological zone (Table 1.6). The farmers in the pastoral system exercise some control over breeding by keeping their better stock for this purpose. In rare cases good genes are taken out of the stock when farmers sell their best animals.

1.3.4 Distribution of small ruminants in sub-Saharan Africa

Livestock populations vary across the agro-ecological zones of sub-Saharan Africa (Table 1.7). According to FAO (1989) statistics sub-Saharan Africa has 162 million cattle, 127 million sheep, 147 million goats, 13 million camels, 11 million pigs, 8 million donkeys, 3 million horses, 1.5 million mules and 631 million chickens.

Table 1.5. *Some examples of management objectives related to flock structures.*

Country/ethnic group	Sheep[1]						Goats[2]			
	Males			Females			Males		Females	
	Use	Total	Castrates	Total	Breeding	Use	Total	Castrates	Total	Breeding
Mauritania/Moor	Meat/hair	22.9	6.2	78.1	58.6	Milk/meat	20.2	1.2	79.8	55.1
Mali/Fulani	Meat/wool	25.5	11.3	74.5	55.9	*	*	*	*	*
Chad/Arab	Meat/milk	26.5	Few	73.3	53.7	Milk/meat	28.3	Few	71.1	48.1
Sudan/Baqqara	Meat	22.2	0.0	77.8	57.7	Milk/meat	23.6	0.0	76.4	51.2
Kenya/Maasai	Meat (fat)	31.4	15.4	68.6	54.2	Meat (fat)/ milk	33.8	10.3	66.2	48.3

1. Percentages of total number of sheep.
2. Percentages of total number of goats.

* = data not available.

Table 1.6. *Management of goats and sheep in the arid, semi-arid and highland zones of sub-Saharan Africa.*

			Micro-management					
			Sheep		Goats		Size of flock/ herding group	
Climatic regime (rainfall, mm)	Macro-management	Examples	Day	Night	Day	Night	Sheep	Goats
Arid (200)	Nomadic	Mauritania/Moor	↑ ↑	Open camp	↑ ↑	Open camp	100–500	30–80
		Ethiopia/Afar		Penned		Penned		
		Sudan/Kababish		Penned		↑ ↑		
		Mali/Twareg	Loose flock	↑ ↑				
(300)	Transhumant	Niger/Twareg		Open camp	Loose flock	Open camp		
		Chad/Zhagawa						
		Kenya/Turkana	↑ ↑	Penned		↑ ↑		
Semi-arid (400)		Ethiopia/Afar			↑ ↑	Penned	200–250	40
		Sudan/Baqqara	Tight flock	Penned				
(500)	Semi-sedentary	Mali/Fulani	Loose flock	Penned	Loose flock	Penned	50–150	30–100
		Kenya/Maasai	Tight flock	Open camp	Tight flock	Penned/tied	20–60	20–80
(600)		Sudan/Daju	Tight flock	Penned			200–500	
	Sedentary	etc.		Penned	[Dry season not herded, Crop season tight flock]		20–80	40–120
						Penned	5–10	5–40
						Tied		
		Mali/Bambara	Tight flock Tied	Penned/tied	Tied	Tied	0–10	2–20
	Stall feeding	West Africa/ Mouton de case Kenya/Thenges		Tied		Tied	1–5	1–5
Highlands (>1000)	Extensive paddocks	Kenya/large ranches	Paddocks				500–1000	

Table 1.7. *Distribution (%) of domestic ruminant livestock by agro-ecological zone and geographic region, sub-Saharan Africa.*

Agro-ecological zone/ geographical regions	Cattle	Sheep	Goats	Camels	All domestic ruminants[1]
Arid	20.7	33.7	38.2	100.0	29.8
Semi-arid	30.6	22.9	26.3	0.0	27.1
Subhumid	22.7	14.4	16.5	0.0	19.6
Humid	6.1	8.3	9.4	0.0	6.1
Highland	19.9	20.8	9.6	0.0	17.4
Total	100.0	100.0	100.0	100.0	100.0
West	24.8	34.2	42.3	15.2	26.3
Central	6.6	4.1	6.4	0.0	5.8
Eastern	54.1	59.5	46.2	84.8	56.3
Southern	14.5	7.2	5.2	0.0	11.6
Total	100.0	100.0	100.0	100.0	100.0

1. Calculated from TLU.

Source: ILCA (1987), after Jahnke (1982).

In the drier areas, which are not suited for crop production, rangeland is used for livestock. Livestock populations are therefore higher in the arid and semi-arid zones than in other areas (Table 1.8). The humid zone and the wetter parts of the subhumid zone do not sustain large populations of livestock due to the presence of the tsetse fly, which transmits the disease trypanosomosis. The cool highlands are less threatened by diseases and thus the zone has a high potential for livestock production. In this zone and in the marginal area between the wet and dry zones mixed crop–livestock systems have evolved in response to high population pressure.

Table 1.8. *Ruminant density and carrying capacity in agro-ecological zones in sub-Saharan Africa.*

Agro-ecological zone	Ruminant density (TLU/person)	Carrying capacity (ha/TLU)
Arid	1.00	10–30*
Semi-arid	0.35	4–8
Subhumid	0.25	3–6
Humid	0.10	–
Highlands	0.40	2.5–3.5

*Carrying capacity is 30 for areas with <250 mm annual rainfall.

The western and eastern parts of sub-Saharan Africa have the largest population of ruminant livestock in the region (Table 1.8). Livestock species differ in their biomass and in order to express livestock numbers in terms that reflect the large differences in body size of the species, livestock biomass is aggregated into tropical livestock units (TLU). A TLU is the equivalent of an animal of 250 kg live weight. The values for ruminant density and carrying capacity are shown in Table 1.8. Carrying capacity is high in the arid zone while the humid zone has the lowest figures because of the diseases afflicting ruminant animals. Ruminant density in sub-Saharan Africa is 0.37 TLU/person, it is 0.20 TLU/person in Asia, 0.33 TLU/person in West Asia and North Africa and 0.67 TLU/person in Latin America. The value for the world is 0.30 TLU/person.

1.4 Function, role and productivity of small ruminants

Livestock play an important role in the lives of people in Africa. Animals provide income and serve as protection against drought years.

1.4.1 Special features of small ruminants

Small ruminants in Africa represent 21% of the world's small ruminant population. The population of sheep in Africa represents 17% of the total world population while goats represent 30%.

Farmers keep small ruminants for many reasons, the major ones being that they are a source of food (milk and meat), fibre (wool and skins), cash and a form of savings.

Other special attributes include:

- sheep and goats are highly adaptable to a broad range of environments
- goats are more effective at grazing selectively
- small ruminants have short generation cycles and high reproductive rates which lead to high production efficiency
- the efficiency of converting feed into milk is higher in goats than in other dairy animals
- certain breeds of sheep and goats (e.g. Red Maasai sheep and West African Dwarf goats) are tolerant of diseases such as helminthosis
- small ruminants are small enough to be consumed by an average rural family in a day or two hence no refrigeration facilities are needed.

1.4.2 Small ruminants as sources of meat and milk

Animal products are of great importance to the diets of pastoral people. Small amounts of animal protein correct amino acid deficiency in diets, particularly of small children, in sub-Saharan Africa.

Meat from small ruminants represent 18% of the total meat eaten by people in sub-Saharan Africa.

Small ruminant meat consumption is 2.1 kg/year per person (11.7 kg/year for all meat). Across the regions in sub-Saharan Africa small ruminant meat production is distributed as shown in Table 1.9.

Table 1.9. *Small ruminant meat and milk production by region in sub-Saharan Africa.*

	Production		
Region	Goat	Sheep (mutton)	% of SSA total
Meat output ('000 t)			
West Africa	240	135	20.0
East Africa	199	265	25.3
Southern Africa*	26	10	5.5
Central Africa	30	17	8.5
Milk volume ('000 t)			
East Africa	1414	1052	84.2
West Africa	288	139	14.6
Southern Africa*	12	–	0.8
Central Africa	21	3	0.4

*Data from the Republic of South Africa are not included.

Negligible quantities of small ruminant meat from sub-Saharan Africa are exported, but no accurate statistics are available. South Africa exports large quantities of meat and with the sanctions against the country lifted, the statistics for exports of meat from sub-Saharan Africa will change. Special markets for small ruminants are expanding, e.g. goats exported from Uganda and Somalia to the Middle East.

Milk from small ruminants is an important source of nutrition for the population in East Africa. This is not the case in southern and western Africa. The contribution of milk from small ruminants across the regions is shown in Table 1.9.

1.4.3 Other contributions of small ruminants in sub-Saharan Africa

Employment and income

Farmers use small ruminants as savings that generate cash when the environment is harsh, e.g. during drought years. Small ruminants are sold to raise money to replace large ruminants lost during droughts. Small cottage industries based on small ruminant products have started to flourish in African cities, e.g. coarse wool for carpets, hides/skin products.

Sustainability of agriculture

Small ruminants are integrated in most production systems and this enhances the sustainability of the system:

- the animals produce manure which is returned to the system (nutrient cycling) to benefit vegetable gardens, food crops and cash crops
- sheep eat weeds reducing weed control costs, e.g. in coffee and coconut plantations
- crop residues are utilised by small ruminants, e.g. straw from rice and wheat and maize stovers are converted into animal products
- small ruminants make use of plants in marginal lands and convert them into animal products
- small ruminants meet social and cultural needs, e.g. payment of dowry, celebrations, gifts to family members
- the animals are a source of savings to be sold when funds are needed (spreading risk).

1.5 Constraints to and opportunities for increased productivity

The human population in sub-Saharan Africa will more than double by the year 2025 (Table 1.2). Increase in population, coupled with urbanisation, will result in higher demand for meat per capita. The resources will be overutilised and more land will be needed to produce food crops. Competition for land between livestock and crops will therefore be more acute. If we continue to produce livestock and their products at the current rates, the increase in livestock production will lag behind human population increases. The potential of small ruminants is not yet fully tapped. FAO (1989) estimated that animal production should be increased by 4% annually to meet the demand of the human population by the year 2010. The factors that affect the productivity of the small ruminants in sub-Saharan Africa are:

- natural resources
- feed supply
- health
- genotype
- farming systems and animal management
- land resources
- policy constraints
- institutional constraints.

Table 1.10 lists these factors against the constraints that limit the productivity of small ruminants, reducing their potential output, and the opportunities that can be tapped to achieve the potential.

Table 1.10. *Major constraints and opportunities affecting the potential of small ruminant production in sub-Saharan Africa.*

Constraints	Opportunities
Natural resource management	
Fragile ecosystem Soil infertility Water scarcity	Sustainable crop–livestock system Sustainable pastoral system Application of fertilisers Recycling of nutrients with manure Mixed crop–livestock systems under trees
Feed and feeding	
Quality and quantity of pastures, forages and crop residues	Crop residue utilisation Fodder banks Stall feeding Cultivated forages Leguminous trees and alley cropping Improved pastures Mineral and protein supplementation
Animal health	
Peste des petits ruminants Contagious caprine pleuropneumonia Helminthosis Trypanosomosis Tick-borne diseases Sheep pox	Vaccines against diseases Health management services
Genotype	
Low productivity African genotypes poorly characterised	Adaptive, reproductive traits Breeding for disease resistance
Socio-economic factors	
Poor extension services Poor infrastructure Deficient inputs Price policies and marketing restrictions Weak public institutions Inefficiency in drug distribution	Strong market potential Flexible livestock resource Low fixed production costs for milk and meat

1.6 Exercises

1. Between 1990 and 2025 there will be enormous demographic and social changes such as population increase, urbanisation and income change across sub-Saharan Africa. Describe the effect these changes will have on small ruminant production using examples from your region or country.

2. Small ruminant production is strongly influenced by agro-ecological zones in sub-Saharan Africa. Elaborate on this statement.
3. There are several factors which impose constraints on small ruminant production. Indicate the significance of these factors by agro-ecological zone by completing the table using the following scale:

xxx = very important; xx = moderately important; x = some importance; blank = no importance.

	Agro-ecological zone				
Factors	Arid	Semi-arid	Subhumid	Humid	Highlands
Crop residue					
Helminthosis					
Trypanosomosis					
Low productivity					

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Module 2: Livestock farming systems research

2.1 Performance objectives

Module 2 is intended to enable you to:

1. List the key concepts of livestock farming systems research.
2. List the steps in the farming systems research process.
3. Describe the components of the livestock systems research process.
4. Describe the four main categories of livestock farming systems.

2.2 Introduction

The farm is a complex system. Often, researchers design experiments without considering the complexity of the system. This chapter is designed to give you an overview of this complex system and ways to approach your research with the needs and goals of resource-poor farmers in mind.

Livestock research in sub-Saharan Africa needs to address the factors that have led to the poor performance of the subsector during the last two decades: inappropriate policies, institutional deficiencies, resource constraints and a failure to design experiments and technologies applicable to the farmer's situation; we will address the last factor in this chapter. The systems approach to research is recognised as the most appropriate means of gaining knowledge of the factors which influence production decisions at the farm level.

This chapter will not cover methods of data collection. Such information is available in two working papers published by ILCA during 1990 (see Box 2.1). This chapter will provide you with a basic understanding of the farming systems research approach and a few references to guide you if you wish to go into more detail.

Box 2.1: Livestock farming systems research: Methods and type of data to be collected for various themes

To conduct research on livestock systems, you need to acquire knowledge and skills. A holistic approach is taken, that requires an understanding of the relationship between the livestock subsystem and the rest of the farming system. Hence, a study of the livestock subsystem cannot be undertaken in isolation, and the researcher must also investigate the relevant parts of the cropping system.*

A. Methods

- Informal surveys
- Developing hypotheses about systems relationships/linkages
- Questionnaire design
- Sampling methods
- Methods of data collection for household budgets
- Methods for animal production: aging by dentition, recall surveys, progeny history method, direct observation and measurement
- Methods for assessing the composition of feed, sampling crop residues
- Sampling to detect disease presence and prevalence rates
- Methods for estimating livestock numbers, offtake and acquisition and to understand marketing functions
- Breeding practices
- Organisation, presentation and analysis of results

B. Type of data to be collected

- Baseline data
  - general characteristics of the study area
  - specific characteristics of farmer/pastoralist within each target group
  - available technologies which might be applicable to the problems identified
- Data for labour input
  - labour available to the household
  - labour use over a period of time by age and sex categories
- Household budgets and assets
  - assets inventory data
  - income data
  - expenditure data
- Animal production
  - inter-species composition of the production system (households) livestock holding
  - herd/flock structure
  - reproductive performance
  - mortality

Box 2.1 cont...

Box 2.1 cont...

- growth and weight gain
- outputs (meat, milk, hides, skins and traction)

- Animal nutrition
  - Production effects: liveweight gain, condition scores, traction power and milk and wool production
  - Amount of feed consumed: feed intake
  - Composition of feed consumed: oesophageal or rumen fistula samples, faecal samples and grazing behaviour studies
  - Feed data: digestibility, energy value of feed and crude protein content
- Animal health
  - Passive data: veterinary records, records of diagnostic or research laboratories and data from slaughter houses, quarantine stations and checking points
  - Active data: data supplied by farmers, data from laboratory analysis and productivity data

* For further information, see ILCA (1990).

2.3 Livestock farming systems: Key concepts

A farming system is a set of interacting activities which can be synergistic or competitive.

The activities are:

- managed towards satisfying the farmer's objectives (short- or long-term objectives)
- decided by one level of management (farmer or household)
- compatible with the environment.

The farmer in this complex system chooses among various resources (e.g. labour, land, capital etc) to produce outputs. Resources and outputs could be:

- synergistic, e.g. nitrogen-fixing legumes contribute nitrogen to other non-fixing crops
- competitive, e.g. crop residues for feeding sheep vs crop residues for mulching the soil.

Farmers manage activities in the farming system with a set of goals in mind. A decision can be made by the farmer or collectively by the family. This decision is determined by the objectives and by the risk the farmer is willing to take. When the farmer has complex objectives, he/she makes complex decisions. The farming system can best operate when it is geared towards stability. Therefore we can infer that:

- a farming system is more than the sum of its components as there is interaction among the components
- introducing an innovation modifies the whole system; it shifts the balance through synergy or competition.

In order for research results to suit complex farming systems and to be accepted by farmers, it is essential that researchers understand the system. For the research to be effective (i.e. to meet the needs of the farmers) it should take into account the following issues:

- Research should be geared towards solving the clients' problems, therefore, a bottom-top approach is best.
- Research should be viewed as an investment for development.
- Information flows between researchers, development agents and farmers should be redefined (Figure 2.1).
- Researchers should recognise the rationale behind farmers' decisions.
- Researchers should consider small farms as complex systems managed by farmers.
- The research should be multidisciplinary.

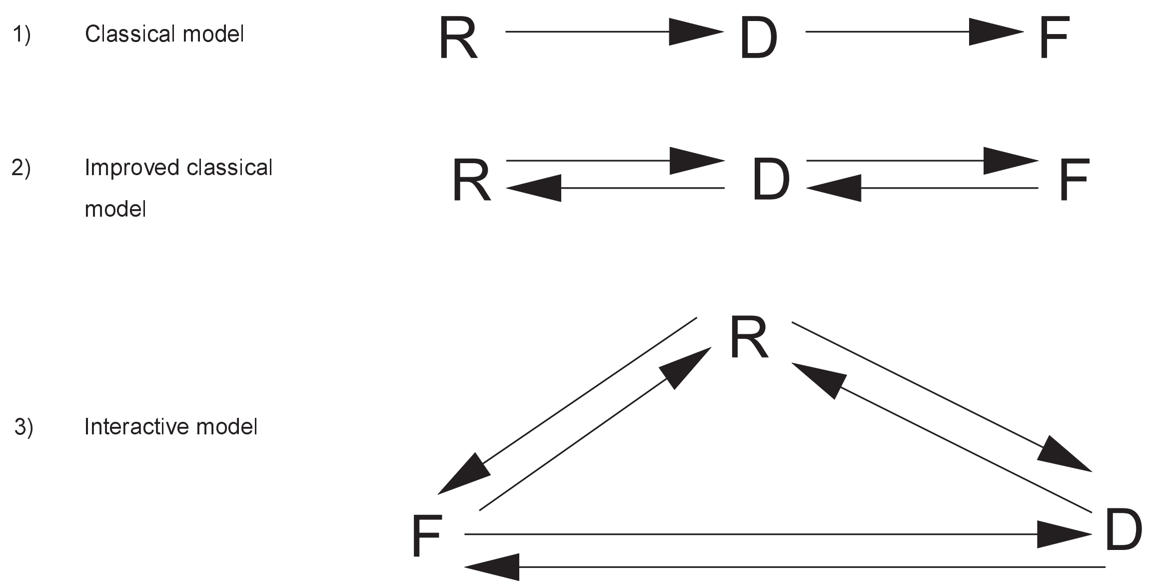


Figure 2.1. *Models for information flow among researchers (R), farmers (F) and development agents (D).*

In the past farmers were used to test information without any thought being given to their needs. Recent research has shown that the information flow in the interactive model (Figure 2.1) is essential for the scientist to exchange information with the farmer. Starting and ending with the farmer (farmer-to-farmer model) allows for direct exchange of information between the scientist and the farmer. The ideal way to exchange information is to involve the three parties: farmer, researcher and the development agent. It is important for the scientist to understand why the farmer does what he/she does because this allows research to provide the solutions needed by the farmer.

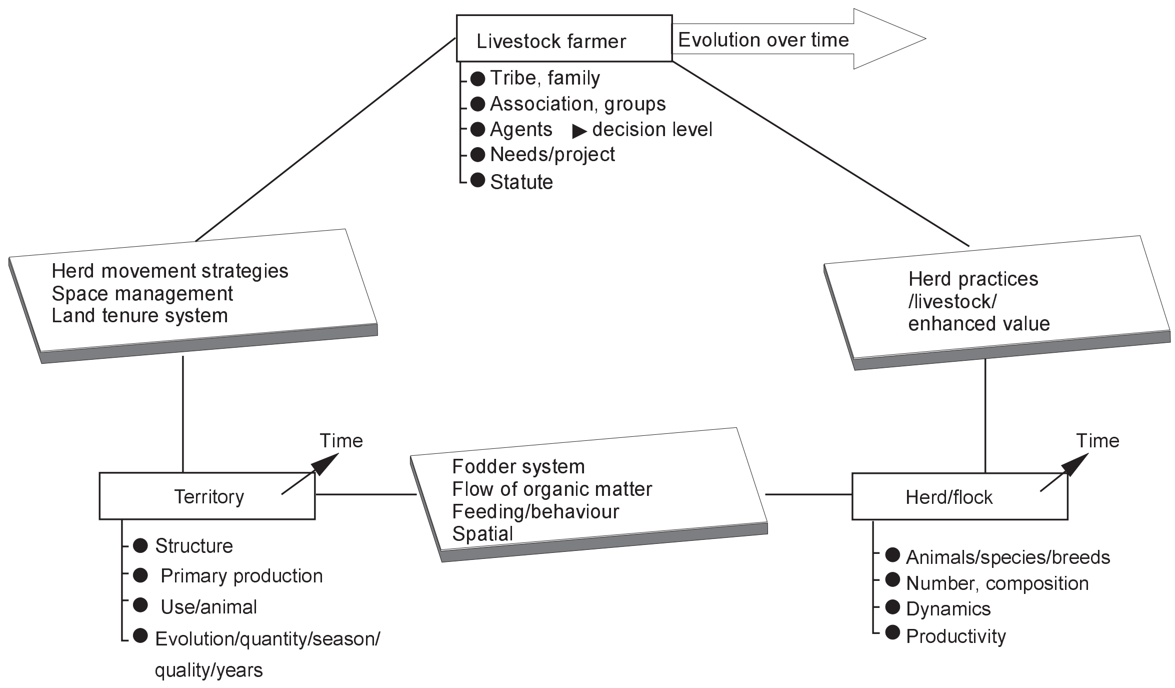
2.4 Livestock farming systems conceptual model

As researchers our objectives for following a farming systems research approach are to:

- gain knowledge about cropping and livestock systems
- conduct research, based on the knowledge of the system, that will provide the information necessary to design interventions for improving the performance of the livestock system.

Implementing these objectives compels us to look at problems using a more holistic approach. It also leads us to use multidisciplinary teams to conduct the research. A conceptual model was developed by Lhoste (1986) to describe these relationships (Figure 2.2).

Livestock systems are part of the agricultural systems hierarchy (Figure 2.3). Studying livestock systems in isolation will make it difficult to see or deal with the total picture. This approach does not necessarily conflict with scientists' specialisation in specific areas.



Source: Lhoste (1986)

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Figure 2.2. *General conceptual model for livestock systems.*

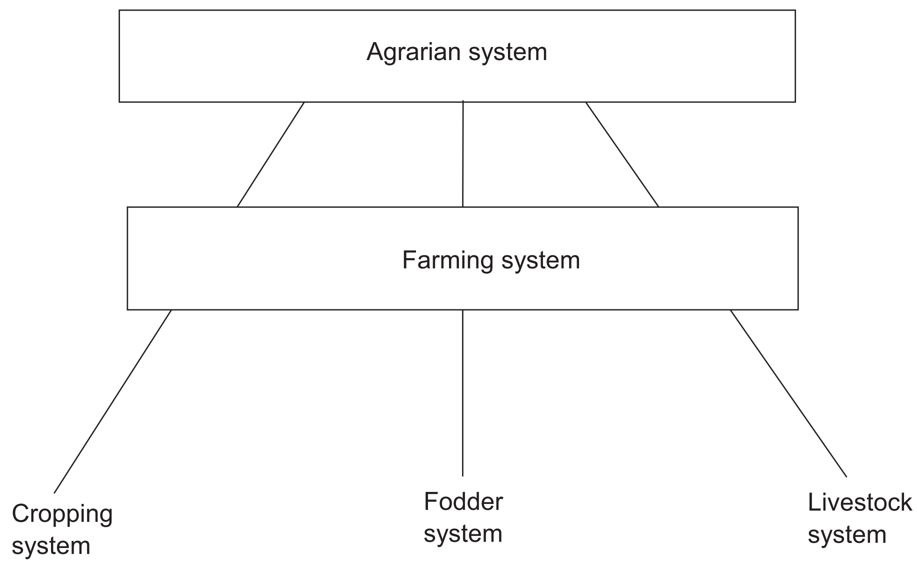

Figure 2.3. *Systems hierarchy.*

2.5 Livestock farming systems process

Livestock farming systems research methodology may be influenced by the nature of the particular system under study but the process involved for all types of farming systems is similar. This includes the terminology used and the sequencing of the process. The following features are prerequisites for the farming systems approach:

- no preconceptions about the system
- it should be improvement oriented
- all factors affecting the household should be examined
- it should involve multidisciplinary teams
- farmer participation is essential
- solutions should be evaluated in biological, environmental, economic and political terms.

The livestock farming systems process involves four main interlinked phases, namely the diagnostic, design, testing and extension phases.

Figure 2.4 illustrates the sequencing and relationships among these phases. We will describe each phase in more detail. Comparing the bottom-up and top-down approaches to research further illustrates the relationship between the phases (Table 2.1). Farmer involvement is central to the bottom-up approach. It allows us to know the farmer's capabilities when improving existing technologies or proposing new ones. The ability of the farmer to economically afford or socially accept the new technology is easier to identify in this approach. The top-down approach, used by most researchers in the past, contributed to the high rate of failure in adoption of technologies by farmers. Solutions generated through the top-down approach may not address the needs of the farmer.

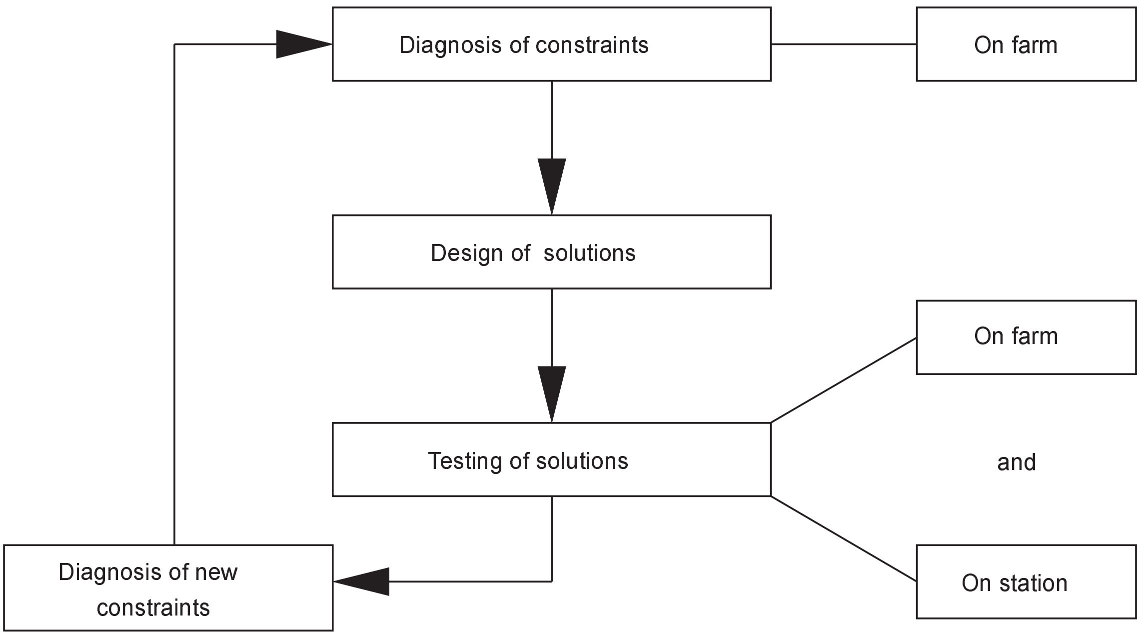

Figure 2.4. *Farming system research process.*

Table 2.1. *Approaches to research.*

Bottom-up approach		Top-down approach	
Location	Activity	Location	Activity
Farm	Diagnosis	Research station	New technology
↑↓		↓	
Research station	Alternative technology		
↑↓			
Farm	Technology testing	Farm	Farm testing

2.5.1 The diagnostic phase

Diagnosis offers answers to the following questions:

1. What is going on? What is the farmer doing? What goes into the system?
2. What is the problem?
3. What is the cause of the problem?
4. What could be done to solve the problem?

Knowing the answers to the first three questions will allow you to (i) address question 4 using a multi-disciplinary approach, (ii) focus your research, (iii) save time and (iv) use limited resources fruitfully.

The main objectives of the diagnostic phase are:

- To describe the production system
  Researchers use this phase to highlight the circumstances and practices of the representative farmers. Understanding the household activities and the wider features of the system is necessary for technology design.
- To identify constraints to resource use
  Farmers' main objectives are to produce for household consumption and for sale and to avoid risk and save for hard times. It is important to identify the factors which prevent farmers from meeting these objectives.
- To understand what causes the constraints
  Unless the underlying forces pertaining to the constraints are understood, solutions will always be elusive.
- To determine opportunities for further improvement
  This involves screening available technologies for their suitability. This information will allow the researcher to decide on an appropriate course of action. Sometimes improvement on farmers' practices can be a solution, e.g. prevalence of parasites in spite of dipping may be due to resistance of ticks to the dipping solutions, improper dipping or reduced animal resistance due to underfeeding. Surveys of indigenous knowledge are recommended as part of meeting this objective.

Diagnostic tools

A few diagnostic tools will be briefly described. For these tools to be effective researchers need to use their feet, ears and eyes as well as brains to diagnose farmers' problems.

1. Surveys

Surveys can be formal or informal and comprise one or multiple visits. To meet the objectives of surveys a researcher should:

- have adequate knowledge about the target population of farmers

- use good questionnaire techniques
- use good sampling techniques
- use skilled surveyors with adequate logistic support (transportation, incentives, knowledge of the area, knowledge of the local language etc)
- involve or consult with a biometrician.

The number of observations and amount of data per observation are important factors in determining data quality. An equilibrium should be reached so that the number of observations match the available resources.

The information collected during a survey should be:

- qualitative and quantitative knowledge on the functioning of the livestock system
- knowledge on variability of livestock systems
- quantitative knowledge on systems performance (function of the farmers' memory and confidence).

Lengthy interviews lead to loss of concentration on the part of the farmer which affects the accuracy of the answers given. Respondent fatigue can also occur when surveys are conducted over a long time.

Formal survey. In a formal survey, a well-structured or semi-structured questionnaire is developed. The questionnaire contains a number of questions to be answered by the farmer. The farmers are randomly selected and the survey is designed to collect data on particular aspects of the production system. Formal surveys can also be used to redefine target groups and identify priorities for research.

Informal survey. In this type of survey no structured questionnaire is needed; information is gathered in an informal way. One needs only to remember the key issues in asking the questions. The reliability of the information depends on the questions and the way in which they are asked. Farmers are busy and in both formal and informal surveys we must not waste their time unnecessarily. The best approach is a combination of both structured and unstructured questionnaires. Both formal and informal surveys should be complemented by observations made during farm visits.

Single-visit survey. In some cases one visit may be enough to gather enough information from a farmer. This is especially so when the farmer is busy during the peak of the seasonal calendar (when the maximum number of activities are being conducted at the same time). This approach is useful for farm inventories and qualitative information.

Multiple-visit survey. Multiple visits are used when we want to verify information or we require more in-depth information. This approach establishes better rapport between researchers and farmers. Researchers have a chance to show interest in the farmer's personal life but they should be careful not to probe matters of privacy or taboo (e.g. income, number of children) directly. This type of survey is particularly useful for semi-structured interviews, and for when farmers are less busy.

2. Farm monitoring

In this method the team of monitors visits farmers over an extended period and records detailed data, e.g. reproduction performance, changes in environment and livestock dynamics. This approach involves collecting continuous data. Depending on the nature of investigation, data collection can take one month to several years. The main disadvantage of this method compared with surveys is its high cost. Its advantages over the survey method are that it can be used to double-check information from rapid surveys and it relies less on the farmer's memory (particularly related to the performance of animals).

To monitor flocks of small ruminants on a farm:

- choose flocks to be monitored
- collect information on resources (territory, flock and family)
- conduct retrospective studies (female productive history)
- pay regular visits to collect data.

2.5.2 The design phase

As mentioned above, analysis of information during the diagnostic phase allows us to identify the problems and their causes (if lucky). Diagnosis is followed by designing a set of research activities to solve the problems (see Biometrics Module). The purpose of designing solutions is to develop technologies that will address the constraints and to adapt the technologies to suit the situation.

Considerations during designing

- Nature of the farms which vary in location and management
- Farmer's capabilities: education and ability to handle technology
- Degree of management control: researcher-managed trials (researcher plans and executes), researcher–farmer-managed trials (researcher plans and farmer executes) and farmer-managed trials (farmer plans and executes)
- Type of trial
- Number of test animals
- Type of statistical analysis
- Available resources (time, money and expertise)

Research should focus on technologies which are compatible with the resources and objectives of the farmer and consistent with the features of the system.

Major rules for designing solutions

- Adapt technologies already developed
- Evaluate all feasible options
- Exploit possibilities in the system

In the short term it is useful to exploit existing options. In any production system major long-term increases can only be obtained by overcoming constraints to production. Whether exploiting existing technologies or developing new ones to improve the system, the economic evaluation is important, as farmers will not use solutions which are not profitable.

2.5.3 The testing phase

The research agenda formulated in the design phase will comprise trials to be carried out at research stations (on-station trials) or in farmers' fields (on-farm trials). The trials may be short or long term. Farmers and policy makers are eager for results and research impact. To sustain their participation, we can demonstrate some spin-offs so that they can look forward to the final result. To maintain the interest of farmers, especially in long-term projects, consistent monitoring and spot analysis of data will help identify opportunities for mid-way interventions. Many researchers delay analysis until the end of the project thus missing many opportunities for spin-offs. Looking at the trend of results can help identify some valuable solutions which will satisfy the farming community.

Considerations

- Farmers should be involved in the trial process and evaluation of technologies on farm
- Experiments should be simple
- The involvement of farmers outside the target area should be considered
- Farmers' reactions to the alternative technologies should be monitored

On-station experimentation

On-station research is needed to arrive at the best alternative among the many tested options. The best option is then tested on farm. However, on station we can only investigate biological factors. Social factors that are of major importance are best investigated on farm.

On-farm experimentation

Simple designs should be used. For each design there are two treatments: the new technology and the farmer's usual practice (control). Testing can be done on one or many farms. We should test alternative technologies in which we have confidence based on data from on-station experimentation. We should be careful that our technologies are not developed for high resource input as this will lead to their rejection by farmers, e.g. crossbred cows tested under good management on station will not perform as well where the farmer has no access to resources similar to those available at the research station.

We need to collect data that will lead to technologies that are technically and socially acceptable and allow us to evaluate performance biologically and economically.

2.5.4 The extension phase

The extension phase occurs after the most appropriate technology option has been identified and tested and found to be acceptable to farmers. The objective of this phase is to extend the option to as many farmers as possible. Monitoring and evaluation are needed to assess impact, but this will be largely outside the scope of a research station and is the responsibility of the extension service. It is essential to monitor:

- production levels and the use of inputs
- resource allocation (e.g. land for crops vs animals)
- institutions (e.g. markets)
- farmers' options—acceptance or rejection of technologies.

Even though this phase is led by the extension service, it requires input from farmers and researchers; such contact should be maintained to ensure feedback.

2.6 Participatory rural appraisal (PRA)

Participatory rural appraisal is:

- An opportunity to learn from the target people about their situation. Target groups can be involved at several points in the process:
  - investigation, identification and prioritisation of needs
  - planning and implementation
  - monitoring and evaluation.
- A method that gives researchers and farmers an opportunity to exchange knowledge. This will enable researchers to design programmes that will meet the needs of the farmers.

2.6.1 Why PRA?

1. The success rate of agricultural projects has been unsatisfactory (a ratio of 3 successful to 55 failed projects in the 1960s) because:

- projects failed to adequately acknowledge the interactions among the component parts of farming systems including ecological, biological and socio-economic elements

- there was limited or no participation by the target groups in conceiving, planning, implementing, monitoring and evaluating the projects.

2. Evolution through the decades

- It started with rapid rural appraisal (RRA), a technique which ignored participation of the target group.
- Rural project appraisal was developed as a new form of RRA; it involved rapid assessment procedures and has the same limitations as RRA.
- PRA overcame the limitations of the two techniques by involving the target group at every stage of the research process.

2.6.2 PRA techniques

Problem identification

PRA techniques are preliminary exercises that provide information about constraints facing the farming system. They complement more formal methods, e.g. surveys.

- Open discussion (non-structured)

  Problems are identified through open non-structured discussion. The main features of the discussion are:

  – the clients lead the discussion (‘we can do it’ attitude) and the researcher acts as a facilitator only

  – the researcher steps in only to seek clarification; otherwise he/she watches, listens and learns.

- Semi-structured (topic investigation)

  – specific answers are obtained for specific questions

  – the researcher’s role is limited to introduction and organisation

  – target group leaders take lead to ensure vigour in the discussion

  – the researcher’s role in the discussion is catalytic.

Gathering data

There is always a wealth of information embedded in a variety of resources. PRA is a quick way to make this information available to the researcher before project planning. To simplify the collection of data, it is classified into many types depending on the source, location, time and social considerations.

- Secondary data: publications, maps, census reports, documents, especially grey literature, and aerial photographs.
- Field-generated data (primary data): This is spatial data collected jointly with the farmer.

  – Sketch maps of the farm are drawn to show resources, activities, opportunities and problems.

  – A transect of the farm is drawn to show items the sketch map may not have included.

  – Farmers and their families draw farm sketches to show land resource and farm size, and to give an idea about operational strategies.

- Time-related data (temporal)

  – A time line is developed showing important local, national and international events observed by the community.

- A trend line is developed showing important changes in the community, why there are changes and the community's attitude to change (since research aims at change, such information is essential).
- Seasonal calendars are developed to show seasonal problems or opportunities in average years.

- Social data (people-related information)
  - Farm household (HH) interviews are conducted to gather socio-economic information and characteristics of a particular community or farm.
  - Information is collected about institutions to provide knowledge about various groups and organisations within the community (including churches, schools, women groups etc), to show insight into the relationship among the institutions and to determine how the community views its institutions (e.g. ranking the contribution of institutions to development).

Ranking and scoring

The impact of problems at the farming systems level can be of varying magnitude. Ranking and scoring are ways of prioritising different interventions and technical solutions that are relevant to and adoptable by farmers. This involves placing things in order of importance at a particular time. Ranking could be done for problems and opportunities.

2.6.3 Virtues of PRA

- Participatory and hence client oriented
- Enabling, as farmers feel the researcher is interested in them
- Empowering because the clients say what needs to be done and the researcher listens
- Semi-structured, leading to local participation in a systematised fashion
- Flexible, gender sensitive and applies to all classes
- Iterative and thus exploits all alternatives and possibilities
- Exploratory and hence looks at all possible situations
- Involves training and orientation which enable the farmer to rationalise and evaluate the products (e.g. weighing small ruminants, weighing milk)
- Focused
- Ensures sustainability

2.7 Categories of livestock farming systems research

Category 1: Farming systems research *sensu stricto*

Farming systems research in this sense studies the farming system as is. The studies are academic and scholarly rather than practical.

Category 2: On-farm research

This is research on farmers' fields with farmers participating and with a farming system perspective. In this category the researcher:

- assumes that only the farmers' experiences can reveal their needs
- isolates a subsystem and studies it in enough depth to obtain new perspectives
- proceeds to on-farm experimentation with the farmers' contribution.

Category 3: Development of new farming systems

The objective is to invent, test and exploit new systems. This involves radical restructuring of farming systems instead of the step-wise change followed in Category 2, e.g. developing an intensified dairy system in place of an extensive pastoral system.

2.8 Exercises

1. Give examples from livestock–crop interactions that show (i) synergistic effects of resources and outputs (ii) competitive effects of resources and outputs.
2. Lhoste (1986) developed a global conceptual model for livestock systems research. Does this model fit the themes from your region? Describe the similarities and the differences.
3. The livestock farming systems research process has four phases. List these phases in sequence and explain what will happen to the value of your research results if any of the phases is omitted.
4. List the categories of livestock farming systems research. Which of these categories suits the available human, financial and physical resources in your situation and why?

2.9 References and reading materials

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Module 3: Reproduction in African small ruminants

3.1 Performance objectives

Module 3 is intended to enable you to:

1. Define and describe the basic concepts of small ruminant reproductive physiology.
2. Compute annual reproductive rates for sheep and goats using field production data.
3. List and compute flock production indices.
4. Describe factors that lead to reproductive wastage in small ruminants.
5. Understand and use techniques for controlling reproduction in ewes.
6. List the methods available to improve the reproductive performance of sheep and goats.

3.2 Introduction

In sub-Saharan Africa sheep and goats provide food and fibre, and produce manure which contributes to agricultural output. The majority of sheep and goats are raised by smallholder farmers on a small scale; profitability is low due to low market weight, overall low reproductive efficiency and high mortality. Small ruminant productivity results from the interaction of reproductive efficiency, growth rate, yield and quality of desired products. Therefore good reproductive efficiency is a pre-requisite for efficient production systems.

3.3 Physiology of reproduction

The basic concepts of small ruminant reproductive physiology are fairly similar across breeds but differences may occur due to genetic and/or environmental factors. In general, small ruminants in Africa are year-round breeders. As a result these animals lamb or kid all year round except where breeding is regulated through specific management systems such as controlled mating. This section will consider the physiological events as they occur during a full reproductive cycle since it is these events that affect the overall reproductive output which in turn affects flock productivity.

3.3.1 Basic concepts of reproduction

Puberty

Puberty is the time when reproductive organs become functional. In the female, it is defined as the time when the first functional oestrus takes place and the earliest age at which reproduction can occur. In some cases, however, ovulation without oestrus occurs before the first observed oestrus. At other times, animals may show oestrus which is not associated with ovulation. The age at which puberty is attained is determined largely by genotype or breed, nutrition, season and other environmental factors (e.g. climate). As a consequence, large variations occur between and within breeds. The age at first lambing may also vary as a result. Full development of the reproductive organs is not reached until puberty.

Example: Puberty in Menz sheep in the Ethiopian highlands

A study (Mukasa-Mugerwa et al 1993) that looked into the reproductive performance of Menz sheep in the Ethiopian highlands reported that ewe lambs attain puberty (first oestrus) at 10 months of age and 16.9 kg mean weight or 56% of mature body weight. The onset of puberty was earlier with higher weaning weight and it is probable that poor nutrition can delay puberty by one season.

Males manifest a marked increase in testis weight and volume with age which coincides with the appearance of the primary spermatocyte and separation of the preputial sheaths. Among females too, the reproductive organs increase in size in line with general body growth. Thus faster growing animals will reach puberty earlier than slow growing animals. In both males and females, puberty generally occurs when animals reach 45–60% of the mature weight for the breed.

Pubertal events are under the influence of pituitary gonadotropic hormones—follicle stimulating hormone (FSH) and luteinising hormone (LH). The anterior pituitary gland of the prepubertal animal contains high amounts of gonadotropins but the level of these hormones is low in the plasma during this phase of growth. The responsiveness of the gonads (testes and ovary) to gonadotropin only increases during growth and as puberty approaches. The hypothalamus also plays part in modulating activities leading to puberty.

Oestrus and ovulation

Oestrus, or heat, is defined as the time when the female is receptive to the male. The critical marker is the male partner (ram or buck). The male is used to detect females in heat by applying dye markers to its belly. This dye rubs off on the backs of females. The immobility of the receptive female is most often used as the critical criterion for identifying oestrus. Oestrus is difficult to detect among ewes alone as they do not exhibit homosexual behaviour. While the short duration of oestrus may make it difficult for farmers to detect heat, the overall duration is adequate to ensure fertility if the ram:ewe ratio is favourable and rams of adequate fertility and libido are running with the flock. Using a teaser ram is the most practical way to detect oestrus in sheep since other observable signs of oestrus (swollen vulva, mucous secretions etc) are most often absent or anatomically difficult to detect. A teaser ram is a castrate that mounts the ewes but does not mate with them.

The ovarian cycle of the ewe is shown in Figure 3.1. The oestrus cycle of sheep is divided into the follicular and luteal phases. In general the oestrus cycle is said to start on the second day of the follicular phase. This phase lasts about three days during which small follicles develop on the ovaries. The luteal phase starts at ovulation and lasts 14 days. An extended ovarian cycle may result from prolonged follicular or luteal phases. The hypothalamic–pituitary–gonadal axis controls the occurrence of oestrus and the duration of the cycle (Figure 3.2). The hypothalamus releases the luteinising hormone releasing hormone (LHRH) which stimulates the release of FSH and LH. The gonadal steroids oestrogen and progesterone regulate the production of LHRH. FSH and pulses of LH stimulate the development of follicles on the ovary. Once the follicles mature they produce and secrete oestrogen, especially oestradiol which is essential for starting sexual receptivity.

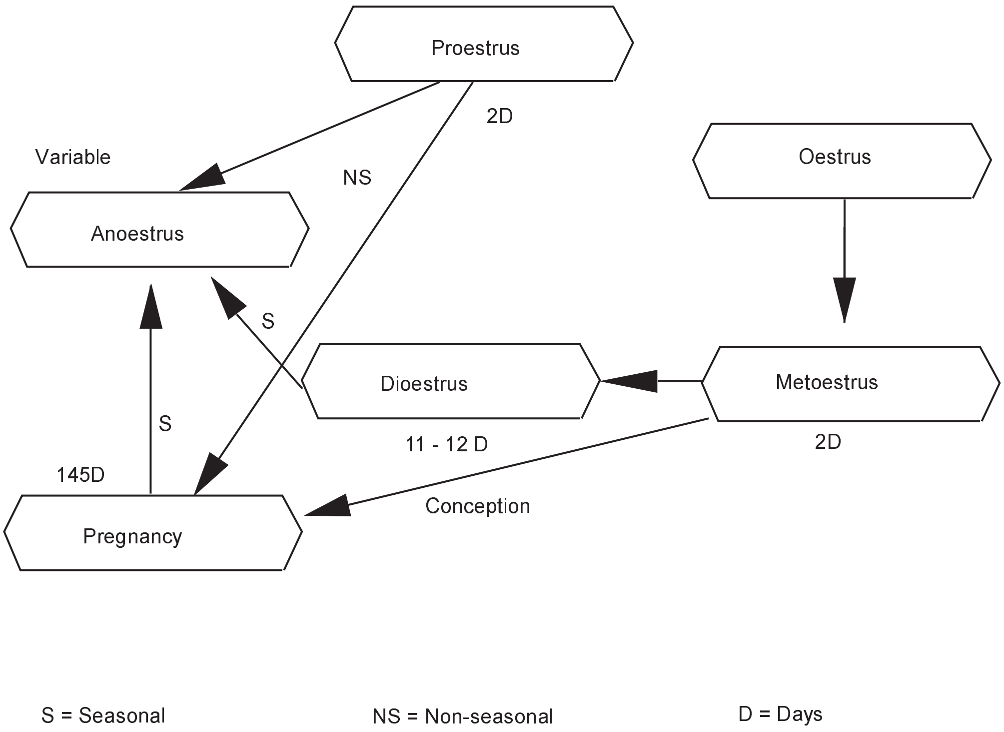


Figure 3.1. *The ovarian cycle of ewes.*

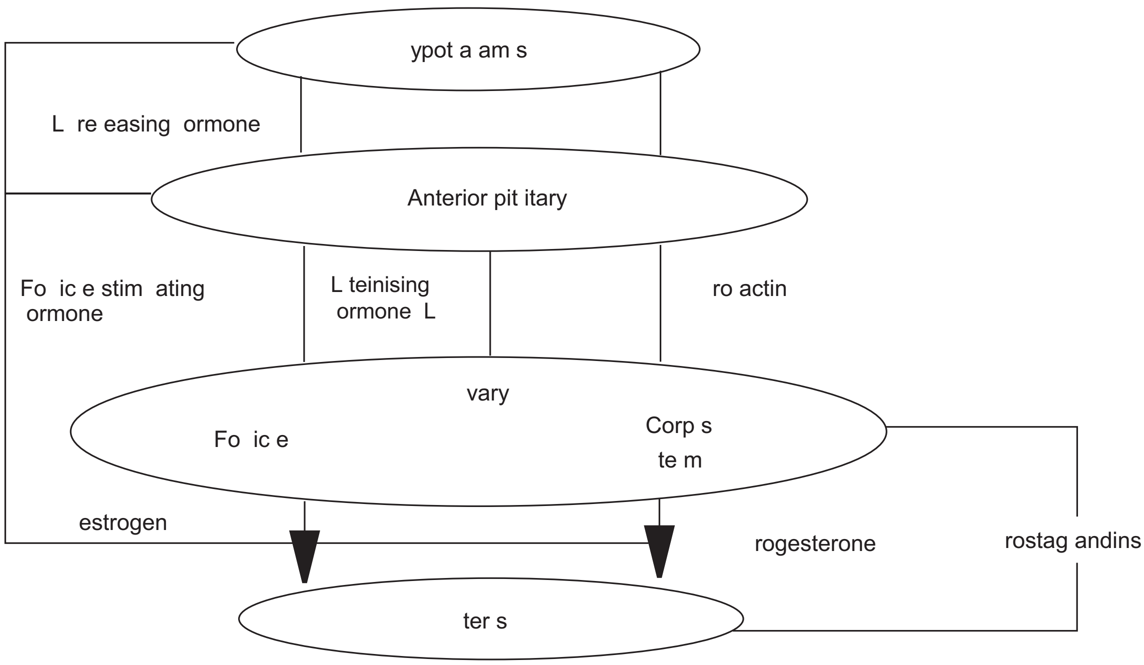
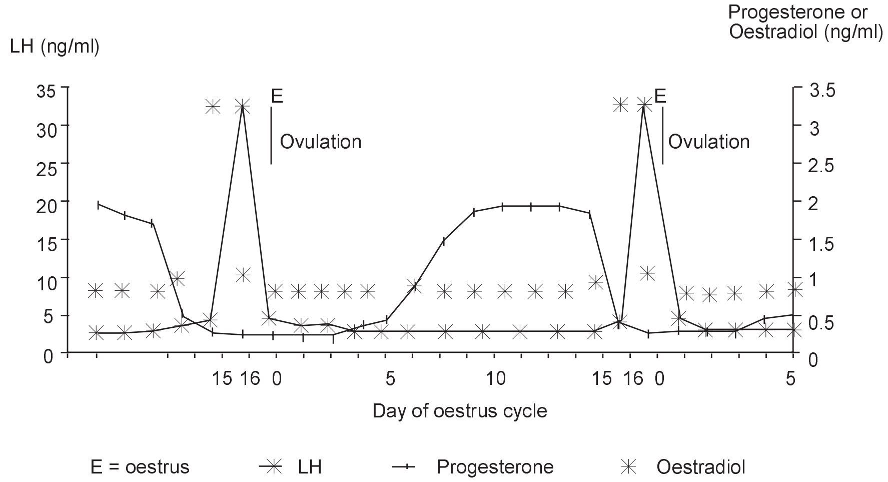


Figure 3.2. *Hormonal control of oestrus in ewes.*

LH is initially secreted in small amounts but large outbursts of the hormone follow and this starts the ovulation process. The follicles collapse and develop into a corpus luteum which produces progesterone that inhibits other follicles from developing. In the normal oestrus cycle, the regression of the corpus luteum is controlled by prostaglandins produced by the uterus. The levels of LH, oestradiol and progesterone in the blood of a normal ewe are shown in Figure 3.3. The ewe in oestrus becomes restless and shows increased activity. The sexual behaviour of the ewe can be divided into two phases: searching for the sexual partner and the sequence of interactions leading to copulation. Among the activities exhibited are sniffing, nudging, mounting and copulation.



Source: Gatenby (1986).

Figure 3.3. *Hormone patterns during the oestrus cycle of ewes*

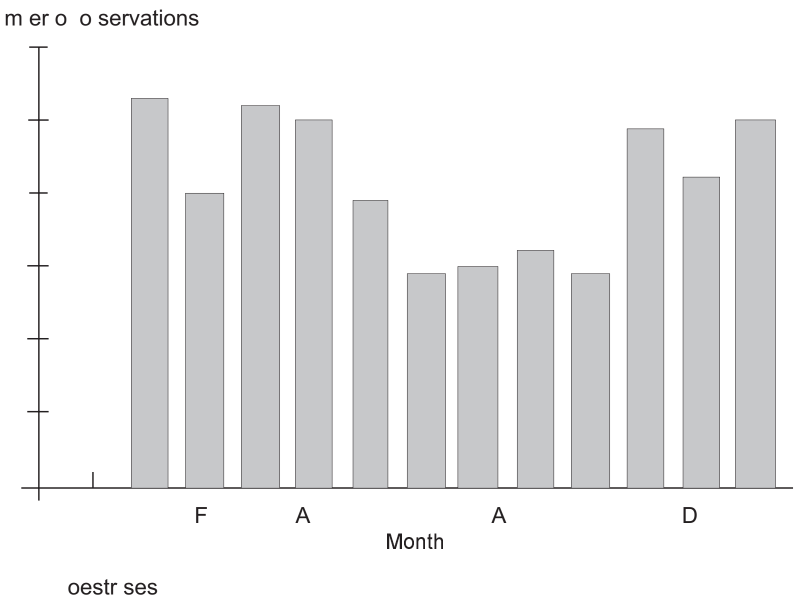
The duration of oestrus in the ewes is 32 to 50 hours for sheep and goats but is highly variable among breeds. During or following oestrus, ovulation of the mature follicle occurs under the influence of LH. Time of ovulation after the onset of oestrus has been estimated as 30 hours for sheep and 30–36 hours for goats.

Oestrus cyclicity and synchronisation

Sheep in the tropics tend to experience oestrus cycles throughout the year, every 14 to 19 days with a mean of 16 days (Figures 3.4 and 3.5). The further one gets away from the equator, the longer the oestrus cycle, a sign of the effect of photoperiod on the ewe reproductive cycle. In a study in the Ethiopian highlands 48 Menz ewes were observed over one year (Mukasa-Mugerwa et al 1993). The ewes were maintained with a vasectomised ram. Results showed that 22% of the cycles were short (<13 d), 56% were normal (14–19 d), 11% were long (20–26 d), 8% were missed (27–40 d) and only 3% indicated anoestrus (>40 d). Exceptionally long cycles are often associated with particular seasons of the year.

Herdsmen need to observe oestrus to effectively manage mating and lambing events, but the observation activity is time consuming. To reduce the time spent in observing oestrus, it is essential to synchronise it. This is often critical when mating and lambing need to be matched with availability of labour or nutritional sources.

Oestrus synchronisation is best achieved by using progestogen or prostaglandin F2α. Progesterone can be administered by daily injections, orally, as subcutaneous implants or in intravaginal sponges. When intravaginal sponges are placed in the vagina for 12 days, most of the ewes come into heat within 2–3 days of sponge removal. Using intravaginal sponges has the advantage of ease of application, no detrimental effect on pregnancy and comparable fertility rates as for untreated controls. In addition to these treatments to induce oestrus, prostaglandin F2α (uterine luteolycin) can be used to very effectively synchronise oestrus in sheep with fairly good fertility rates.



Source: Mukasa-Mugerwa and Lahlou-Kassi (1995).

Figure 3.4. *Monthly variation in number of oestrus cycles of Menz ewes in Ethiopia.*

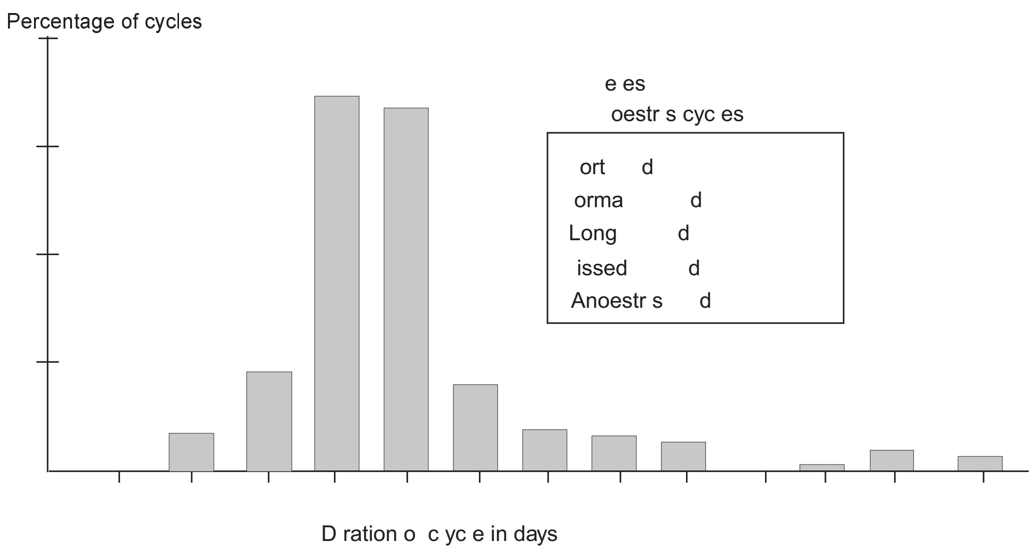


Figure 3.5. *Frequency distribution of the duration of oestrus cycle length in Menz ewes.*

Follicular populations, ovulation rate and litter size

Small ruminants have the genetic ability to carry more than one litter in a pregnancy. The ovary of the adult ewe has a large pool of very small or primordial follicles from which it has been estimated that 3–4 follicles develop every day. These follicular populations appear to influence the ovulation rate which is a primary factor limiting litter size. Since ovulation rates are genetically controlled, improvement in this trait can be and has been achieved by selection. In breeds with low litter size, increased twinning can be achieved by using pregnant mare serum gonadotrophin (PMSG), usually administered after sponge withdrawal.

Example: Effect of environment and nutrition on manifestation of oestrus

Even though ewes in the Ethiopian highlands manifest oestrus throughout the year there is a depression coinciding with the peak of the rainy season (July to September). Progesterone profiles of the ewes reveal that failure of certain ewes to show oestrus in the wet period is, however, due to increased frequency of ovulations that are not accompanied by oestrus (silent heats). Rams also experience a depression in their fertility during the rainy season (Mukasa-Mugerwa and Lahlou-Kassi 1995). This reproductive pattern is reflected in the pattern of lambing activity in Menz sheep which also peaks during the rainy season (Figure 3.6).

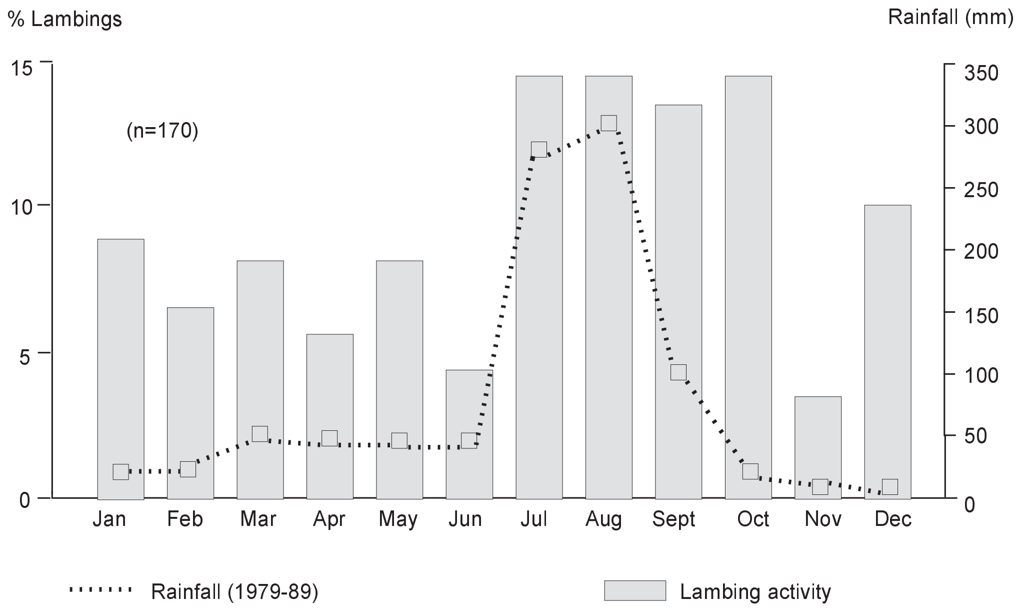


Figure 3.6. *Monthly distribution of lambing activity in Menz sheep under natural mating.*

Breeding and artificial insemination

Females can be bred naturally or artificially. Under natural mating, a ratio of 50 to 1 ewes/ram can be used. The ram must be mature and have good libido, particularly when the ewes are synchronised into oestrus. Under artificial mating, a larger number of ewes may be bred by the same ram. Ram fertility is generally related to the production of large numbers of high quality spermatozoa.

For artificial insemination (AI) semen is collected, processed and stored before insemination. Collected semen is used immediately or stored in liquid nitrogen as frozen pellets.

Insemination of sheep is preferably done by the intra-uterine method; the intra-cervical method can also be used. If AI is done intra-cervically, a large number of spermatozoa should be used. To ensure success, insemination should be done at the onset of oestrus in goats (1–12 hours) and at the end of oestrus in sheep. The time of ovulation, duration of sperm transport in the female genital tract and survival time of the male and female gametes are factors that should be considered to achieve success in AI. Using hormones to synchronise oestrus also plays an important part in determining the timing of AI. Double insemination (12 hours apart) may be attempted to improve success. Usually sperm deposition is made 48–58 hours after sponge removal when PMSG is used.

Fertilisation

Fertilisation is the introduction of hereditary material from the sire through sperm activation of the ovum; the sperm and the ovum join to form a new cell. It is the most important step in reproduction.

In small ruminants the sperm has to undergo physiological changes in the female genital tract before it can fertilise the ovum. Insemination before ovulation (6–24 hours) is therefore recommended. The fertile life of a sperm is 30 to 48 hours and is even shorter for the ovum (less than 24 hours).

Gestation and parturition

Gestation is the period from fertilisation to delivery of the foetus. Its duration is 148–150 days for sheep and goats and is influenced by age of the dam, litter size and environmental factors (nutrition).

During pregnancy the blood vessels in the vulva and vagina increase. The cells of the cervix secrete mucus to form the 'cervical mucus seal' and the uterus enlarges. The Graafian follicle transforms into a corpus luteum which persists throughout pregnancy, secreting progesterone which is essential for maintaining the pregnancy. However, after the first trimester the sheep's placenta can produce enough progesterone to maintain the pregnancy even if the corpus luteum is removed. The placenta is formed to maintain the exchange of material between the foetus and the mother.

The process of parturition in small ruminants is more complex. Foetal and maternal roles have been studied and reviewed by several scientists (Mukasa-Mugerwa et al 1994; Mukasa-Mugerwa and Lahlou-Kassi 1995). There are subtle differences in the prepartum course of events culminating in parturition in sheep and goats. In sheep progesterone levels in maternal plasma decline 7 to 15 days before term. However, reducing the influence of progesterone on the sheep uterus is not critical for labour initiation. In goats, an abrupt decline in progesterone which occurs 24 hours before delivery is the critical event for activating the uterus. Oestrogens increase during the last day of pregnancy in ewes and rise gradually in goats. These events culminate in stimulating the muscles of the uterus to contract. The foetus and placenta are expelled and this is followed by the regeneration of the uterine wall. About 24 days are needed for the uterus to return to its normal size (involution). Oestrus cycles may start again as early as 14 to 21 days after parturition. In some cases silent ovulation may occur before behavioural oestrus. Suckling delays the onset of oestrus but this observation is variable in the tropics.

Pregnancy diagnosis in sheep and goats

To diagnose pregnancy in small ruminants you can use:

- rectal palpation after two months of pregnancy
- abdominal palpation in advanced pregnancy
- hormonal tests
- Doppler or Ultrasonic techniques
- direct palpation after laparotomy
- vaginal biopsy for the presence of cornified epithelial cells
- laparoscopy
- foetal electrocardiography
- immunologic methods: antigens specific to pregnancy.

3.4 Reproductive performance

For small ruminants to be highly productive, good levels of reproductive performance need to be achieved. Reproductive efficiency can be assessed by measuring fertility, prolificacy (litter size), fecundity (fertility × prolificacy) and survival. The following sections will deal with these factors briefly. For more details see the section on reading materials (Section 3.7).

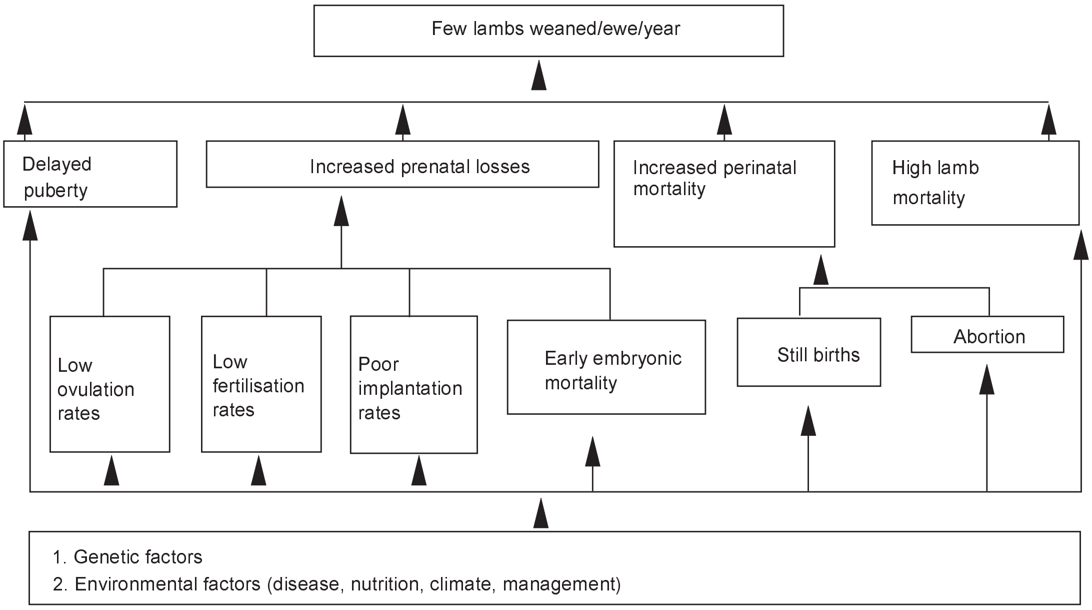


Figure 3.7. *Causes of poor reproductive performance in sheep.*

Major factors that affect productivity in small ruminants include reproductive rate, survival rate, growth rate and policies that affect prices of livestock and their products. Figure 3.7 shows how these factors can lead to poor reproductive efficiency and how they relate to each other. This chapter deals with manipulation of the animal environment and of genetic factors to correct for impairment in reproductive performance. The physiological control of puberty will be described as will manipulation of physiological processes in relation to the environment and the hormone flow in sheep and goats.

3.4.1 Annual reproductive rate

The impact of reproduction on sheep and goat productivity is best estimated by the annual reproductive rate (ARR) which is defined as the number of lambs or kids weaned per ewe or doe of reproductive age per year. It is generated as:

$$ARR = S(1-M)/I \qquad \text{(Equation 1)}$$

where S is litter size, M is the rate of lamb or kid preweaning mortality and I is lambing or kidding interval in ewe or doe in years. Equation 1 can also be used to estimate the flock productivity by including the number of lambs/kids weaned per ewe/doe in the flock per year as follows:

$$ARR' = S(1-M)P/I \qquad \text{(Equation 2)}$$

where P is the proportion of ewes/does in the flock of reproductive age. However, there are several ways of assessing the reproductive rate in small ruminants, e.g. for sheep:

- Fertility = number of ewes lambing/number of ewes available for mating.
- Prolificacy = litter size = number of lambs born alive/number of ewes lambing.
- Fecundity = fertility × prolificacy = number of lambs born alive/ewes available for mating.
- Lambing rate = number of lambs born/ewes available for mating (often expressed as a percentage).
- Weaning rate = number of lambs weaned/ewes available for mating (often expressed as a percentage).

The above relationships show that reproduction rate is influenced by litter size, young mortality and interval between parturitions.

Productivity of tropical sheep is said to be low because of scarce documentation or poor measurement of outputs such as meat, milk and manure. Since milk, blood and manure are rarely measured, productivity is expressed in terms of 'per unit weight of breeding ewe' rather than 'per unit input'. Justification for this is based on the proportionality of the number of breeding ewes to the quantity of real inputs needed by the flock. Initial lamb weaning weight and subsequent parturition interval were used by Wilson et al (1985) to construct three flock production indices which can be expressed as follows:

1. Index I (kg/ewe) = (total live weight of litter at 90 days × 365)/subsequent parturition interval (days).
2. Index II (g/ewe) = Index I/post-partum weight of dam (kg).
3. Index III (g) = Index I/post-partum weight of dam0.73 (kg).

Index I is derived in kg/ewe and represents lambing interval as a percentage of a year and considers lamb performance until weaning. Since the dam is the source of input until weaning, it was necessary to assess productivity in g/kg of dam weight (Index II) or in kg/kg metabolic weight (Index III). When lambs die before weaning, the index is zero.

Examples: Annual reproductive rate and productivity indices

The mean annual reproductive rate (ARR) in Africa is 1.2 (Mukasa-Mugerwa and Lahlou-Kassi 1995) while that reported for Menz sheep in the Ethiopian highlands was 1.4 (Gatenby 1986; Wilson 1989). Estimates of productivity indices (Index II) from sheep flocks are shown in Table 3.1. The productivity of the West African Dwarf sheep was studied in Senegal. Index I had an average value of 11.5 kg/ewe and Index II was 0.47 g/kg dam weight. Flocks were studied in semi-arid Africa and Index II ranged from 0.47 to 0.60 g/ewe. It was found that Index II is the most useful of the three indices. Fitzhugh and Bradford (1983) calculated Index II for sheep in Latin America and West Africa. Values for Index II range from 0.42 g/kg dam weight for West African Dwarf sheep to 0.53 g/year for Barbados Blackbelly. The values are similar to the ones calculated by Fall et al (1983).

Table 3.1. *Productivity Index II for sheep in sub-Saharan Africa.*

Breed	Location	Index II* (g/ewe)
West African Dwarf	Senegal	0.47
Afar	Ethiopia	0.51
Baggara	Sudan	0.60
Bambara	Mali	0.56
Maasai	Kenya	0.47
Menz	Ethiopia	0.52
Barbados Blackbelly	Latin America	0.53
Blackhead	Brazil	0.38
Pelibuey	Latin America	0.43
West African Dwarf	West Africa	0.42
Mean		0.48

*Index II (g/ewe) = [(total live weight of litter at 90 days × 365) subsequent parturition interval (days)]/post-partum weight of dam (kg).

3.4.2 Litter size

Most estimates of litter size in tropical sheep range from 1.0 to 1.5 indicating that twinning rate is generally between 0 and 50%. Mean litter size may be less than one, indicating that the rate of pre- and perinatal losses in the form of stillbirths is greater than the twinning rate in the flock. In Africa there are some breeds which are recognised to be prolific, e.g. West African Dwarf and the Moroccan D'Man, as they usually deliver two or more young. Table 3.2 gives some estimates of litter size in African sheep.

Table 3.2. *Estimates of litter size in African sheep.*

Breed	Location	Litter size (number)
Afar	Ethiopia	1.05
Awassi	Egypt	1.12
Bornu	Mali	1.05
Desert	Sudan	1.30
Dorper	Botswana	1.10
Maasai	Kenya	1.02
Maure	Chad	1.07
Nungua	Ghana	1.13
Uda	Niger	1.07
West African Dwarf	Côte d'Ivoire	1–1.31
West African Dwarf	Senegal	1.12
Yankasa	Nigeria	1.23
Average		1.14

The major determinant of litter size is the number of eggs shed, i.e. the ovulation rate. This is modified by such factors as fertilisation rate and embryonic and foetal losses before parturition (Table 3.3). Although the ovulation rate of D'Man ewes averages 2.5, only about 42% of the eggs develop to full-term foetuses. Ovulation rate varies among breeds. It increases with ewe age up to 6–7 years and is greatest in the first half of the breeding season among seasonal breeders. The trait is highly repeatable within individuals. Since ovulation rate is genetically controlled, it is possible to select for it and achieve improvement. Litter size is influenced by environment, age and ewe body weight at mating. The body weight is affected by nutrition. Litter size can be increased 10 to 40% by improving the nutrition management of the premating ewe or by treatment with gonadotropins. Litter size in sheep and goats can also decrease through abortion (Table 3.4). Abortion can be caused by diseases, poor nutrition, litter size and dam age; genetic factors also play a role in inducing abortion.

Table 3.3. *Estimates of embryonic losses in sheep.*

Breed	Location	Embryonic losses (%)
Mixed	USA	32.7
Romney	New Zealand	22.1
Hampshire	USA	28.6
Merino	Australia	24.0
Merino	Australia	22.8
Menz	Ethiopia	22.0

Table 3.4. *Estimates of abortion rate in sheep and goats in Africa.*

Breed	Location	Abortion (%)
Sheep		
Balami	Nigeria	3.0
Fat-tailed	Rwanda	2.9
West African Dwarf	Côte d'Ivoire	3.7
Mossi	Burkina Faso	10.7
Goats		
Sahel	Chad	4.6
Sahel	Mali	12.6
Nubian	Sudan	8.0
Cross	Kenya	10.0
Sokoto	Niger	6.5
Malawi	Malawi	11.7

Embryonic and foetal losses can occur due to slaughter of pregnant females. Failure to diagnose early pregnancy can partly explain this behaviour; however, in times of crisis farmers may deliberately sell pregnant animals. It is estimated that 20 to 70% of the does and ewes slaughtered in sub-Saharan Africa are pregnant (Table 3.5).

Table 3.5. *Estimates of losses due to the slaughter of pregnant females in sub-Saharan Africa.*

Location	Estimate (%)	
	Sheep	Goats
Ethiopia	70	–
Mali	20	32
Chad	44	72
Togo	40	39
Average	40	42

Example: Losses due to slaughtering of pregnant ewes in the Ethiopian Highlands

Most farmers in the Ethiopian highlands sell their sheep to generate income. These sheep are slaughtered for human consumption. Farmers are usually reluctant to sell pregnant ewes. Ewes that have conceived but without the farmer's knowledge end up being sold. A study found that 70.1% of the slaughtered females (for market consumption) were pregnant, 24% with twins (Mukasa-Mugerwa and Tekelye 1988). A high proportion of these females were pregnant in their third to fifth months of gestation. In this example pregnant sheep were slaughtered all year round. The authors extrapolated reproductive efficiency from these data if the pregnant ewes were not slaughtered and were allowed to lamb. The fertility rate would have been 73.2%, fecundity 125.1% and twinning rate 25.1%.

Perinatal lamb losses greatly minimise reproductive rate. They occur in the first few days of life and can be substantially reduced through management. Small lambs are always weaker than those with larger birth weight; very large lambs may be lost due to dystocia. Lambs born singly often have a higher survival rate than twin or triplet births; twins and triplets have a lower survival rate due to delivery malposition coupled with low birth weights. The weight change of the dam during pregnancy significantly influences lamb birth weight. Improved nutrition during the last trimester of pregnancy, when 60 to 70% of foetal growth takes place, increases dam weight. As ewes become older and more experienced, their ability to milk, deliver and care for their young improves, leading to a decline in perinatal losses.

3.4.3 Lamb mortality

In traditional flocks an estimated 10 to 50% of the lambs die annually before weaning. The mortality rate varies between years and is affected by lamb age, litter size, birth weight, ewe nutrition and dam parity. Mortality can result from the combined effect of birth weight and mothering ability especially in terms of milk production. Ewes that are undernourished often give birth to low-weight young that are likely to die of starvation. Supplementing ewes with extra feed during the second and third trimesters produces heavier lambs with higher chances of survival. While milk production and mothering ability improve with age, there is a peak age beyond which dams lose condition and the ability to rear the young. Lambs born in the wet season have low survival rates because of cold stress and disease infection especially pneumopathies. Preweaning mortality rates among sheep in Africa are shown in Table 3.6. These losses affect weaning rate and hence productivity as the resources invested in the mother are wasted.

Table 3.6. *Estimates of preweaning mortality rate among sheep in Africa.*

Breed	Country	Mortality
East African Fat-tailed	Rwanda	18
West African Dwarf	Côte d'Ivoire	10
West African Dwarf	Ghana	32
West African Dwarf	Senegal	33
Sahel	Mali	30
Maasai	Kenya	32
Menz	Ethiopia	29
East African Blackheaded	Uganda	21
Mean		25

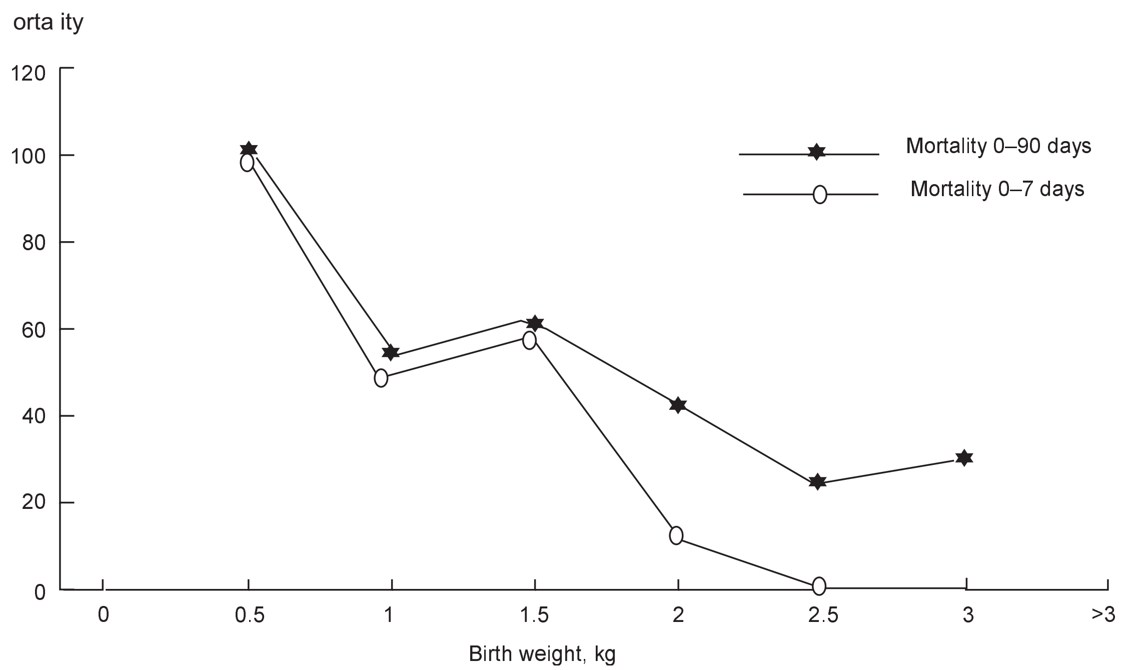
Example: Lamb mortality

Mukasa-Mugerwa et al (1994) found that Ethiopian Menz breed lambs which weigh <2.0 kg at birth are more likely to die due to starvation, mismothering and exposure (the SME syndrome). The rate of survival increased from 37% (1 kg birth weight) to 69% (1 to 2 kg birth weight) and 98% (2–3 kg birth weight); beyond 3 kg birth weight no losses were experienced (Figure 3.8). As lambs grow older, their chances of survival are higher: mortality is 25–45% in the first year, 10% during the second year and <2% in age groups over two years. Birth weight (<3 kg) and breed (pure bred) greatly accentuated the cause of death. Studies on Horro and Menz sheep in Ethiopia revealed similar conclusions: starvation, mismothering and pneumonia were major factors for mortality among the lambs (Table 3.7). Trauma and accidents were not important.

Table 3.7. *Post-mortem diagnosis of causes of mortality among Horro and Menz sheep in Ethiopia.*

	Mortality (%)	
Cause of mortality	Horro	Menz
SME* complex	20	15
Pneumonia	20	29
Gastro-intestinal problems	9	13
Septicaemia	14	17
Still-birth	6	7
Joint and navel infection	4	1
Endoparasites	4	1
Trauma and accidents	–	1
Undetermined	20	16

*SME = starvation, mismothering, exposure.



Source: Mukassa-Mugerwa and Lahlou-Kassi (1995).

Figure 3.8. *Effect of birth weight on lamb mortality in Menz sheep.*

3.4.4 Lambing interval

The interval between two parturitions is the lambing or kidding interval. Lambing interval has three phases: the gestation period, the post-partum anoestrus period and the service interval. Extended lambing intervals commonly arise from long post-partum anoestrus intervals, repeated cycles of service intervals without conception, embryo death or abortion. Lambing interval generally declines with age suggesting that young ewes take longer to regain condition after lambing. Good management strategies remove breeding ewes with problems from the flock. Farmers usually keep such ewes in the hope that the situation may improve; this results in wasted resources in terms of feed, and a lower flock production index.

Lambing intervals in Africa ranged from 230 to 437 days (Wilson 1989). About 65% of Menz sheep in the Ethiopian highlands have a lambing interval of eight months and are capable of three lambings in two years except when mating is managed.

3.4.5 Proportion of reproductive ewes

The fraction of a flock that is of reproductive age is dependent on age at puberty, the length of reproductive life of ewes, lamb mortality and the ratio of rams to ewes. Traditional animal owners generally maintain flock structures for maximum output while minimising risks. The average value for ewes and does of reproductive age (P) in tropical flocks commonly ranges from 0.45 to 0.75 with an average of 0.55. Using equations 1 and 2 for the values S=1, M=0.15, I=0.75, P=0.55 we can arrive at the following situation:

ARR = S(1–M)/I = 1.0(1–0.15)/0.75 = 0.85/0.75 = 1.1 lambs per ewe per year

ARR' = 0.6

Values established for African sheep ranged from 0.8 to 1.2. All the components of ARR are inter-related and must be considered collectively to effect meaningful improvement. For example, a 10% increase in litter size does not by itself increase ARR by 10% because a rise in litter size will be accompanied by increased lamb mortality and extended lambing intervals unless this is accompanied by improvement in overall management. Breeding ewe lambs at an early age may raise the value of P but the impact of this may not be achieved due to small litter size, high lamb mortality and longer lambing intervals.

3.5 Management of reproduction

One of the major advantages of tropical sheep is that they can cycle throughout the year. Most of these sheep graze natural pastures or utilise crop residues. The quantity and quality of these feed sources fluctuate seasonally leading to periods of serious nutrition deficits which compromise the ewes' natural ability for continuous breeding. This results in fluctuating lamb production which does not necessarily peak at the time when market prices are highest. Understanding and manipulating the reproductive cycle of sheep could help to alleviate this problem. Better control of sheep reproduction would also allow producers to meet the needs of export as well as expanding urban markets. These factors require better breed improvement programmes that will use technologies such as AI and multiple ovulation and embryo transfer (MOET) to maximise rates of gain for important carcass traits.

3.5.1 Techniques for inducing oestrus and ovulation

The male or ram effect

As mentioned earlier, farmers introduce a ram into a previously isolated flock as the breeding season approaches to induce ewes to breed earlier in the mating season. The effect appears to result from an increase in LH which induces the maturation of the pre-ovulatory follicle. The ewes' ability to respond to this effect depends on the depth of anoestrus.

Use of exogenous hormones

Reproduction is the sum total of oestrus, ovulation, fertilisation and parental foetal growth and development. These processes can be induced with hormones but to achieve the best results this must be supported by genetic selection and proper management. The main aims of hormonal control of reproduction are to:

- synchronise breeding during the mating season
- increase ovulation rate and subsequent multiple births

- induce fertile mating during the anoestrus period
- induce early puberty.

Three types of hormones are often used to control sheep reproduction: progestogen, oestrogen and gonadotropin.

Progestogens. These are female sex hormones that are produced naturally in the animal or made synthetically. Progesterone is produced by the corpus luteum (CL) during the luteal phase before the animal shows oestrus. It is used to synchronise oestrus and ovulation during the breeding season. When ewes are in the anoestrus phase, progestogens are used to prepare the uterus for pregnancy and sensitise the animals to respond better to hormones that can stimulate oestrus and ovulation. Using progestogens to synchronise oestrus is discussed in Section 3.3.

Oestrogens. Oestrogens are also female sex hormones produced naturally by the ovary or synthesised chemically. In the animal they are produced in large amounts by the follicle just before or during oestrus. When used in combination with progesterone, oestrogens are valuable in sensitising the ewe to better respond to the effects of ovulatory hormones and help to prepare the uterus for pregnancy.

Gonadotropins. These are hormones that cause ovulation (e.g. LH and FSH) and are produced by the pituitary gland. The most commonly used is pregnant mare serum gonadotropin (PMSG). It is produced by the uterine lining of the mare in the first phase of gestation. The human chorionic gonadotropin (HCG) hormone is also used. The hormone PMSG is best given on the day progesterone treatment stops. PMSG at the rate of 200 to 300 iu increased twinning in Menz sheep (Mukasa-Mugerwa and Lahlou-Kassi 1995). It is noteworthy that an immune response which may last for up to one year may develop from repeated use of PMSG. The normal recommendation is to apply PMSG and HCG in a ratio of 8:1 on mating ewes synchronised with sponges. The combined use of sponges plus PMSG appears to have potential for improving lamb production for specialised situations, e.g. a condensed lambing period for research purposes where small sire groups are desired. Particular attention to details of management of mating are important, e.g. 2% of sponges get lost and need immediate replacement, a high incidence of multiple births is expected and better management at and soon after lambing is required to minimise perinatal losses.

Use of melatonin

Day length is perceived by the eye and translated into a circadian pattern of melatonin secretion which increases during the time of longer darkness. Several slow-release formulations of melatonin are available:

- slow biodegradable subcutaneous implant, e.g. REGULIN
- an intra-ruminal glass bolus
- a hydrogel polymer-based implant. This approach is, however, less relevant in the tropics.

Use of laparoscopy for AI in sheep

A major obstacle to maximising the benefits of genetic selection and improvement programmes in sheep, in contrast to cattle and pigs, is the unsuitability of existing AI procedures. The factors leading to this situation are short shelf-life of semen (<10 h) and the low conception rate (20 to 30%) following the insemination of frozen semen via the cervical route. Apparently this arises from poor semen motility after thawing. The laparascopic technique has helped to overcome some of these limitations and make the use of frozen semen more practical. This technique results in conception rates ranging from 47 to 79% (compared to >90% when fresh semen is used).

Potential role of laparoscopy in embryo transfer (ET)

The rate of genetic progress for important traits can be doubled if each ewe contributes 10 offspring to the breeding programme. This is possible using the multiple ovulation and embryo transfer (MOET) technique.

The major obstacle to MOET is variation in superovulatory response using current gonadotropins. These hormones are given during the last two to three days before sponge removal or injection of prostaglandin to synchronise oestrus. Although the laparascopic embryo recovery technique gives 15% less embryo recovery in contrast to surgical procedures, it allows for repeated flushing even at monthly intervals and does not interfere with subsequent ewe breeding potential.

3.6 Exercises

1. Define oestrus and describe practical ways to detect it.
2. Improved nutrition and health would lead to improved reproductive output. Do you agree with this hypothesis? Design experiments to test this hypothesis in the following situations: a. pastoral b. agropastoral c. urban.
3. The following table lists the reproductive rates in sheep in three African countries.

Country	Litter size (number)	Parturition interval (days)	Annual reproductive rate (young/year)
Ethiopia	1.08	262	1.50
Kenya	1.05	312	1.23
Sudan	1.17	437	0.98

What conclusions can you draw from the difference in parturition interval among countries?

4. Even though sheep in the tropics can cycle throughout the year, in many places in sub-Saharan Africa the quantity and quality of feed fluctuate seasonally leading to periods of serious nutritional deficits which affect the ewe’s natural ability for continuous breeding. Manipulating the reproductive cycle of sheep, therefore, could help alleviate this problem. Describe how you can achieve this objective using hormones.

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Module 4: Health and diseases

4.1 Performance objectives

Module 4 is intended to enable you to:

1. Describe briefly the symptoms of diseases of economic importance in sheep and goats.
2. Describe in detail helminthosis as it affects sheep and goats.
3. List control strategies for major diseases of small ruminants.

4.2 Introduction

In spite of the numerical and economic importance of small ruminants in developing countries of the tropics, productivity is generally low owing to inadequate feed resources, poor management and diseases. Losses from diseases alone reduce productivity by 50–60% (Pritchard 1988; Winrock 1992). The recurrent loss in productivity and profit is often due to parasitic infections, particularly helminth infections which are a common and major problem for small ruminant production in most parts of the tropics.

One of the main problems faced by African smallholder farmers in controlling diseases of small ruminants is lack of adequate veterinary services. These services are often provided by government agencies which lack facilities for surveillance and diagnosis of diseases and are unable to maintain adequate vaccine supply/production (Winrock 1992). To alleviate these constraints these services need to be strengthened in both governmental and private organisations.

4.3 Background information

Diseases can be defined as any deviation from health. Healthy animals are alert, active and show interest in their environment. Disease can also be defined as a change in the normal condition of the animal caused by any invading living organism including parasites, bacteria, viruses, protozoa and fungi. Infectious diseases which are spread from one animal to another directly or indirectly are called contagious diseases while those that are spread by a vector are referred to as vector-borne diseases. The definition of a disease implies knowledge of the normal condition of the animal, but this information is beyond the capacity of this manual. Readers are urged to familiarise themselves with this knowledge. By carefully watching the animals and learning how they behave it is possible to observe deviations which may be caused by diseases. Many factors are important for optimum health and productivity. These include good livestock management and animal husbandry. Paramount among these is nutrition. Management and nutrition interact to maintain optimum health (Figure 4.1). The relationship among the host (ruminant animal), the agent (the causal living organism) and the environment demarcates the line between a healthy or diseased animal (Figure 4.2). To illustrate this concept: sub-Saharan Africa harbours the vector (tsetse fly) which transmits trypanosomosis to ruminant animals, a case where the environment determines the occurrence of trypanosomosis. The type of environment may have an adverse effect on the condition of the animal, predisposing it to disease. The climate may favour vegetation that also harbours vectors such as snails which serve as intermediate hosts for *Fasciola gigantica* and *F. hepatica*, the two common liver flukes of sheep and goats.

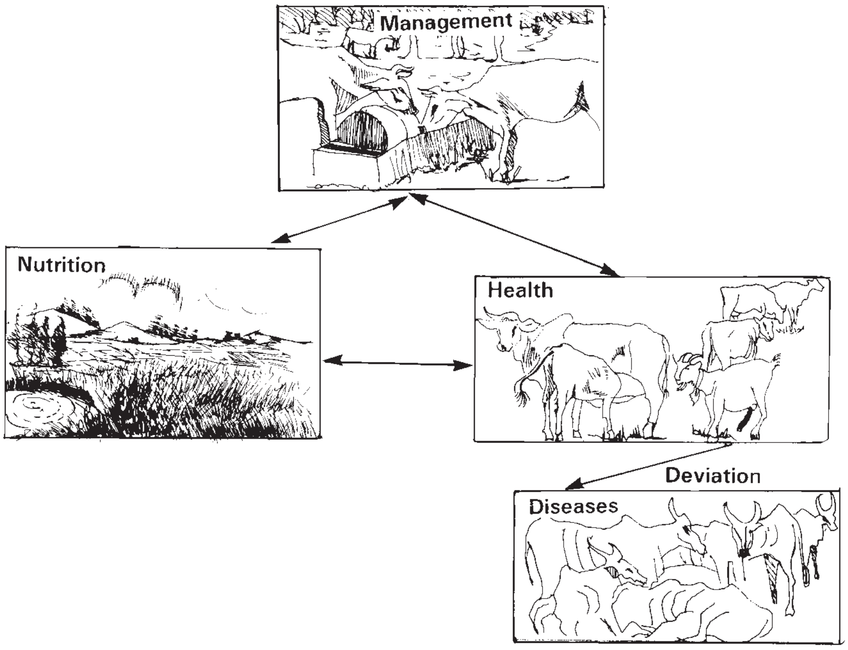

Figure 4.1. *Relationships among factors affecting health.*

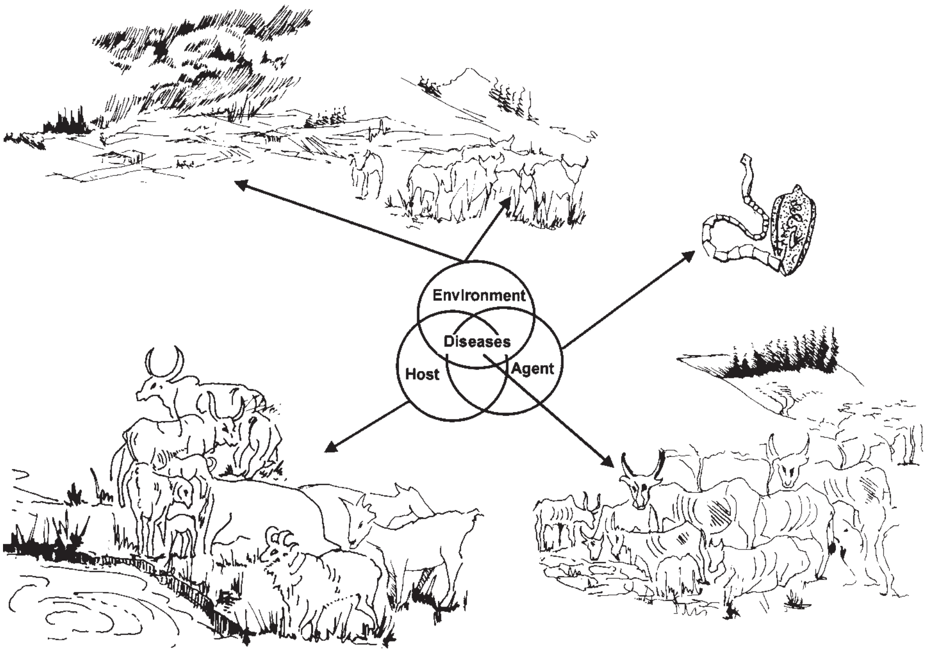

Figure 4.2. *Relationships among host, environment and disease causal agent.*

There are a few terms that need to be defined as they are used frequently both in this manual and in the literature:

- Incubation period: The period from when the invading organism enters the animal's body to when signs of disease are shown.
- Symptoms: Signs or changes in the health of the animal.
- Morbidity: The number of animals in a herd or flock which are affected by disease. The morbidity rate is usually expressed as the percentage of animals that are clinically affected compared with the total number of animals exposed to the same risks.
- Mortality: The number of animals dying from disease. The population mortality rate is the percentage of all exposed animals which die.
- Immunity: The ability of the animal to resist or tolerate the disease. This could be innate immunity (natural resistance) or acquired immunity (exposed or vaccinated).
- Immunisation: Administration of vaccines to protect animals from diseases by imparting artificial immunity.
- Tolerance: A form of resistance acquired through contact with the disease through many generations.
- Susceptibility: The animal is affected by the disease on exposure as it has no tolerance of, immunity or resistance to the disease.
- Diseases are clustered into three groups based on the epidemiological features that take into account the relative importance of the environment, production system and the pathogens (Winrock International 1992) .

4.3.1 Group I: Epidemic diseases

Group I includes highly contagious epidemic diseases that constitute a widespread risk and cause high mortality rates and economic losses (Provost 1991). These diseases:

- are independent of the production system and the environment
- are widely distributed (regional and international)
- cause moderate to severe disruption of production or depressed productivity.

The most important diseases in Group I are: peste des petits ruminants (PPR), foot-and-mouth disease (FMD), contagious caprine pleuropneumonia (CCPP), Rift Valley fever and blue tongue. The main control strategy is immunisation of the animals. If not controlled, Group I diseases lead to high mortality rates. Due to effective immunisation and preventive efforts by national and international agencies, the diseases are being gradually brought under control in East Africa and are almost eradicated in West Africa.

4.3.2 Group II: Parasitic and viral diseases

Group II constitutes the main disease constraints to ruminant productivity in sub-Saharan Africa. They are:

- infectious and largely parasitic diseases
- widely distributed
- strongly influenced by the environment and the production system
- known to depress productivity and cause mortality.

Group II diseases are the parasitic and viral diseases and they are mainly transmitted by vectors. The most important diseases in this group are insect borne (including trypanosomosis), tick-borne diseases, helminthosis, heartwater, brucellosis, contagious agalactia and Q fever. Vaccines to control most of Group II diseases are not readily available. The most common control methods include the use of chemotherapeutic drugs but resistance to these drugs is easily developed. The cost of the drugs and/or irregular availability limit their use by smallholder farmers. Effective and economically sound technologies for controlling these diseases are therefore needed.

4.3.3 Group III: Diseases associated with intensification

Group III includes both infectious and non-infectious diseases that are associated with significant mortalities. These diseases cause serious economic losses through reduced productivity (Provost 1991). They:

- are endemic in nature (that might be viral, bacterial or protozoal), significantly depress animal productivity, but are very often insidious
- become increasingly important as production systems are intensified
- are often associated with poor nutritional status of the animals, genotype, management practices and environmental characteristics
- cause reproductive wastage.

Since sub-Saharan Africa is moving towards intensification of animal agriculture, these diseases will cause great losses and need to be controlled if farmers are expected to adopt intensification-related technologies. The most important diseases in this group include: soil-borne diseases (anthrax), infectious reproductive tract diseases (brucellosis), diarrhea and pneumonia of the newborn, tuberculosis (tbc) and sheep and goat pox. Control measures for these diseases are achieved through management, effective immunisation and proper disposal of animals which die from infections.

4.4 Major diseases of small ruminants in sub-Saharan Africa

This section gives a summary of the major diseases of sheep and goats in sub-Saharan Africa (Tables 4.1, 4.2 and 4.3). For convenience we will group the diseases into three types:

- Respiratory diseases are characterised by symptoms of coughing, running nostrils and poor condition in general. This group includes enzootic pneumonia, pasteurellosis, lungworm infections and CCPP.
- Diseases of the digestive system may be associated with parasites, bacteria and viruses and are very important in Africa.
- Other diseases include those that affect the reproductive system leading to infertility, abortion, still birth or early death of lambs; these diseases are very important in economic terms. Diseases of the skin include external parasite infections and foot-rot. The systemic diseases include PPR, sheep pox, cowdriosis, anthrax, enterotoxaemia and trypanosomosis. There are other diseases of sheep and goats which are related to the nervous system or are caused by lack of essential nutrients. Since these are minor we will not deal with them in this manual.

To achieve maximum productivity in sheep and goats, it is important to prevent and control the diseases mentioned above. We also believe that research resources should be focused on the diseases that cause the most economic losses at the farm level. This module will therefore describe helminthosis in detail because:

- infection is widespread in sub-Saharan Africa
- most of the other diseases have received attention, and preventive measures such as vaccination are available to control them
- helminthosis severely reduces productivity
- little research has been done on this disease with the aim of providing cheap and effective control measures

Table 4.1. *Diseases of sheep and goats of economic importance in sub-Saharan Africa: viral diseases.*

Diseases and causal organisms	Occurrence	Clinical signs	Economic impact	Prevention and treatment
1. Rift valley fever: infectious—non-contagious (for sheep) —Zoonosis				
• characterised by fever, abortion and hepatitis • caused by a virus; cattle and goats and humans are susceptible and frequently attacked • vector-borne disease transmitted by mosquitoes	• all breeds and sexes • seasonal occurrence: moist warm months	• declined feed consumption • fever • death of lambs and ewes • weakness • death within 24 hours • high mortality (95%)	• abortions • protein deficiencies • cost of preventive programmes	• vaccinations
2. Nairobi sheep disease (NSD)				
• acute infectious (non contagious) • characterised by fever, diarrhoea and hoemorrhagic gastro-enteritis • caused by a virus • vector-borne disease transmitted by ticks	• all breeds and sexes • more commonly attacks adult animals than lambs • goats and possibly some wild ruminants are susceptible	• high temperature • diarrhoea • respiration difficult • mucopurulent exudate	• deaths • cost of preventive programmes • threat of spread to new geographic area • protein deficiency	• control of brown ticks • vaccination
3. Peste des petits ruminants (PPR)				
• rinderpest-like disease of small ruminants • caused by a virus	• goats and sheep	• fever, ocular and nasal discharge • coughing and sneezing • oral necrosis • diarrhoea, enteritis and pneumonia	• morbidity and mortality rates higher in goats than in sheep • this results in reduced productivity	• vaccination • quarantine measures • slaughter of infected animals
4. Sheep pox (*Variola ovina*)				
• acute, contagious and often fatal disease • characterised by generalised papules on the skin and plagues on mucous membranes • caused by a virus	• all breeds, sexes and ages of sheep; young more susceptible than adult animals	• fever • dermal eruption • physical depression • loss of appetite • muculae form on eyelids, nostrils, lips, cheeks, perineum, prepuce and udder	• economic losses result from high mortality, reduced meat, milk and wool production	• animal vaccination in endemic areas • proper disposal of dead animals • antibiotics to control bacterial infection of papules
5.Contagious caprine pleuropneumonia (CCPP)				
• caused by *Mycoplasma mycoides ssp caprae/M. m. capr*	• occurs in many African and Near-East countries • only affects goats	• dyspnoea • fever, pneumonia • diarrhoea • high mortality rate	• losses due to high morbidity and mortality	• antibiotics

Table 4.2. *Diseases of sheep and goats of economic importance in sub-Saharan Africa: bacterial diseases.*

Diseases and causal organisms	Occurrence	Clinical signs	Economic impact	Prevention and treatment
1. Enzootic pneumonia (pasteurellosis)				
• acute infectious disease of sheep characterised by pneumonitis and pleuritis • caused by interaction of Chlamydial, mycoplasma, bacteria, viruses and environmental stresses	• all breeds and sexes	• fever • nasal discharge • respiration accelerated, difficult and often accompanied by coughing • morbidity up to 50%	• deaths • reduced live weight • cost of treatment	• avoid excessive crowding • Sulfonamides • antibiotics
2. Anthrax (splenic fever; charbon)				
• acute contagious septicaemia • characterised by splenic swelling and blood, exudations from body openings • caused by a sporing bacterium; soil-borne disease; zoonosis	• all breeds and sexes • more common in adult animals	• fever • loss of appetite • congestion of mucous membranes • sudden death	• deaths • quarantine enforcement • cost of immunisation • treatment practices • dead animal disposal • incapacitation of people affected	• dead animals, bones, skin, bedding—properly disposed of • individual treatment at early stages • Antibiotics • immunisation
3. Black disease (infectious necrotic hepatitis)				
• acute infectious toxemia of sheep • characterised by liver necrosis and sudden death • caused by interaction of bacteria and liver flukes	• black disease develops in sheep one year of age and older • animals in excellent physical condition are most likely to develop the disease	• acute in nature and short course • usually escape detection in the clinical phases • depressions in co-ordination • Fever • morbidity 15% • mortality 100%		• controlling flukes (use of anthelmintics), • proper disposal of dead animals • vaccine against infection from *Clostridium novyi*
4. Brucellosis				
• contagious bacterial disease of cattle, swine, goats, sheep, man • characterised by abortion, genital infections and formation of localised lesions in various body tissues	• all breeds • frequent occurrence associated with close housing and intensive management methods	• primary signs: abortion, although all infected pregnant animals do not necessarily abort • retained placenta • vaginal discharge in females, loss of sexual desire and infertility in male	• economic losses result from abortions, stillborn lambs, early deaths of lambs, cost of prevention programmes	• vaccinations of young stock • sanitary measures • testing of adult animals

Table 4.3. *Diseases of sheep and goats of economic importance in sub-Saharan Africa: parasitic diseases.*

Diseases and causal organisms	Occurrence	Clinical signs	Economic impact	Prevention and treatment
1. Verminous pneumonia (lung worm infections)				
• chronic and prolonged infection of sheep and goats • characterised by bronchitis and broncho pneumonia	• all breeds, sexes and ages • seasonal occurrence (mostly during cold seasons)	• coughing, nasal discharge, rapid breathing • death may result from accompanying bacterial infections	• unthriftiness • retarded growth • reduced production of meat, milk and wool • deaths • cost of prevention and treatment	• pasture management • vaccination • anthelmintics
2. Parasitic gastro-enteritis (PGE)				
• acute or chronic disease of sheep • caused by a wide range of species of gastro-intestinal nematodes	• most breeds, sexes, ages of sheep (evidence for breed resistance) • seasonal occurrence	• anaemia • reduced live weight • Inappetence • sometimes diarrhoea • oedema	• unthriftiness • depressed growth • cost of preventives and control programmes • deaths • reduced milk production	• adequate nutrition • avoidance of overstocking • pasture management • use of anthelmintics • resistant breeds
3. Liver fluke infections (fasciolosis; distomatosis)				
• acute parenchymal hepatitis and chronic cholangitis • characterised by unthriftines, loss of weight, anemia, oedema and eosinophilia • caused by two species of trematodes *Fasciola gigantica* and *F. hepatica*	• most breeds, sexes, ages (some evidence for breed resistance) • occurrence of the disease in goats, cattle camels, wild ruminants	• anaemia • bottle jaw • Inappetence • loss of live weight	• inefficient feed conversion • retarded growth • deaths • condemnation of infected livers • cost of preventive and treatment programmes	• pasture management (avoid swampy areas) • anthelmintics • breeding for resistance
4. Trypanosomosis				
• acute or chronic disease • characterised by remittent fever, anaemia, reduced weight • caused by protozoan parasites	• domestic and game mammals	• peracute, acute and chronic forms • fever, anaemia oedema of limbs, scrotum and eyelids • neurological disturbances • enlargement of peripheral lymph nodes	• reduced productivity	• control of tsetse flies • reduce reservoir hosts in the wild fauna • treatment of infected animals with trypanocidal drugs • resistant breeds

- even though drugs are available on the market to control helminthosis, they are expensive and beyond the reach of the smallholder farmer; in many places the parasites are developing resistance to these drugs.

4.5 Helminthosis

Helminth infections are of economic importance in the tropics. Helminthosis is one of the diseases causing great economic losses worldwide to sheep and goat production (Gatenby 1986). This disease constrains animal production by causing poor growth and impaired fertility.

Helminthoses are infections caused by internal parasites called helminths. These parasites can be divided into two major groups: the Platyhelminthes or flat worms (trematodes and cestodes) and the Nemathelminthes or round worms (nematodes). There is great variation in the prevalence and the geographic distribution of helminth infections in small ruminants in sub-Saharan Africa. Helminths generally spend part of their life cycles outside their definitive hosts (i.e. sheep or goats), either in the ground, on grass or within invertebrates such as snails, insects or earthworms. Temperature, rainfall and the type of soil determine the occurrence of a given parasite species. Therefore, the knowledge of their epidemiology in different agro-climatic zones is essential for successful control strategies. One approach to achieve this aim is to conduct a cross-sectional (vertical) study in which all categories of animals are examined according to age, sex and breed at a particular time to provide the point prevalence. A more appropriate approach is the longitudinal (prospective) study in which groups of animals are monitored over an extended period of time, preferably three years, to take climatic variations into account.

Pathological conditions associated with helminth infections are characterised by loss of appetite, anaemia, infertility or mortality. The identification of parasites present can be carried out either:

- during post-mortem examination of animals for adult and immature morphological characteristics or
- through identification of parasite eggs in faecal samples from live animals (for detailed procedures see Box 4.1).

Assessing the level of infection is done by faecal egg count (FEC) which is an indirect method of quantifying worm burdens in live animals, differential worm counts at necropsy, faecal culture, packed cell volume (PCV) and pasture larval counts.

Helminthosis affects small ruminant productivity and may lead to death of infected animals, especially young ones. The major effects of the disease are slow growth (of infected young animals), weakness and lowered resistance to other diseases.

The largest number of parasites are found in the intestinal tract from where they can absorb food and suck blood from the wall of the intestine. A heavy worm load may block the intestinal tract. Parasites may lead to direct production loss, i.e. death of the animal, or indirect production losses such as:

- impaired growth
- reduced milk, meat and fibre production
- reduced reproduction performance
- reduced work performance
- condemned organs
- high cost of control measures.

The pathogenicity of the diseases depends on the parasite species involved, the number of parasites and their stage of development, and age, sex and the nutritional status of the host animal. General symptoms arising from helminth infections include loss of appetite, digestive disturbances, loss of condition, anaemia, pale mucus membranes, constipation or diarrhoea, coughing and symptoms of bronchitis.

Box 4.1. Helminth parasites of small ruminants: diagnostic procedures

Internal parasites of small ruminants cause severe reductions in the productivity of sheep and goats in sub-Saharan Africa. Economic losses occur due to mortality, low productivity and high costs of anthelmintics. Effective control measures rely on appropriate diagnostic methods and identification of resistant breeds or individual animals. This box gives a brief description of the most commonly used procedures for diagnosing helminth parasites.

A. Parasite identification

At the start of any parasitological investigation it is essential to identify which parasite species are present in an area by conducting initial surveys. If this information is already available, this step can be skipped. Identification to the species level is done through examination (i) post-mortem or (ii) identification of parasite eggs/larvae in faecal samples from live animals.

B. Major measurement techniques

1. *Faecal egg count (FEC)*. To diagnose parasites in sheep and goats, it is essential to recover the parasites, eggs or larvae from the digestive tract or faecal material. Resistance has normally been assessed by faecal egg count which was shown to be a good indicator of worm burdens in the animals (especially lambs and kids); care should be taken as this may not be the case in all species. To identify and quantify the eggs:

- collect faecal samples
- separate eggs from faecal material and concentrate them
- using a microscope, examine and count.

2. *Faecal culture*. Sometimes it is necessary to differentiate parasite species that have similar egg shape. This differentiation is achieved by using faecal cultures which provide a suitable environment for the helminth eggs to hatch into larvae (the infective stage). The same steps used for FEC are used followed by:

- preparation of faecal culture
- isolation and identification of larvae from cultures.

3. *Isolation of larvae from herbage*. This is a procedure for isolating, identifying and counting larvae from samples of grass taken from a grazing area. Many factors, such as warm temperature and adequate moisture, affect the number of larvae in herbage and therefore care should be taken in interpreting data from this procedure.

4. *Packed cell volume (PCV) determination.* An effective way to detect infection by parasites is measuring the faecal egg count. Sometimes disease infection can proceed and show its effect before the eggs appear. One of the early effects of parasite infection is anaemia. The packed cell volume (PCV) technique allows the assessment of anaemia to detect such cases even before eggs appear. In this technique we measure red blood cells in a sample of circulating blood. Since anaemia can be caused by many other agents, it is advisable to do this test as well as the FEC when the eggs appear. The procedure requires sampling blood into a test tube containing a coagulant. The blood sample is centrifuged at 12,000 rpm for 4 minutes. The tube is placed in the reader and the reading is expressed as a percentage of packed red cells in the total volume of whole blood.

For detailed information on procedures read MAFF (1977), Hansen et al (1990) and Bekele et al (1992).

The following section describes in detail the two groups of parasites of sheep and goats mentioned above: Platyhelminthes (trematodes and cestodes) and Nemathelminthes (nematodes).

4.5.1 Trematodes

Fasciola gigantica and *F. hepatica*, the two major liver flukes of sheep and goats, cause a disease referred to as fasciolosis. Both species are found in the cool tropics of the African highlands, particularly in the Ethiopian highlands. Several species of snails serve as their intermediate hosts. The life cycle of the liver fluke is shown in Figure 4.3. The eggs, which are laid by the adult worm in the bile ducts of the livers of infected animals, are passed into the environment through the faeces. When deposited in a wet environment, a miracidium (larva) develops, escapes from the egg and actively swims to seek the right snail species. Upon penetration into the snail intermediate host, the miracidium passes through various stages. The developed larvae (cercariae) leave the snail, attach to the grass and encyst to become metacercariae, the infective stage. Grazing animals eat the encysted cercariae along with the grass for initial infection. Hay or fresh grass cut and carried can transfer metacercariae to confined animals. The duration of the life cycle is 2.5 to 3 months depending on the parasite species.

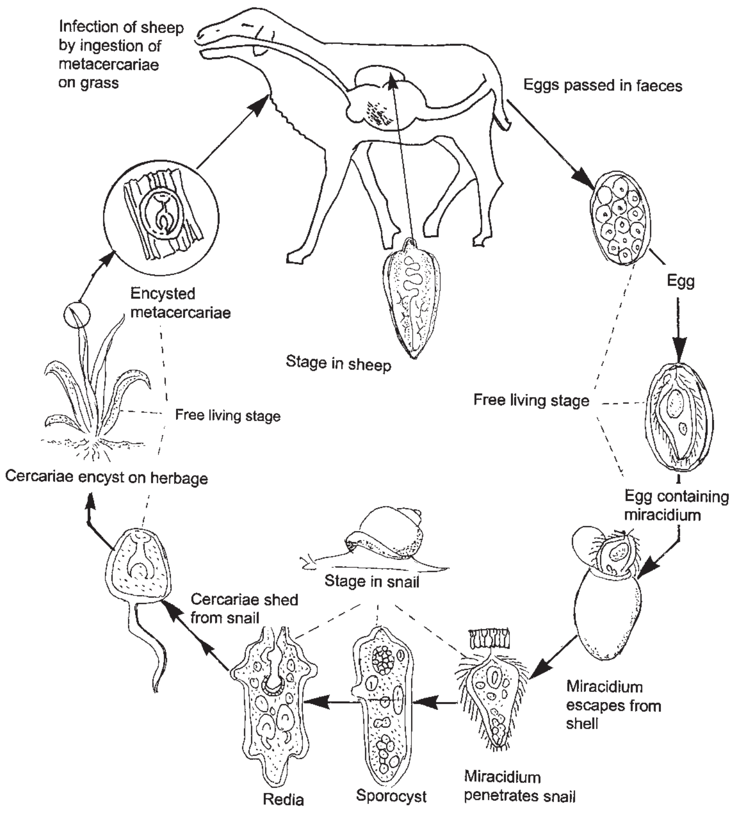

Figure 4.3. *The life cycle of the liver fluke (*Fasciola *spp).*

The symptoms of the disease vary depending on the stage of development of the parasite within the definitive host and the duration of the infection. In sheep, liver flukes cause an acute disease which results in sudden death or a chronic disease (in more resistant breeds) whose symptoms are diarrhoea, anaemia, jaundice and oedema (bottle jaw). In chronic cases, animals lose weight progressively and may ultimately die from the infections. The disease is diagnosed by examining faecal samples, by serological techniques and liver function tests. We look for the parasites in the liver and examine the faeces for the presence of eggs (for further details see Box 4.1). Liver damage, arising from liver fluke infection, causes high mortality.

4.5.2 Nematodes

A number of nematode species can parasitise sheep and goats. The nematodes that infect small ruminants are small thread-like worms (usually 10–30 mm long) localised in the intestine. During development, a nematode moults at intervals shedding its cuticules. In the complete life cycle, there are four moults, the successive larval stages being designated L_1, L_2, L_3, L_4 and finally L_5 which is the immature adult. The life cycle of nematodes with a few exceptions is usually direct with no intermediate host involved (Figure 4.4). The survival, development and transmission of the nematode infective larvae are mostly influenced by climatic conditions (moisture, temperature and rainfall). Susceptibility of the host is determined by many factors: age, breed, physiological status (parturition, depression of immunity), level of immunity (previous exposure) and plane of nutrition. Infection of sheep and goats by round worms is manifested by two major types of symptoms, namely, lack of appetite and anaemia. Young animals are affected more than adults.

Mortality in young animals can reach 25%. The diseases resulting from nematodes can best be diagnosed by recovery of worms at necropsy and by examination of the faeces (Box 4.1).

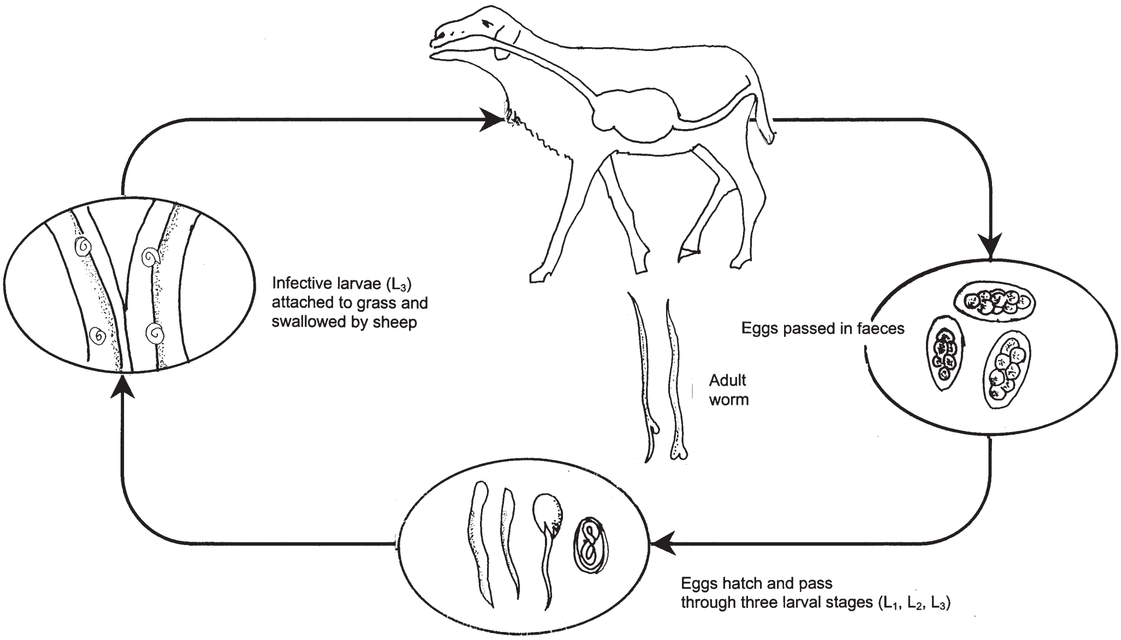

Figure 4.4. *The life cycle of gastro-intestinal nematodes (*Haemonchus, Ostertagia, Trichostrongylus *and* Cooperia*).*

4.5.3 Cestodes (tapeworms)

Tapeworms (cestodes) are long, segmented, flat white worms, a few species of which may infest sheep. They are located in the small intestine of the host. The tapeworms range from 0.5 to 5 m in length and from 2 to 20 mm in width. They shed white rings that can be observed easily in the faeces of infested animals. The rings contain large numbers of eggs.

Sheep may also harbour the larval stage of a tape worm of dogs and jackals (*Taenia multiceps*) (Figure 4.5). Dogs become infected by ingesting raw offal (brain) of dead animals containing the cystic (larval) form of the worm. The cysts develop into adult stages within the definitive host (dogs and jackals). When the segments containing the eggs become ripe, they break off and pass into the environment with faeces. Sheep ingest eggs while grazing, and embryos from the fertile eggs enter the blood stream and are carried to the spinal cord or the brain. Infected sheep develop symptoms of unsteady gait and walking in circles, a condition called circling disease.

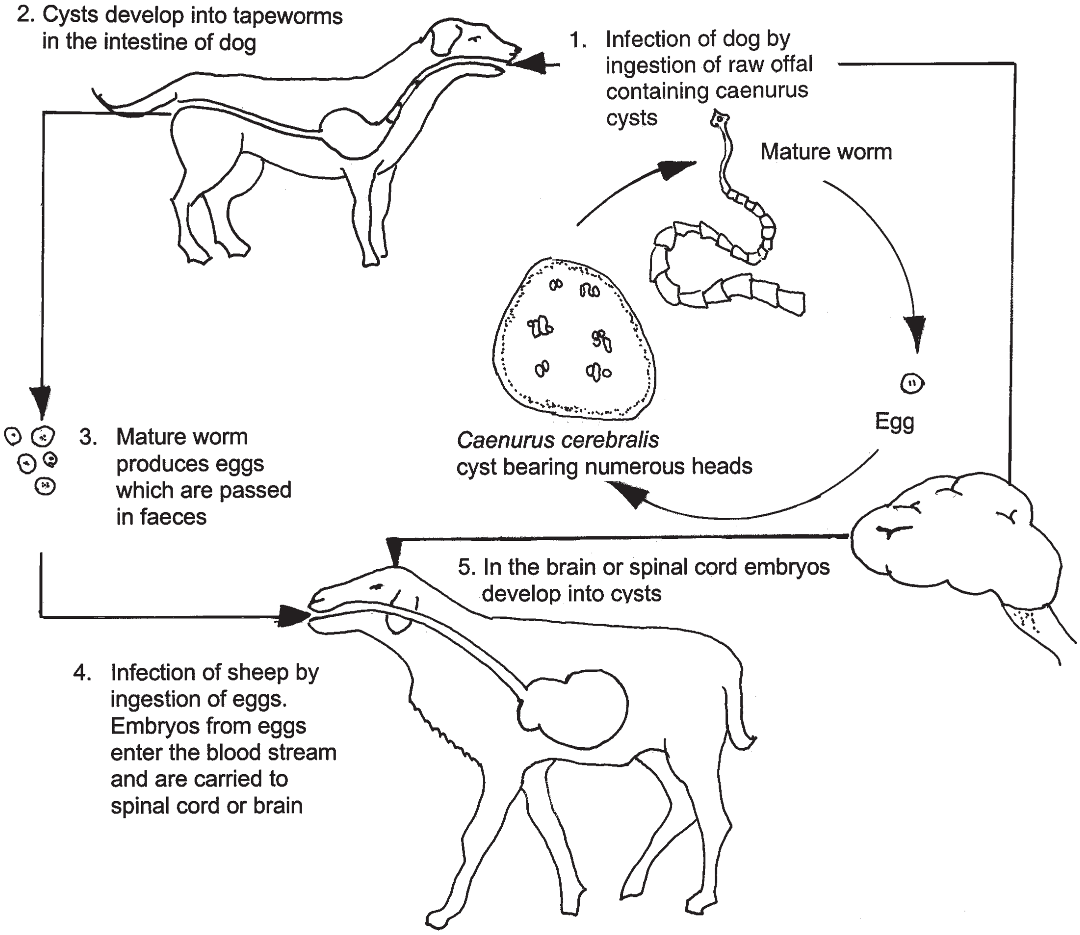

Figure 4.5. *The life cycle of a tapeworm (*Taenia multiceps*).*

4.5.4 Control strategies for helminthosis

Control strategies are usually aimed at keeping infection at a level compatible with production at an acceptable cost (for details of treatment and control strategies see Hansen and Perry 1990). Control is best effected through livestock and pasture management, chemotherapy, immunisation and through a good knowledge of local epidemiology.

- Chemotherapy involves use of modern anthelmintics. Effective drugs are not readily available in many developing countries and their high cost limits their use by smallholder farmers. In addition, most farmers lack information on how to use the medication. The frequent use of anthelmintics leads to parasites developing resistance to the drugs. Smallholder farmers may also use indigenous medicinal plants to treat their sick animals. However, no formal studies have been carried out to assess the effectiveness of these local treatments.
- Pasture management is done through the cut-and-carry technique, proper rotational grazing and avoiding marshlands. This strategy is ideal but is difficult to implement in the traditional production system. However, it is important to develop awareness of grazing management techniques among the farmers.

- Vaccines for controlling internal parasites are still not available for sheep and goats; there are major problems with derived antigen variations. However, there is a commercial vaccine for lung worms in cattle.
- Vector control through environmental management is a feasible strategy, e.g. using molluscicides against snails. The limitations of this strategy are the toxicity of the chemicals against non-target animals and organisms and the high cost to the smallholder farmers.
- Breeding sheep and goats that are resistant to helminths is a long-term strategy. This minimises the risk of parasites becoming resistant to anthelmintics and reduces the cost of intervention. Research at ILRI and its collaborative networks with national agricultural research systems (NARS) is proceeding to achieve this goal. Success has been achieved in both Australia and New Zealand for cattle resistance to ticks and sheep resistance to nematodes.
- Improved nutrition is an important strategy for helminth control. Immunity to gastro-intestinal nematode infections can be enhanced in grazing animals through economical supplementation with protein-rich concentrates.

Improvement in the control of helminth infections in sheep and goats offers opportunity to increase small ruminant productivity in sub-Saharan Africa. Livestock owners will continue to rely on the use of anthelmintics for quite sometime before effective vaccines against helminth infections become available. Therefore, sustainable control measures should combine strategic anthelmintic treatments, based on sound epidemiological data, and other means of control such as pasture management, use of resistant breeds and biological control methods.

Example: Improved nutrition as a strategy for helminth control in small ruminants

Research has demonstrated that improved nutrition can enhance immunity to gastro-intestinal nematode infections in grazing small ruminants. Nutrition can be improved by supplementing the animals with protein-rich concentrates. For example urea and cottonseed cake can be used as concentrates but this supplementation is expensive and beyond the means of many smallholder farmers. To solve this problem, researchers identified low-cost energy and protein supplements that can be added to low quality roughage diets (Shaw et al 1995; Knox and Steel 1996). The use of low-cost supplements such as urea–molasses blocks (UMB) has been proven effective to enhance an animal's ability to utilise the available diet and assist the animal to withstand infection (Anindo et al 1998). At times the parasite infection can be very high. During such emergency situations, medicated UMB can be used for short periods.

4.6 Exercises

1. Cost-effective control programmes for helminth infection in small ruminants should be based on sound epidemiological knowledge of the time relationship between contamination of pastures and seasonal availability of infective larvae in a given geographic area.
   a. List experiments you would conduct and data you would use to verify this hypothesis.
   b. Since the use of anthelmintic drugs is costly, what long-term alternative control measures will you target?
2. Management and the environment interact to maintain optimum health. Using examples from your region, describe the health status of small ruminants in your area in relation to this statement.

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Module 5: Genetic improvement of African small ruminants

5.1 Performance objectives

Module 5 is intended to enable you to:

1. Define concepts of animal genetic resource characterisation and conservation.
2. Identify indigenous breeds of sheep and goats in sub-Saharan Africa.
3. Describe the main features of the important indigenous breeds of sheep and goats in sub-Saharan Africa.
4. Describe methods for characterisation and conservation of small ruminant genetic resources in sub-Saharan Africa.
5. Describe selection methods for small ruminant improvement.
6. Describe cross-breeding methods for improvement of small ruminants in sub-Saharan Africa.

5.2 Introduction to genetic concepts

Small ruminants in sub-Saharan Africa, like all livestock in the continent, evolved to survive in harsh environments at the expense of all other factors (production included). Hence most African breeds under ideal conditions are not as productive as temperate breeds, although under harsh conditions, temperate breeds may be less productive than tropical breeds. The challenge facing scientists in Africa is how to improve production traits of the indigenous breeds without losing their capacity to survive in harsh environments.

Farmers try to improve the productivity of their small ruminants by using the best producers in their flocks for breeding. Characteristics that can be passed on are due to genetic factors, which constitute the genotype; other characteristics cannot be passed on and are due to the environment. The two components (genotype and environment) taken together are termed the phenotype. The main difficulty is to separate these two components once the phenotype value of the character (performance) is measured.

5.3 Characterisation and conservation

Most sheep and goats in Africa are of the indigenous types. There are many types and numerous breeds in sub-Saharan Africa (Table 5.1). Detailed information about other breeds can be found in: Devendra and Burns (1983), Gatenby (1986) and Peacock (1996). Sheep breeds indigenous to sub-Saharan Africa can be categorised into (i) thin-tailed (ii) fat-tailed and (iii) fat-rumped. Thin-tailed breeds are most common in the dry tropics, e.g. the African long-legged type which is predominant in the Sahara. This type is usually large (Figure 5.1) and well adapted to a migratory existence. Examples include: West African Long-legged, the Dongola, Northern Sudanese and Zaghawa. In West Africa the thin-tailed sheep, found in the humid areas, are smaller than their dry tropic counterparts and often referred to as the dwarf or forest sheep (Figure 5.2). Fat-tailed sheep are predominant in eastern Africa. Breeds of this type are: Abyssinian, East African Blackheaded and Maasai. Fat-rumped types predominate in north-east Africa but are also found in South Africa and other countries of the southern region (Figure 5.3). In South Africa wool breeds were imported from Europe to the temperate environments in the country, e.g. South African Merino. Breeds for harsher environments were developed from African hair sheep, e.g. the Blackhead Persian. Cross-breeding between wool and hair sheep was done in South Africa, e.g. Dorper.

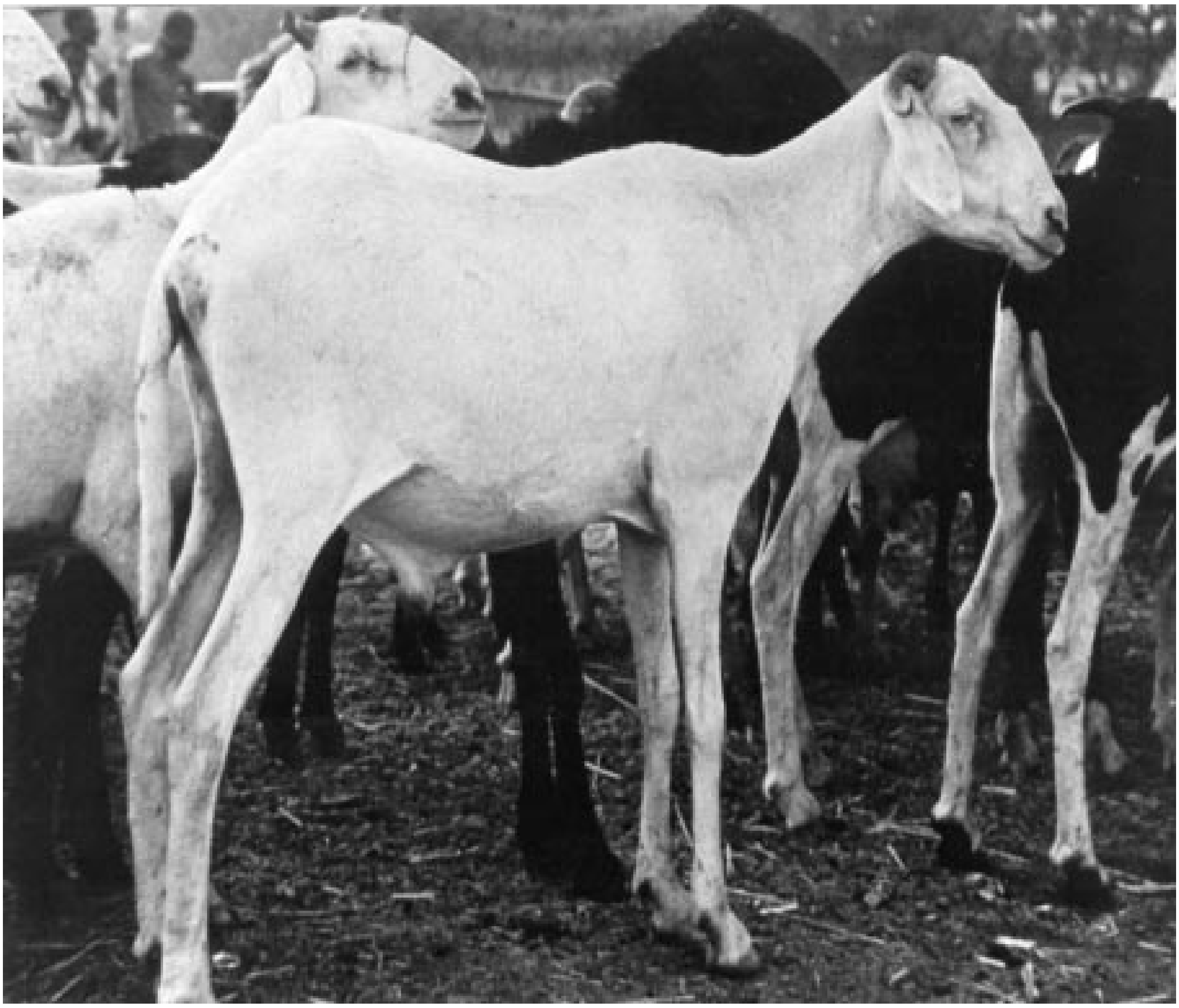


Figure 5.1. *A thin-tailed sheep.*

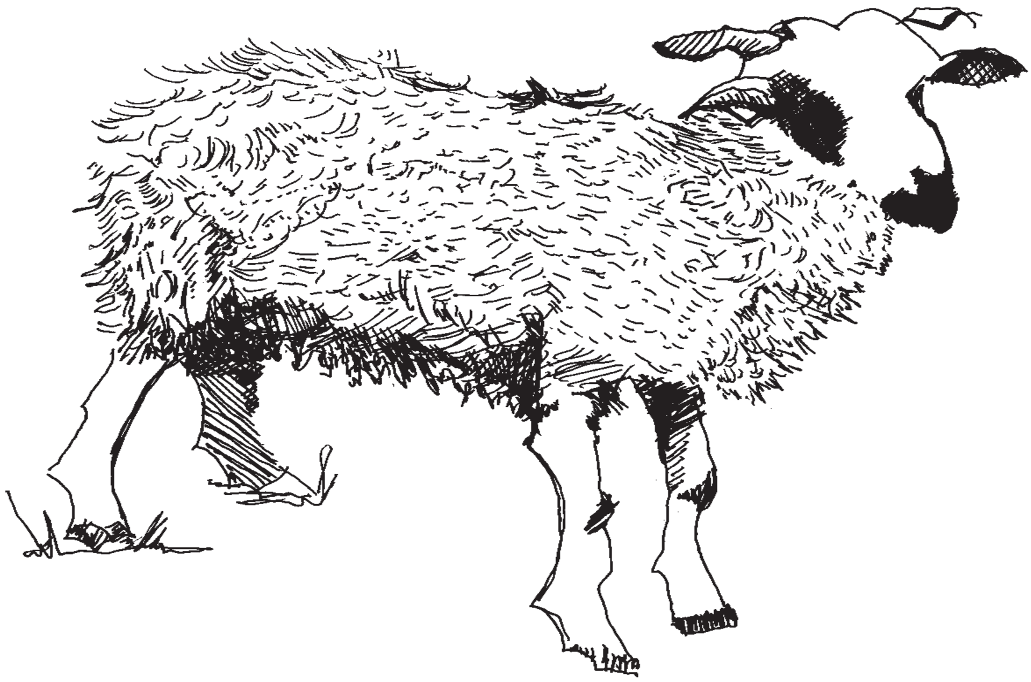


Figure 5.2. *A West African Dwarf ram.*

Figure 5.3. *A fat-rumped Blackhead Persian sheep.*

Table 5.1. *Selected examples of breeds of sheep and goats in sub-Saharan Africa.*

Name of breed	Location	Characteristics	Use
Sheep			
African Long-fat-tailed	Tanzania, South Africa, Malawi, Zimbabwe, Madagascar	Tail usually long, fat and broad with hanging tip, twisted, cylindrical, strap-shaped, funnel-shaped or carrot-shaped	Meat and hair
Blackhead Persian	South Africa	White with black head and neck, polled, fat-rumped	Hair and meat
Fulani	Senegal to Cameroon	West African long-legged type, white, pied or coloured	Meat
Menz	Ethiopia	Black or dark brown with white on head, neck and legs, weight 20–30 kg female, male usually horned, female usually polled, fat-tailed with woolly undercoat	Meat and coarse wool
West African Dwarf	Southern West Africa	White, usually with red or black spots, occasionally black hair, male with mane, weight 30 kg male, females 20 kg, male horned, female polled	Meat
Goats			
Afar	Eritrea, Ethiopia	Leggy, curved horns	Milk and meat
Sudanese Desert	Sudan	Both sexes are horned but those of males are longer twisted horns, long-legged, coat usually grey	Meat and skins
West African Dwarf	West and central Africa	Short legs, small, weighing about 20 kg and are about 50 cm in height	Meat
Boer	South Africa	Colour is white, medium size, ears long, broad and droopy	Meat, milk and skins
Small East African	Kenya, Uganda, Tanzania	Small light horns and ears, colour variable, small, adult weight around 30 kg	Meat and skins

Indigenous goats fall into two main groups: (i) long-eared and (ii) short-eared. Goats are also classified as (i) large (ii) intermediate and (iii) dwarf types (Figure 5.4). Large types, which usually have long legs, are found at the edge of the Sahara and in southern Africa. The intermediate types are mainly found in east and north-central Africa. The dwarf types are mainly found in humid West Africa.

Figure 5.4. *West African Dwarf goats.*

Exotic breeds of small ruminants were introduced mainly by South Africa for commercial purposes. There are large populations of Merino sheep (Kenya, Lesotho, Zimbabwe), Karakul sheep (Angola, Botswana, Namibia, Rwanda) and Angora goats (Lesotho, Madagascar). Other countries have exotic breeds but of smaller populations.

There is pressure from exotic breeds on indigenous sheep and goats through indiscriminate cross-breeding and upgrading. Since these indigenous breeds have evolved under a stressful environment (poor nutrition, high temperatures and high incidence of disease), they are well adapted and it is important to characterise and conserve their genetic resources. Under experiment station conditions, the indigenous African goats and sheep breeds showed good growth and reproduction performance, indicating their potential. Thus improvements in management can give responses of better productivity. However, indigenous breeds are not distinct from one another and few characterisation studies have been carried out.

Some 40 years ago, governments and non-government organisations discussed and published documents on conservation of animal genetic resources. Many conferences, seminars, symposiums and other meetings were held to raise the awareness of the public about the conservation issue. The Food and Agriculture Organization of the United Nations (FAO) played an important role through cataloguing, maintaining and using of animal genetic resources (AGR) at the very beginning of its activities. This effort was targeted towards policy makers. The United Nations Conference on Environment and Development (UNCED), which was held during 1992 in Rio de Janeiro, Brazil, gave due attention to the issue of biodiversity. ILRI, formerly ILCA (International Livestock Centre for Africa), started activities on conservation and characterisation of livestock during 1977. These activities led to the creation of a network that dealt with trypanotolerant animals in Africa. Other organisations dealing with biodiversity in animals in Africa included the Organization of African Unity (OAU) and CIRAD–EMVT (Centre de coopération internationale en recherche agronomique pour le développement–Département d'élevage et de médecine vétérinaire des pays tropicaux, France); CIRAD–EMVT focused its activities in francophone Africa.

The first step to conservation is to learn which breeds or populations to conserve. It is therefore necessary to define the current situation through characterisation and evaluation of breeds or populations before embarking on any programme of conservation. The concepts of conservation and characterisation are defined in Box 5.1.

Box 5.1. Conservation and characterisation: Definition of major concepts

Animal genetic resources

Genetically unique breed populations, formed throughout the domestication process, within each animal species used for the production of food and agriculture together with their immediate wild relatives.

Domestic animal diversity

Genetic variation or genetic diversity existing among the species, breeds and individuals, for all animal species that have been domesticated, and their immediate relatives, to meet human needs for food and agriculture.

Conservation

Conservation embraces preservation, maintenance, sustainable utilisation, restoration and enhancement of the natural environment to meet immediate and short-term requirements for food and agriculture and this diversity remains available for future use. It can be in the:

- *Narrow sense:* preservation—storing of genetic resources that are not currently popular among farmers for possible use in the future.
- *Broad sense:* all operations involved in the management of genetic resources, such as inventory, monitoring and characterisation of genetic resources, the development and better use of the adapted indigenous genetic material, the maintenance of unique resources to help meet future requirements and the establishment of better access to a wider variety of these resources particularly for research and development.

In situ *conservation.* Active breeding of animal populations for food and agriculture, such that the diversity is used both in the short term and maintained for the longer term. Operations pertaining to *in situ* conservation include performance recording schemes, development (breeding) programmes and ecosystem management and use for sustainable production for food and agriculture. *In situ* conservation of wild relatives is generally called *in situ* preservation. Live populations are maintained in their adaptive environment or as close to it as practically possible.

Ex situ *conservation. Ex situ* conservation involves collection and cryopreservation of samples of breeds in the form of live semen, ova or embryos, which can be used to generate animals. DNA techniques do not constitute *ex situ* conservation.

Characterisation. Characterisation is the enumeration and description of:

- genetic identity of an animal species, breed, strain or population
- the environment to which such species, breed, strain or population is adapted, partially adapted or not adapted.

This involves the distillation of all available knowledge (published or unpublished) which contributes to the reliable prediction of genetic performance in defined environments.

Monitoring of genetic diversity. Monitoring of genetic diversity involves surveys and registration of all available breeds, populations or groups of interbreeding animals. Information collected includes whether a breed is going to be endangered, be a candidate for conservation and whether conservation should be performed as a concerted effort of several countries with the same breeds.

Breed. Population with similar genetic traits common to the group.

Landrace. Population that has lived sufficiently long locally to adapt to the various conditions of the locality.

5.3.1 Rationale for characterisation and conservation

Why characterise? The main reasons behind characterisation of animal genetic resources are:

- threat to the indigenous livestock
- a number of different breeds are named after their location, ethnic group or by physical characteristics and may not necessarily be genetically different
- most censuses in developing countries are done by species which does not give an accurate picture of the population trend of individual breeds over time in order to determine populations at risk of extinction
- little knowledge is available about existing breeds to understand:
  - unique qualities of the breed, e.g. particular adaptation to the local environment
  - the potential contribution to productivity if treated as improved breeds
  - the potential to make the greatest variety for future contribution and determine special genes that could be useful in the future
  - the genetic variability (within and between breeds) for future needs.

There is a threat to livestock populations and some breeds may be approaching extinction. Factors that lead to extinction are:

- demand for higher animal production due to growing human population, improved standards of living and urbanisation
- natural disasters (drought, famine, disease outbreaks, flooding, earthquakes etc) which decimate flocks
- socio-political instability
- negligence (low commercial value, ignorance)
- loss of genetic variability through:
  - use of a limited number of species and a few specialised breeds within species (since the production of improved breeds is high, less productive animals are displaced)
  - intensive selection for important traits facilitated by artificial insemination (AI), i.e. small number of males are being used for reproduction
  - upgrading of native breeds with superior breeds, including exotics.

The actions listed above lead to genetic erosion which is accentuated by international trade and ease of transportation throughout the world. As part of the global biological diversity, there is an urgent need to conserve and preserve African animal genetic resources in order to meet the needs of future generations.

Most developing countries, particularly in Africa, lack activities relating to animal genetic resources. Most conservation activities in Africa have been directed towards plant genetic resources and wild life. Many meetings have been held to discuss biodiversity, but small ruminants have never been considered. Little information exists on African Small Ruminant Genetic Resources (SRGR) in the FAO data bank (Table 5.2). This is due to lack of suitable data recording facilities in most African countries. Table 5.3 shows the status of small ruminant genetic resources in Africa. At present five breeds of sheepare already extinct, one breed of goat and three breeds of sheep are endangered and 10 breeds of sheep are decreasing in number (Box 5.2).

Table 5.2. *Information on African small ruminant genetic resources in the FAO data bank.*

Species	Number of references		
	Number of breeds	Population information	Production information
Sheep	133	47	46
Goats	59	19	21
Cattle	175	84	51
All*	434	179	120

* Buffalo, cattle, goats, sheep, pigs and horses.

Table 5.3. *Status of African small ruminant genetic resources.*

Breed status	Species	Country
Extinct	Hottentot sheep	South Africa
	Steekhaar (variety of Ronderib Africander)	South Africa
	Walrich Mutton Merino	South Africa
	Wooled Persian sheep	South Africa
	Permer sheep	Nigeria
Critical or endangered	Pafuri goat	Mozambique
	Bezuidenhout Africander	South Africa
	Namaqua Africander sheep	Namibia, South Africa
	Nungua Blackhead sheep	Ghana
Decreasing in number	Black Maure sheep	Mauritania, Mali,
	Macina sheep	Senegal, Mali,
	Variety Koundoum	Niger
	Dongolla sheep, Murle, Dinka, Nuba Mountain	Sudan
	Touareg sheep	Mali, Niger, Chad
	Ronderib Africander sheep	South Africa

5.3.2 Characterisation and conservation methodology

The first step to conservation is to know which breed to conserve. Characterisation consists of collecting information on available stocks and the environment in which the stocks are performing. Basic information includes:

- preliminary characteristics such as type/breed/variety; predominant location and climatic conditions; utility, management and production systems; physical and special genetic characteristics; production traits; and population status
- DNA information about genetic distinctiveness, and genes responsible for valuable traits.

Ex situ conservation is done through cryopreservation of animal germplasm by storing sperm, oocytes and embryos. For this technique to be effective, progeny of at least 25 sires should be stored. The facilities in Africa for this technique are not well developed. The germplasm can be collected in Africa and stored in countries where facilities are available.

In situ conservation is the preservation, multiplication and utilisation of indigenous breeds in their native habitats and maintenance of pure breeds or strains. The minimum number recommended for sheep is 60 ewes and the maximum is 1500 ewes. Special conservation flocks can be established as part of the cultural heritage for the endangered breeds or breeds in critical status. Nucleus breeding flocks can be established in co-operative breeding programmes to supply breeding stocks to farmers. This conservation method requires long-term funding and therefore it is practical in Africa if donor funding is secured. *In situ* conservation requires good management of the conserved flock. Appropriate breeding programmes should be designed and properly implemented. These programmes should:

Box 5.2. Criteria to determine breeds at risk

Breeds are classified into one of the seven categories defined by the Food and Agriculture Organization of the United Nations (FAO) United Nations Environmental Programme (UNEP) as follows:

1. **Extinct**

It is no longer possible to recreate the breed population. This situation becomes absolute when there are no breeding males (or semen), breeding females (oocyte) or embryos remaining**.**

2. **Critical**

The total number of breeding females is less than 100 or the total number of breeding males is less or equal to 5.

or

The overall population size is slightly above 100 but decreasing and the percentage of females being bred pure is below 80%.

3. **Endangered**

The total number of breeding females is between 100 and 1000 or the total number of breeding males is greater than 5 but less than or equal to 20.

or

The overall population size is slightly below 100 and increasing and the percentage of females being bred pure is above 80%.

or

The overall population size is slightly above 1000 and decreasing and the percentage of females being bred pure is below 80%.

4/5. **Critical-maintained/Endangered-maintained**

This is the situation when active conservation programmes are in place or populations are maintained by commercial companies or research institutes.

6. **Not at risk**

The total number of breeding females and males are greater than 1000 and 20, respectively.

or

The overall population size approaches 1000 and is increasing and the percentage of females being bred pure is close to 100%.

7. **Unknown**

Information on population figure is unknown.

- balance breeding objectives for all important traits and allow economic weights on each of them to reflect the local or national situation
- prevent deterioration of fitness or adaptive and functional traits
- optimise selection strategies with respect to the long-term effects of inbreeding and genetic variance

- harmonise local or national breeding goals with sustainable agriculture, i.e. integration of crop–livestock production
- utilise genes from the world gene pool that are not in conflict with the breeding goals.

Genetic markers and breed identification as tools in conservation

A genetic marker for a trait is a DNA segment which always exhibits the same characteristics when present in a genotype. Genetic markers serve several uses in conservation of genetic resources but are not a method. Three major uses include:

- Validation of pedigree through the verification of parentage: A correct pedigree is important for developing breeding strategies that minimise inbreeding.
- Estimation of the level of genetic diversity: Analyses of genetic marker variation allows you to objectively measure the genetic variation within the breed.
- Identification of the breed: Gene markers are used to determine whether an individual is a member of a particular breed or to compare breeds by calculating genetic similarity or genetic distance. This exercise allows the estimation of the distinctiveness of a particular breed in relation to the other breeds of the same species.

The most common types of DNA markers are: RFLP (Restriction Fragment Length Polymorphism), VNTR (Variable Number of Tandem Repeats), microsatellites, RAPDs (Randomly Amplified Polymorphic DNAs) and PCR (Polymerase Chain Reaction).

The choice of conservation method depends on the safety offered and the cost involved. There are advantages and disadvantages to using *in situ* over *ex situ* conservation methods. The advantages are:

- *In situ* conservation allows the evaluation, identification of animals with unique characters and their utilisation in genetic improvement programmes.
- *In situ* conservation allows animals to adapt to changes over time to physical environment and diseases.
- Methods for freezing semen or oocyte and techniques for embryo preservation are not available for all species.
- Live animal conservation can serve an aesthetic and cultural need.
- *In situ* conservation can generate funds through sales of live animals. Revenue for local communities can be raised by charging a fee to tourists who want to see the conserved animals.

The disadvantages are:

- Live animal conservation is costly in terms of facilities and supervision.
- *In situ* conservation is subject to inbreeding and random genetic drift due to the small size of conserved animals.
- *In situ* conservation is subject to natural and artificial selection.
- Live animal conservation is subject to natural calamities such as drought, floods and disease epidemics.

Breeds to be given priority in conservation programmes should be selected based on their comparative advantage obtained through objective evaluation. Priority should be given to:

- breeds that have reached critical or endangered status
- genetically diverse stocks
- stocks with unique characters
- stocks with high overall economic merit.

In the majority of African countries, opportunities to raise productivity through the use of temperate breeds are minimal because these exotic breeds need an improved production environment, a costly exercise. Therefore there is need to improve the indigenous types to raise their production potential.

5.4 Genotype × environment interaction

The genotype × environment interaction is defined as the change in the relative production performance of two or more genotypes measured in two or more environments (Gatenby 1986). It may involve changes in rank order of the genotypes in different environments and/or changes in the magnitude of the phenotypic, genetic or environmental variances. It may not be true to assume that parents selected based on their superiority in one environment will still be superior in any other environment. It is therefore advantageous to design selection programmes with local populations because:

- there will be ample time for concurrent improvement in management, disease control and feeding
- losses to adaptation in local environments are minimal
- management is much easier.

5.5 Utilisation of biodiversity

Genetic variation is the raw material for animal improvement and a means to overcome selection limits. Animal breeding aims to create genetic changes in the population. The classical techniques for genetic improvement are:

- selection (which animals to keep as parents)
- cross-breeding (which breed combination).

The heritability value is the main criterion for choosing between selection and cross-breeding but in many cases the two choices are combined.

5.5.1 Selection

Selection is the process in which the best animals are chosen to be parents of the next generation. The frequency of genes resulting in animals with favoured phenotypes is increased. The aim of selection is to achieve improvement in quantitative and measurable performance traits of economic value. Examples of traits that are most often used as a basis for selection are given in Table 5.4.

Selection can be either direct or indirect. The higher the heritability, the greater is the rate of improvement by selection. The heritability can be classified as high (h^2>0.50), medium (0.25<h^2<0.50) or low (h^2<0.25).

Table 5.4. *Traits used as a basis for selection in small ruminants.*

Productivity factors	Traits
Reproduction	Age at first lambing Fertility Lambing Lambs raised to weaning
Growth	Birth weight Weaning weight Adult weight Feed conversion efficiency
Stress	Resistance to diseases
Milk yield	Milk yield Fat content Protein content Lactation length

The response to selection (R) is the difference between the mean phenotypic value of the offspring of the selected parents and the phenotypic value (before selection) of the population from which the parents were selected. R depends on the superiority of the selected animals in relation to the mean of the population from which they come, the extent to which the superiority is inherited (h^2) and the interval between generations (L). It is estimated as:

$$R = h^2.S$$

The selection differential (S) is the mean phenotypic value of the individuals selected as parents expressed as deviation from the population mean.

The annual genetic progress (ΔG) obtained through selection is expressed as:

$$\Delta G = (h^2.S)/L$$

where h^2 is heritability, S is the selection differential and L is the generation interval.

The selection differential, S, is expressed in units of the phenotypic standard deviation (σ_P) to standardise its value:

$$\Delta G/\sigma_P = (h^2.S)/(L.\sigma_P)$$

Selection methods

Different methods are used to combine traits in a selection programme.

Tandem selection. Priority is given to one trait at a time. When the selection goal for that trait is achieved, another trait is considered. Progress with this method depends on the genetic correlation between traits. It is the least efficient method.

Independent culling. A minimum level is set for each trait. Potential animals must meet all the levels. There is no compensation for poor performance.

5.5.2 Cross-breeding

Cross-breeding aims at (i) combining all desirable characteristics of two or more breeds in one progeny type and (ii) exploiting the hybrid vigour or heterosis.

Heterosis is attained when the average performance of the crossbred offspring is better than the average performance of the parents. Heterosis is due to dominance or overdominance. Cross-breeding increases the number of heterozygous gene pairs. The greater the genetic difference between the parental populations, the greater are the heterozygosity and the heterosis expected. Heterosis depends on the genetic diversion. There is a reciprocal relationship between heterosis and heritability. Traits that demonstrate the most hybrid vigour are those that have the lowest heritability, e.g. fitness and reproductive traits. Expression of heterosis is environment-dependent and greater heterosis is shown in stressful environments.

Cross-breeding is useful in the creation of new breeds. The desirable qualities in crossbred foundation stocks are combined to form new synthetic breeds or strains. Cross-breeding is useful in upgrading stocks. With continuous back-crossing with males (or females) of the desired breed, the proportion of genes from the original population decreases with each generation to half the one present in the previous generation. After five generations, there is little difference between the genotypes of the upgraded animals and animals of the desired breed. The original population can be changed completely. Cross-breeding also results in the production of crossbred animals for slaughter. Sires of one breed are mated to females of another breed to produce superior commercial progeny, not used for breeding. For example, a prolific sire breed is mated with hardy local ewes to produce fat lambs. Examples of breeds developed from cross-breeding are shown in Table 5.5.

Cross-breeding has its drawbacks:

- it requires more management than pure breeding
- in order for it to continue, pure breeds should be maintained.

Table 5.5. *Examples of goat and sheep breeds developed through cross-breeding in sub-Saharan Africa.*

Breed	Location
Goats	
Vogan (Djallonké × Sahelian)	Togo
Boer {(Africander, South African common) × (indigenous Bantus, European, Angora, Indian Blood)}	South Africa, Rwanda, Kenya, Lesotho, Swaziland, Zimbabwe, Burundi
Pafuri (Boer × Landim)	Mozambique, Namibia
Long-legged Hair Sheep	
Toronké (Sambourou × Maure)	Mali
Vogan (Oudah × Djallonké)	Togo
Varalé (Toubire × Peul-Peul)	Senegal
Ingessana (Sudan Desert × Nilotic)	Sudan
Meidob (Zaghawa × Sudan Desert)	Sudan
Fat-rump Hair Sheep	
Nungua Blackhead (Blackhead Persian × Djallonké)	Ghana
Wiltiper (Wiltshire Persian) × (Wiltshire Horn × Blackhead Persian)	Zimbabwe
Van Rooy {Van Rooy White Persian} × {Blackhead) Persian × [Rambouilet × Ronderib Africander]}	South Africa
Coarse Wool Sheep	
Okuma (Dorper × Kirdi)	Gabon
Permer (Blackhead Persian × German mutton Merino)	Nigeria
Bezuidenhout Africander {Wooled Persian} {Africander × [Wooled Persian × Blackhead Persian]}	South Africa
Dorper {Dorset Horn × Blackhead Persian} White Dorper [Dorsian, Dorsie]}	South Africa
Vandor (Dorset Horn × Van Rooy)	South Africa
White Wooled Mountain {German mutton Merinox (Dorset Horn × Blackhead Persian)}	
Fine Wool Sheep	
Afrino {South Africa Mutton Merino × [Ronderib Africander x South Africa Merino]}	South Africa South Africa
Döhne Merino (German Mutton Merino × South Africa Merino)	South Africa
Dormer {Dorman [Dorset Horn × German Mutton Merino	South Africa
Letelle Merino (Derived from Ramboillet)	
Walrich Mutton Merino (Précoce × South African Merino)	South Africa

Crossing can be done in any one of the following ways (see Figure 5.5):

Single two-way cross. Pure bred females (or males) of one breed are mated with pure-bred males (or females) of a second breed to produce the first filial generation F_1.

Three-way cross. Males (or females) of a third breed are mated with females (or males) of the single two-way cross. Three-way crosses can lead to superior traits because they utilise hybrid vigour.

Four-way cross. Populations A and B are first crossed with each other and so are D and C. The resultant F_1 generations of the first two crosses are then crossed to produce the final four-way cross.

Two-way rotational cross. Males (or females) of each of the two breeds are crossed alternately.

Three-way rotational cross. Males (or females) of each of the three breeds are crossed alternately.

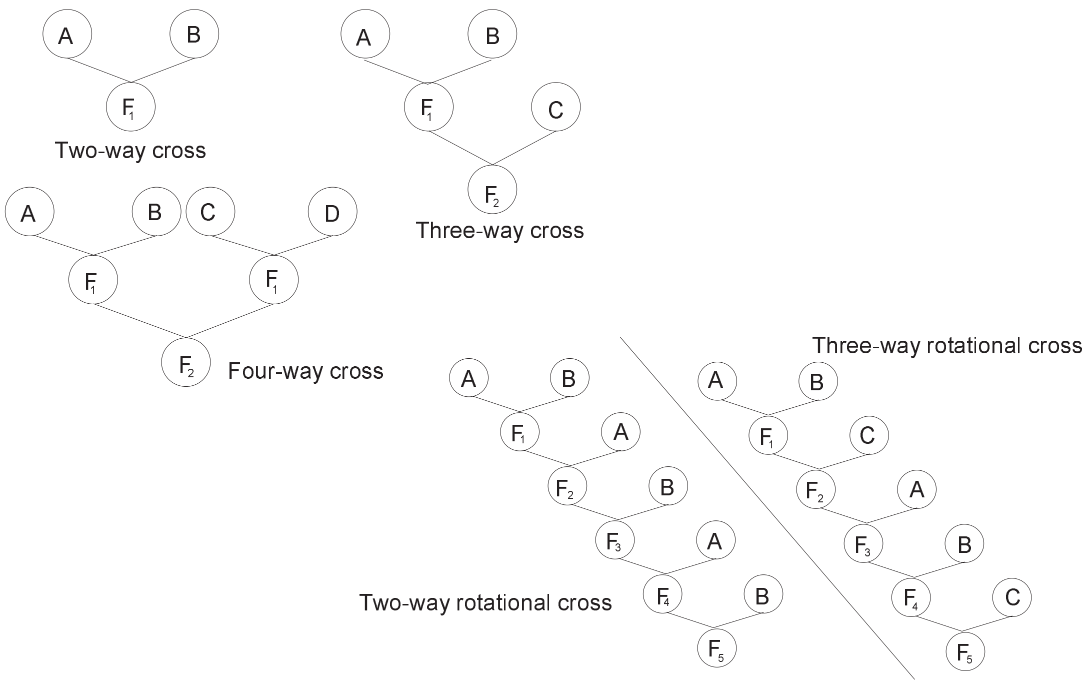


Figure 5.5. *Crossing types.*

5.5.3 Inbreeding

Inbreeding results from mating related individuals, i.e. individuals with common ancestors. This usually happens when the size of the population decreases. Selection tends to increase inbreeding because it reduces population by restricting reproduction to a few animals.

The consequences of inbreeding are:

- decrease in growth rate, disease resistance, reproductive performance and viability
- increase in the proportion of homozygotes, therefore decrease in the proportion of heterozygotes and increased frequency of undesirable traits due to recessive genes.

Increase in population size and careful monitoring of mating programmes help to avoid inbreeding or reduce its level to a minimum.

5.6 Introduction to improvement

Genetic improvement requires an accurate and continuous recording system. Selection is associated with recording the performance of individual animals. Accurate records are needed to identify the best and poorest performing animals on-farm; at the national or regional levels records of the population are needed. Performance recording is also an aid for making management decisions. It is difficult to keep records for small ruminants in most African countries, especially for those raised by smallholders under range management conditions. This is due to the vast distances that need to be covered by the record keepers, the constant movement of the animals and the reluctance of the smallholders to provide accurate information so as to avoid taxation.

5.6.1 Nucleus breeding schemes

Small ruminants in Africa are fed extensively on rangeland or on agricultural by-products in dry areas. In the humid and subhumid zones of Africa, small ruminants are kept in small numbers by smallholders. It is almost impossible to conduct within-flock selection under such conditions. An alternative is to establish a nucleus flock in a group breeding programme.

A nucleus breeding programme is a centralised improvement programme in which very superior animals are brought together from supply farms to form an elite nucleus flock. Farmers have to agree to put together their superior animals. The nucleus or base may remain open to the best animals from the supply flocks. This system is therefore called the open nucleus breeding scheme.

Once the nucleus is established, an efficient recording and selection programme can be implemented. With the actual production environment in Africa, this system seems much easier to realise than conventional breed improvement programmes. Institutional or government flocks can serve as the nucleus and then be linked with private and small farmers.

The nucleus breeding scheme is much used in Australia and New Zealand where it is referred to as a co-operative breeding scheme. An open nucleus breeding scheme has been used in Côte d'Ivoire since 1984 to improve growth of the indigenous Djallonké sheep (Figure 5.6). An optimum nucleus breeding programme for sheep must have a minimum of 300 breeding females and be able to distribute 70 to 110 rams annually to participating farmers (Figure 5.7). By rotating rams among farmers, inbreeding can be avoided. The modelling of an open nucleus breeding programme has shown that the rate of genetic gain may be increased by 10–15%.

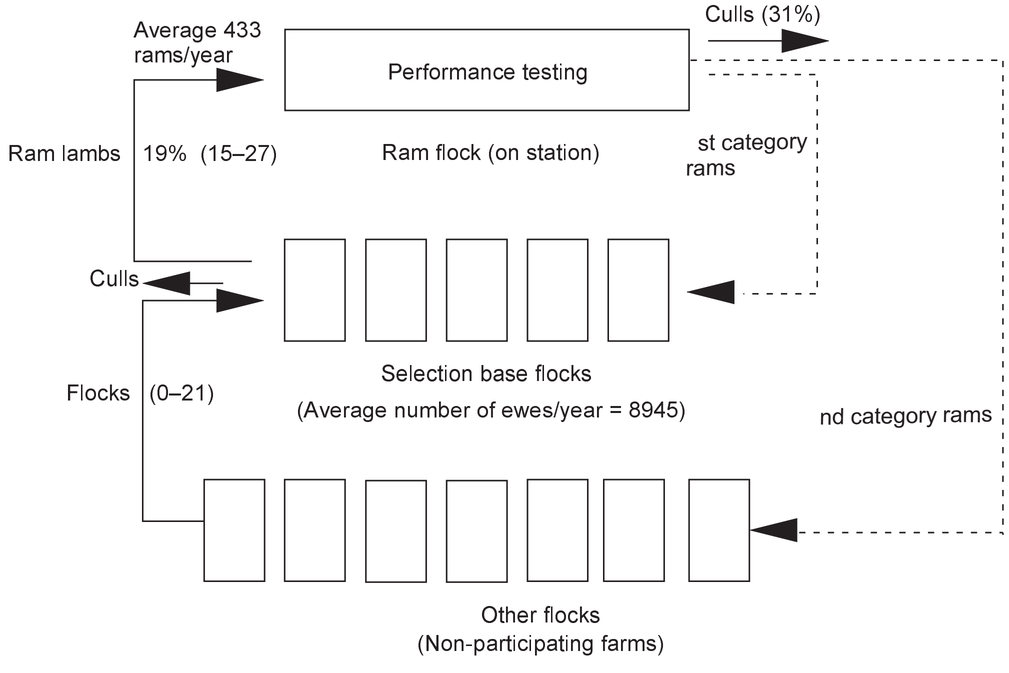


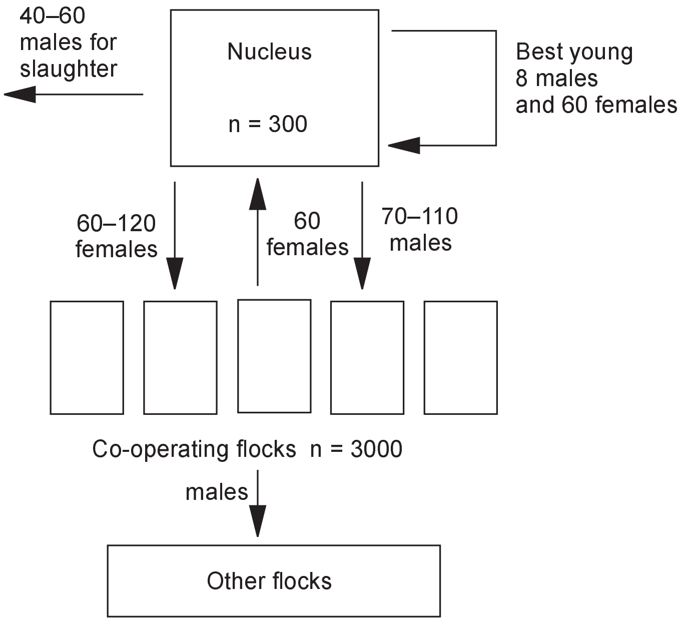
Figure 5.6. *Outline of the structure of an open nucleus breeding scheme in Côte d'Ivoire.*

The advantages of open nucleus schemes can be summarised as follows:

- animals entering the nucleus are tested under farm conditions
- selection is based on records for traits of economic value
- the improvements are quickly spread as farmers participating in the schemes receive their replacement sires from the nucleus

- a rapid generation turnover can be maintained
- inbreeding is avoided
- objectives are maintained for many years
- small farmers benefit from co-ordinated effort, policy, pooled experience and shared facilities.

Figure 5.7. *Example of an optimum structure of a nucleus breeding programme.*



5.6.2 Genetics of diseases resistance

The exploitation of genetic resistance to disease is becoming important in livestock development programmes. This is further encouraged by the high cost of control measures, complexity of control recommendations and ecological damage from control treatments to the environment. Candidate diseases for genetic resistance are trypanosomosis, helminthosis and tick-borne diseases. Packed cell volume (PCV) and enzyme-linked immunosorbent assay (ELISA) have been used as selection criteria during trypanosome infection in cattle (see Box 5.3).

5.7 Exercises

Box 5.3. Research on genetic resistance to helminths in tropical small ruminants: Red Maasai sheep

Helminthosis is of considerable significance in a wide range of agro-climatic zones in the tropics and represents one of the most important constraints to small ruminant production. Losses in production, costs of antihelmintics and death of infected animals are major problems. Current control methods focus on anthelmintic treatment or controlled grazing to reduce pasture contamination. In the tropics, these control methods are limited by the high cost of antihelmintics, their uncertain availability, increasing frequency of drug resistance and limited scope for controlled grazing. A sustainable and low-cost solution is breeding for genetic resistance.

Resistance to endoparasites has been assessed by faecal egg counts (FEC) or packed cell volume (PCV). FEC has been shown to be a good indicator of worm burdens especially in young animals. This correlation can be affected by the parasite species. PCV is a good indicator of worm burdens such as *Haemonchus contortus* (Baker et al 1994).

Box 5.3. cont...

Box 5.3. cont...

There is clear evidence that in the subhumid zone of coastal Kenya, Red Maasai sheep, which are indigenous to Kenya, are more resistant to endoparasites than the introduced Dorper sheep breed. Red Maasai lambs, recorded between birth and one year of age, have significantly lower FEC and higher PCV and lower lamb mortality than Dorper lambs. In addition, Red Maasai ewes have lower FEC and higher PCV than Dorper ewes during the same lambing–lactation period. The relative resistance to endoparasites of the Red Maasai sheep at the Kenyan coast confirms earlier reports from research conducted in the Kenyan highlands. The results demonstrate that this breed expresses its endoparasite resistance when climatic conditions are conducive to high and persistent levels of challenge with the blood-sucking parasite *Haemonchus contortus*.

In addition to confirming genetic variation in resistance to endoparasites, this shows evidence of variation among African breeds. Estimates of heritability of both PCV and FEC increase with age, with significant heritabilities among lambs at about 10 months. At this age the heritability of FEC is 0.220.07 for all lambs, but higher in Dorper-sired lambs (0.320.13) than Red Maasai-sired lambs (0.110.07). This suggests that after many centuries of natural selection under endoparasite challenge, the Red Maasai sheep have become fixed for some of the important genes for resistance, yet still retain important within-breed genetic variation for resistance.

In contrast to the clear breed difference in Kenya, the breed difference for resistance in Ethiopia is less marked with the Menz sheep being a little more resistant to endoparasites than the Horro sheep. While genetic variation for resistance to endoparasites within breeds was virtually non-existent in young lambs in Kenya, this was not the case in Ethiopia. The heritability of FEC in lambs at weaning (3 months of age) in Ethiopia is 0.240.08, which is very similar to the heritability of 10-month-old lambs in Kenya.

Helminthosis is a global animal health constraint, affecting the tropical and temperate regions. Breeds of livestock that have originated and evolved under the severe disease challenge conditions in the tropics are more likely to possess disease resistance traits. Widening the use of tropical livestock genetic resources to enhance sheep and goat production is the challenge of the future.

1. There is pressure from exotic breeds on indigenous sheep and goats in sub-Saharan Africa. Do you agree with this statement? Describe the situation in your locality or region. If you agree with this statement, what steps do you suggest should be taken to solve this problem?

2. Most of conservation activities in Africa have been directed towards crops and wildlife. What reasons can you suggest for giving attention to genetic conservation of small ruminants?

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Module 6: Nutrient requirements and feed resources

6.1 Performance objectives

Module 6 is intended to enable you to:

1. List strategies to improve ruminant livestock nutrition.
2. Describe feed intake for ruminant livestock.
3. Describe nutrient requirements: protein, energy, minerals, vitamins and water for ruminant livestock.
4. Calculate crude protein from nitrogen analysis data.
5. List *in vivo* and *in vitro* methods for measurement of digestibility.
6. Describe feed resources: natural pastures and ways to improve them, artificial pastures, fodder trees, crop residues and industrial by-products.
7. Describe methods for conserving forages.
8. List feeding techniques.

6.2 Introduction

Preceding modules described the production systems in sub-Saharan Africa and they stressed the following facts:

- one of the major factors limiting productivity of small ruminants in sub-Saharan Africa is poor nutrition.
- variations in birth weight may be related to the plane of nutrition at the time of conception and during late pregnancy in ruminants.
- neonatal losses can be closely correlated with birth weight, which is a reflection of maternal nutrition during the last two months of gestation.

- undernourished animals are highly likely to contract diseases.
- feed supply is limited during the dry season.

The above factors necessitate that nutrition must be considered in any strategy to increase productivity. In this module we will highlight (i) nutrient requirements and (ii) availability and use of feed resources. More details about ruminant nutrition (methods of feed evaluation, nutrition strategies) can be accessed in manuals produced by ILRI (ILCA 1990; Osuji et al 1993).

Insufficient forage during the dry season is a major constraint to ruminant productivity. Forage availability determines the overall carrying capacity of the land. In sub-Saharan Africa human population is increasing, forcing farmers to use grazing areas for arable farming. Even though this may have a negative effect on pastoralists, it also results in a symbiotic relationship. Pastoralists can graze their animals on crop residues in the dry season and the settled farmers benefit from the animals' manure.

To assist you in learning the following sections, Box 6.1 contains the definitions of some basic concepts to nutrition and feed. Solutions to nutritional constraints depend on the nature of the system. In pastoral systems the scope is limited as the situation is complicated by land tenure and stocking rates. In mixed crop–livestock systems there is potential for improvement. The following are a few strategies to improve ruminant livestock nutrition through technological solutions:

- Crop improvement: This pathway includes (i) selection of crop varieties which yield residues of high nutritive value and/or in large quantity (ii) changing crop combinations, e.g. intercropping with legumes and (iii) changing time of planting.
- Livestock management strategies: This involves changing livestock management to match feed availability with livestock feed requirements.
- Pasture improvement strategies: This involves improving the management of the range principally through increasing the amount and quality of forage.
- Feed supplementation strategies: These involve using fodder banks, fodder trees, by-products such as oilseed cakes and meals, and urea–molasses blocks to supplement crude protein shortages.

Box 6.1. Definition of concepts related to nutrition and feeds

Crude protein. The amount of protein in the feed available to the ruminant. It is calculated using nitrogen content of the feed corrected by a factor of 6.25 based on the assumption that feed protein contains, on average, 16% nitrogen. Assumes that all faecal nitrogen is in the form of proteins.

Crude fibre. A fraction of feed that contains the cell wall and consists of carbohydrates (hemicellulose and cellulose) and lignin.

Digestibility. The digestibility of a feed determines the amount that is actually absorbed by an animal and therefore the availability of nutrients for growth, reproduction etc.

Energy. Derived from organic constituents of food and used as fuel for body functions and production.

Maintenance. This is the condition when an animal's energy requirements are in balance (equilibrium) and it is not reproducing or producing output.

Metabolism. Metabolism is the sum of all the physical and chemical processes taking place in living organisms. For example the excretion of waste products (manure and urine) from the body is part of the metabolic process.

Scientists conduct research to develop feeding systems that provide sets of tables that give nutrient requirements of the animal and the nutritive value of feed, both expressed according to the feed evaluation system. The feeding systems are prepared to help farmers calculate rations for their animals. Scientists conduct research to find solutions to nutritional problems. This involves studying the relationship between nutrition and performance, management and grazing conditions. To achieve this goal, data are collected to:

- examine the effect of nutrition on production
- determine the amount of feed consumed
- determine the composition of the feed consumed.

This module presents some concepts and methods used to collect these data. Table 6.1 summarises the types of data. For further details, you are referred to the reading materials.

Table 6.1. *Types of animal data used to diagnose animal nutrition problems.*

Objective	Type of data
Production effects	Liveweight gain, condition scores, traction power, milk and wool production
Amount of feed consumed	Feed intake
Composition of feed consumed	Rumen fistula samples, faecal samples and grazing behaviour

Detailed methods for data collection are described in ILCA (1990).

6.3 Feed intake

Feed intake is the amount of feed an animal consumes. It can be estimated by using either digestibility data or markers.

6.3.1 Using digestibility data

When digestibility data are available, intake can be estimated by multiplying the dry-matter (DM) weight of faeces by a digestibility factor. The factor is known as the feed:faeces ratio and is expressed as:

DM intake = 100/(100 – digestibility) × DM weight of faeces where digestibility is in per cent

For example if the dry-matter weight of faeces of an animal is 870 g/day and the percentage digestibility of the feed consumed is 60%, then the amount of dry feed consumed would be:

DM intake (g/day) = (100/40) × 870 = 2175

6.3.2 Using markers

Digestibility and intake data can be derived from the indigestible components of a diet, known as ‘markers’. Markers are classified as internal, if they are ordinarily present in the diet (e.g. lignin), or as external if they are added to the diet (e.g. chromic oxide, iron oxide and barium sulphate). They are used when the measurement of feed intake and faecal output is difficult.

The formula used to estimate faecal output is:

Faecal output (g) = Grams of marker in feed per day/Concentration of marker in faeces

For example an animal is dosed with 50 g of chromic oxide per day to determine its daily faecal output. The concentration of marker in the dry-faeces sample is 5.75% and the dry-matter weight of the faecal output is:

Faecal output = 50/0.0575 = 870 g

If the proportion of marker in the diet is 3.4%, then we calculate dry-matter intake as follows:

DM intake (g/day) = 870 × (5.75/3.4)

6.4 Nutrient value of feed

It is important to know the supply of different nutrients to ruminant livestock in systems in relation to their need for these nutrients. This module will cover energy, protein, water, minerals and vitamins. Methods to estimate amounts of these nutrients can be found in ILCA (1990).

6.4.1 Energy

The energy yield of a source of feed (such as natural pasture) can be estimated from its dry-matter weight per unit area. Feeds with a high biomass per unit area are often low in energy since they also contain a high proportion of indigestible fibrous matter.

6.4.2 Protein

Protein is the basic structural material from which all body tissues (e.g. muscles, nerves, blood cells) are formed. It is therefore essential for production and maintenance and cannot be replaced by other nutrients in the feed. The requirements of the animals are for essential amino acids, which are the building blocks of the protein. This is expressed as protein requirements, where crude protein (CP) is obtained by using this equation:

$$\text{Crude protein} = \%\ \text{nitrogen} \times 6.25$$

where the value 6.25 is based on the assumption that feed protein contains, on average, 16% nitrogen.

Crude protein is highly related to grain yield at the time of harvest (Church and Pond 1982). On a per hectare basis, grain yield was related to CP in the leaf. Such relationships can be used to indicate the availability of CP in the different sources and/or at different stages of plant growth.

When estimating the CP content of browse plants and crop residues, it should be kept in mind that the presence of certain chemical compounds (e.g. tannins) in these feeds can affect the availability of nitrogen to the ruminant.

It is important to know that ruminants are able to synthesise protein from non-protein nitrogen sources (e.g. urea) by microbial action in the rumen.

6.4.3 Minerals

Ruminants require essential minerals as part of their feed for tissue growth and regulation of body functions. If one of these minerals is missing in the diet, symptoms of deficiency occur; if any mineral is in excess, the animal experiences toxicity. Usually under extensive livestock systems in the tropics, mineral imbalances are rarely seen. Analysis for minerals should only be attempted if mineral deficiencies are clearly evident. Even then, if other nutrients such as energy or crude protein are more limiting (as is likely to be the case in African rangelands), the mineral constraint should be dealt with only after the primary deficiencies have been rectified. A more detailed account of symptoms of mineral deficiency and the role of minerals in ruminant nutrition can be found in basic nutrition texts (e.g. Church and Pond 1982).

6.4.4 Vitamins

Ruminant livestock require vitamins, in very small amounts, to regulate body functions. Although vitamin deficiencies do occur in ruminant animals in the tropics, in general they are of minor importance. Under more intensive systems (e.g. peri-urban dairy), providing vitamin supplements is advised. Many of the vitamins are synthesised in the rumen, especially many of the members of the vitamin B complex and vitamin C. If animals are exposed to the sun, they are able to manufacture vitamin D. Vitamin A is essential during pregnancy. Small ruminants can obtain provitamin A from green forages and convert it into vitamin A. Young herbage and cereal grains contain adequate amounts of vitamin E.

6.4.5 Water

Ruminants require water because:

- it affects voluntary intake; less water leads to inadequate intake of dry matter
- it is needed to maintain the water content of the body.

For animals kept under the pastoralist system, the frequency of watering is very important. During the dry season water is available only from wells or some lakes/streams. This leads to overgrazing around the watering points forcing pastoralists to move their animals far away from water sources to obtain pasture. The situation presents a dilemma to nomads because water intake increases as watering frequency decreases and food conversion efficiency becomes lower as watering intervals increase.

Heat stress increases the water requirement of sheep. It is recommended that sheep and goats be given water *ad libitum.* The water requirements increase when the ewe is pregnant or lactating. Lactating ewes require 50% more water during early lactation and 25% more during late lactation. The extra water required is equivalent to the amount of milk produced.

6.5 Evaluation of feed

The chemical composition of a feed determines its nutritive value. The difference in energy value of feeds is due to their differing digestibility. The digestibility of a feed determines the amount that is actually absorbed by an animal and therefore the availability of nutrients for growth, reproduction etc. A few methods to evaluate feed for digestibility are listed. [For more details about the methods consult Osuji et al (1993a)].

6.5.1 *In vivo* measurement of digestibility

Feeding trials

A feeding trial is used to obtain data to calculate digestibility values. Faeces from several animals is collected for at least one week following an adaptation period of two weeks. The following equation is used:

$$\text{Digestibility} = 100 \times (DM_{food} - DM_{faeces})/DM_{food}$$

where DM_{food} is the dry matter consumed and DM_{faeces} is the dry matter excreted in the faeces.

Nylon bag technique

You place samples of feed in small nylon bags, which are then placed in the rumen through a fistula. The degradation of the feed is recorded after two days.

Indigestible marker technique

You can mix chromic oxide with the feed. The concentration of chromic oxide in the faeces is used to calculate digestibility.

6.5.2 *In vitro* methods for measuring digestibility

- You can use equations to calculate digestibility from chemical analysis.
- Incubate a feed sample in rumen fluid and then transfer it to a pepsin solution. Include one or two standards which were measured *in vivo* to monitor accuracy.
- You can use the Menke *in vitro* gas production technique. In this method gas is produced when feed is incubated in rumen fluid. The amount of gas is correlated with digestibility. This method determines the gas produced over a 24-hour incubation period.

6.6 Feed resources

6.6.1 Natural pastures

Natural pastures are the most important feed resource for sheep and goats in sub-Saharan Africa. Pastures differ in their species and canopy coverage. The canopy coverage depends on the amount of moisture in the soil and sunlight. UNESCO (1979) adopted the following classification for natural pastures:

- Savannah: It is composed of grasses and shrubs or trees. The acacia grasslands of East Africa fall into this category.
- Grasslands are composed of pure grasses. There is little true grassland in the tropics. Aquatic grasslands are found in southern Sudan, around Lake Chad and in the seasonal flooding areas of East Africa.

The potential carrying capacity of the pasture is determined by the quantity of vegetation. The productivity of sheep and goats on pasture is affected by the quality of the vegetation. The quantity and quality of pasture is affected by:

- climate and season
- burning: accidental fires or burning for pasture management
- legume content: the mixture of legumes and grass has a better quality than grass alone.

At the start of its growth, natural pasture has a high water and protein content which is not advantageous for animals because of limited energy intake; cellulose increases thereafter. Natural pasture with 30–40% cellulose content is adequate for the maintenance requirements of sheep. Higher cellulose content becomes detrimental because rumen micro-organisms are unable to cope with its degradation. This makes pastures with high cellulose content low in nutritive value and hence unable to support the nutrient requirements of small ruminants. The highest quality of grasses are reached during stem elongation and the quality decreases after heading.

6.6.2 Improved pastures

The yield and quality of natural pastures can be improved by:

- changing the species composition, e.g. introducing a legume such as *Stylosanthes guianensis* in a natural pasture to increase the protein yield per hectare
- improving management, e.g. grazing control or applying fertilisers.

Improving pasture in the dry zones of the tropics is limited by cost such that only simple measures can be implemented. There is more scope for improvement in the subhumid and humid zones of sub-Saharan Africa provided a solution is found for control of the tsetse fly and associated small ruminant diseases.

Introducing new species must be done carefully. An aggressive species will dominate the less aggressive ones. Introduced species should be able to:

- grow in soils of low fertility
- withstand stress, i.e. heat, moisture and waterlogging
- withstand severe grazing pressure
- spread on hill slopes to help control erosion.

The list of species and the methods used to establish and maintain pasture are beyond the scope of this manual. Specialised texts can be consulted for more details (see Crowder and Chheda 1982). The successful use of improved pastures depends on grazing control. The use of barbed wire or electric fences is beyond the means of resource-poor farmers. Recently the use of fodder trees or nonpalatable shrubs as fences was demonstrated as a possible means of controlling grazing (Charray et al 1992). However, the use of this technology is limited by labour and inadequate knowledge of the management of trees/shrubs.

6.6.3 Cultivated pastures or fodder crops

Even though natural pastures are used extensively in sub-Saharan Africa, they can only support the desired productivity of sheep and goats to a certain level and for a short period. Cultivated pasture or fodder crops are grown with the aim of:

- increasing forage production per unit area
- improving the feed value of the grasses.

When choosing a fodder crop we should ask the following questions:

- Is it easy to sow? And establish?
- How is it to be used?
- What is the length of the vegetative cycle?

Fodder crops are not yet widely used in sub-Saharan Africa because of the high cost of inputs such as land, labour and fertiliser. These crops are attractive when grown as:

- Catch crops growing in a period when the land is otherwise unused.
- Break crops, which improve the yield of subsequent crops by improving soil fertility or reducing pests and diseases.
- Intercrops, grown between the rows of another crop to improve soil fertility, provide shade or control erosion.

Fodder crops must give higher yields or have better quality than pastures. Legume fodder is known to have these attributes. However, feeding excessive legumes to sheep and goats may cause bloat (the accumulation of gases in the rumen) in the animals.

Fodder banks were found to improve the nutritional status of livestock during the dry season (Mohammed-Saleem 1985). These are special plots of legumes grown by pastoralists adjacent to their homes to serve as supplements to dry-season grazing. For Nigerian pastoralists, ILRI developed fodder bank technology packages that use low inputs. The farmers received the technology well and researchers and extension teams worked with them to overcome difficulties related to establishment, utilisation and regeneration.

Supplementation of roughage

Dry natural pastures can only provide low-quality roughage and therefore small ruminants will benefit from any form of supplementation of the roughage. Supplements usually consist of at least one of the following:

- concentrates
- molasses
- non-protein nitrogen (e.g. urea)
- minerals.

They can be fed to animals separately, incorporated into a complete diet or as feedblocks. Important points to consider when supplementing roughage:

- Supplementation with molasses must be accompanied with urea.
- Urea is not palatable to sheep; mixing it with molasses overcomes this problem.

Supplements to roughage are beneficial to small ruminants because:

- they provide essential nutrients to the rumen micro-organisms.
- the enhanced activity of micro-organisms in the rumen results in better digestibility
- they provide nutrients for the sheep.

6.6.4 Conserved forage

During the dry season, the quality of pasture is low and forages are scarce. One way to solve this problem is to conserve forages. Conservation aims at retaining the feed value of the forage. Fodder can be conserved as hay or silage.

Hay

Hay is dried fodder. To produce hay of high quality, it is essential to harvest the fodder at the right time. When fodder is harvested too early, its moisture content is too high resulting in hay with reduced dry-matter content. If the fodder harvest is delayed, the plants develop a high lignin content. Hay made from fodder with high amounts of lignin is of poor quality because its digestibility is low. In the humid zone heavy rainfall forces farmers to delay fodder harvest until the dry season resulting in fodder with high lignin content. In addition, at the end of the rains most crops are ready for harvest so hay-making competes with crop harvests for labour.

Hay can be sun dried to 10–15% moisture content. Low air humidity is needed to achieve this level of moisture in the hay. This is easy to achieve in the arid and semi-arid zones but difficult in the humid zone where the rainfall and relative humidity are higher.

There are many methods for making hay. The simplest and cheapest method is drying the forage on the ground. The grass is cut (using a machete) early in the morning and is spread on the ground in the field. The heaps of forage are turned over many times to avoid picking up moisture from the soil. Sophisticated methods for drying forages are available but they are costly and beyond the reach of smallholder farmers. Hay should be protected from rain and the sun as exposure to these factors reduces its feed value. Sheep and goats may refuse hay of low quality unless they are starving. Hay can never be equal in feed value to the fresh forage from which it is made.

How do farmers use hay?

- Feed it to animals on maintenance diet.
- Feed it to lambs and kids to accelerate rumen development and the rumination process.
- Use it as roughage for lambs destined for fattening on rations with large amounts of high-energy, high-protein concentrates.

Silage

Silage is produced by fermenting the sugars in green herbage under anaerobic conditions. The desired product is reached when enough acids are produced (low pH which prevents bacterial decomposition) and fermentation stops. Silage can be stored for at least a year.

Silage can be made in silos of various shapes. The easiest method is to use pit and trench silos which can be built using simple materials. The silo and its wall must be completely airtight to prevent the fodder putrefying. The bottom of the silo must be covered with stones to allow the liquids resulting from fermentation to drain off. To ensure successful silage making:

- After harvesting the forage, keep it at low moisture by exposing it to the sun. The harvested forage should not be exposed to rain.
- Chop the forage into fine pieces (with a machete) of not more than 10-cm length.
- Compress the forage in the silo to remove as much air as possible (treading with feet can be used to compress forage in small silos).
- Cover the silo as soon as possible with compacted straw or a sheet of plastic (if available) and place soil on top (a layer of about 50 cm). Compact the upper layer of the soil to maintain good coverage.

6.6.5 Crop residues

There are many crop residues which can be used for feeding sheep and goats. Sheep and goats make better use of these agricultural by-products in crop–livestock systems. Farmers with no animals may use crop residues to improve fertility of the soil or sell the residues.

Straw

Straw is mostly a by-product of cereal crops that is used as roughage for ruminants. Straw of the following crops is used in sub-Saharan Africa: maize, millet, sorghum, wheat, barley, rice and teff. Residues from other crops are also used on small scale: sugar-cane, cocoa, banana, cotton, cassava and legume crops.

Straw has low nutritive value. The energy content of straw ranges from 5.5 to 9.6 MJ ME/kg DM. Energy values vary with the cereal variety and the management of the residue after grain harvest. Straw is high in lignin, which lowers its digestibility. Straws of most crops are low in crude protein and minerals (especially phosphorus). The nutritive value of straw and its coarse physical form limit the activity of micro-organisms in the rumen and contribute to the low rate of passage through the digestive system. All these factors result in low voluntary intake. You can improve the feed value of straw by:

- Adding supplements of energy, protein and minerals, which will give an adequate supply of nutrients to both the rumen micro-organisms and the animal. Research at ILRI (Getachew et al 1994; Umunna et al 1995) has shown that supplementation with forage legumes is a sustainable way of improving the feed value of poor-quality crop residues especially for resource-poor African smallholders. The results indicate that *Stylosanthes guianensis*, *Lablab purpureus* and *Sesbania sesban* were useful as supplements for sheep in Ethiopia.
- Grinding or chopping the straw or heating it with steam to increase voluntary intake. The cost of treatment is high because it requires labour.
- Treatment with chemicals, particularly alkalis (e.g. sodium hydroxide, potassium hydroxide, calcium hydroxide and sodium carbonate) and nitrogenous compounds (urea and ammonium hydroxide). These treatments will increase digestibility and nitrogen content but they are expensive and availability of chemicals may pose problems for small farmers. This practice is therefore suitable only for research stations and a limited number of farmers.

Bran

Bran is produced from cereals and it consists of the outer parts of the hulled grains, some broken grain and germ. Bran is palatable and is a valuable feed for small ruminants. Its crude protein content is 12%. The main problem with bran from rice and maize is its relatively high oil content (around 10%). Fatty acids turn rancid with storage and this lowers the nutritive value and palatability of the bran.

Example: Feeding sorghum stover

Sorghum (bird-resistant Seredo) was grown at Melkassa in the Rift Valley in Ethiopia. Fourteen days after hand-harvesting grain in November 1988, stover was hand-cut and transported to the research station at Debre Zeit. The stover was chopped (tractor-mounted Alvan Blanch Chaff Cutter) and stored for 1 month before feeding to 24 bucks (12 months old) and 24 rams (15 months old). Animals were individually penned and given 155 g/day of cottonseed cake and offered one of the three amounts of stover *ad libitum* (25, 50 or 75 g/kg animal mass per day). Salt lick and water were provided. This continued for 75 days. The results showed that both goats and sheep are capable of selective feeding leading to increased intake and growth when they are offered increasing amounts of chopped sorghum stover *ad libitum*. Growth rate of rams was double that of bucks. The generous feed strategy used offers a method of alleviating the low nutritive value of sorghum stover as a dry-season feed for small ruminants.

Source: Aboud et al (1993).

6.6.6 Industrial by-products

Cottonseed cake

Cottonseed cake, when available, is an excellent feed for sheep and goats. It has a high content of protein (25–40%), fat (10–23%) and cellulose (25–30%). Once the animal gets used to cottonseed cake, intake is increased. The best results are obtained by mixing the cake with salt and molasses. This was tried with West African Dwarf ewes and a mixture of 50:50 molasses and cottonseed cake gave good results (Charray et al 1992). The high protein content allows the amount of cottonseed cake to be reduced without detrimental effects. Unfortunately cottonseeds contain the toxic substance gossypol which reduces the growth of young animals but has little effect on adults. There are cotton varieties that are glandless and their seeds are free of gossypol.

Oilseed cakes

Oilseed cakes (oilmeals) are by-products of processing a variety of oil crops: groundnut, sunflower and soybean. These cakes are like cottonseed cakes: rich in protein and fatty acids. They can be used alone or mixed with molasses for effective results. Research at ILRI (Osuji et al 1993b) showed that sunflower cake was utilised effectively by Menz sheep in the Ethiopian highlands in terms of rumen microbial nitrogen synthesis, nitrogen retention and growth. The addition of small amounts of energy such as crushed maize grain increased microbial nitrogen synthesis, nitrogen retention and liveweight gain. The cost and availability of the cakes will determine the likelihood of their adoption by farmers.

Brewery by-products

When beer is made, the residues are the spent grains and yeast. Sheep and goats readily accept these as feed. Sources for these by-products are beer factories, which are increasing in sub-Saharan Africa, (including home-made installations). The by-products from home installations are richer in energy and protein than the residues from the factories.

Sugar industry by-products

The by-products from sugar-cane factories are dried sludge, molasses and bagasse.

Sheep can be fed all three by-products. Farmers mostly use molasses, a thick dark brown liquid which contains 50–65% sugar with little protein or water. It is thus a high energy feed. When added to cottonseed cakes, it increases the intake of coarse and less readily accepted cakes.

It can be added to the herbage during silage production. Molasses therefore is an excellent feed provided it is supplemented with protein and minerals.

Example: Supplementation with molasses

At ILRI's research station in Debre Zeit, Ethiopia, four ruminant fistulated crossbred (*Bos taurus* × *Bos indicus*) steers (mean live weight 468 kg) were fed twice daily a basal diet (Diet MO) comprising native grass hay *ad libitum* (free eating) and 4 kg dry matter (DM) of wheat bran. Three other diets were tested: 1. Native grass hay plus 750 g wheat bran per kg DM and 250 g molasses per kg DM; 2. Native grass hay plus 500 g wheat bran per kg DM and 500 g molasses per kg DM; and 3. Native grass hay plus 250 g wheat bran per kg DM and 750 g molasses per kg DM. The native grass hay was predominantly *Pennisetum* species. Wheat bran and molasses were mixed and fed together from a bucket. Increasing the level of molasses did not affect the intake of hay. There was no effect on digestibility of wheat bran. It was concluded that replacing wheat bran with different levels of molasses did not affect the function of microbes in the rumen. Rumen microbes utilised energy equally from molasses fermentation compared with wheat bran.

Source: Osuji and Khalili (1994).

6.6.7 Fodder trees

The integration of sheep and goats with tree crops is common practice in many places in sub-Saharan Africa. Sheep and goats are allowed to graze under trees, e.g. goats and sheep feed on the leaves and pods of *Faidherbia albida* in the parklands of West Africa. The animals are fed the branches of trees and subsequently manure is deposited under the trees. Farmers in the Kenya highlands feed leaves of *Leucaena* to small ruminants and cattle. The dry-matter yield of *Leucaena* is between 2 to 20 tons per hectare per year. The tree leaves contain mimosine which is toxic to sheep. Many other tree species are used for fodder, e.g. *Sesbania sesban*, *Calliandra* spp and *Gliricidia sepium*. Fodder from trees is especially useful during the dry season when it is used to supplement roughage or hay. Research at ILRI concluded that *Erythrina abyssinica* has high forage potential and can effectively serve as a cheap source of protein supplement for low quality diets during the dry season for resource-poor farmers with stall-fed sheep and goats (Larbi et al 1993). Supplementation of pasture in Zimbabwe with 110 g *Acacia angustissima* per goat per day was found to result in an increase of 12 g per goat per day.

6.7 Feeding techniques

This module will only provide a list of feeding techniques. For more information consult Charray et al (1992).

The following are common feeding techniques:

- Grazing: Pastoralists feed their sheep and goats on rangeland. Sheep and goats are free to graze for at least 8 hours per day. Pastoralists have developed complex management systems for grazing.
- Continuous grazing: This method is used when an area of forage is allocated for sheep and goats to graze freely. The enclosed area is calculated based on the carrying capacity of the pasture.
- Rotational grazing: This method leaves time for the grass to recover between successive periods of use. The stock grazes a plot for a specified time then moves to another plot, returning to previously grazed plots when they recover.
- Zero-grazing (also known as cut-and-carry): In this method feed is brought to the sheep and goats which remain confined.

Example: Feeding multi-purpose trees as supplements

Many multi-purpose trees have been tested as supplements to feed of livestock ruminants. In this example we will focus on results of an experiment that used *Erythrina abyssinica*. The literature has ample examples of other fodder trees. The feeding value of *E. abyssinica* leaves was evaluated with native sheep and goats at Soddo, southern Ethiopia, in a 21-day digestibility trial and an 80-day growth trial. In the digestibility trial, wilted leaves were fed *ad libitum* (freely), while in the growth trial, animals were offered a basal diet of *Pennisitum purpureum* with 3 levels (0, 500 and 1000 g/head per day) of *E. abyssinica* leaf. When levels of *E. abyssinica* leaf supplementation were increased, liveweight gains of sheep and goats increased. Sheep gained weight faster than goats. It was concluded that *E. abyssinica* has high forage potential and can effectively serve as a cheap source of protein supplement for low quality diets during the dry season for resource-poor farmers with stall-fed sheep and goats.

Source: Larbi et al (1993).

6.8 Exercises

1. A lamb is given a diet of 11.0 MJ ME per kg DM. Its DM intake is 511 g per day. Assuming it eats *ad libitum*, and that energy is the limiting nutrient, how fast will it grow?
2. Do farmers in your region conserve forages to feed to small ruminants? If so, describe indigenous methods used by farmers in your area to conserve feed for their small ruminants.

3. Mark the correct answer:

   A. Multi-purpose trees are useful as supplements because they can provide nitrogen and they all lack toxic substances.

   B. Multi-purpose trees are useful supplements because they can provide nitrogen but a few contain toxic substances.

   C. Multi-purpose trees are useful supplements because they can provide nitrogen in the diet of the ruminant and the rumen can detoxify any toxic substances that a few MPT species may contain.

4. Smallholder farmers use more crop residues than industrial by-products. List two reasons for this behaviour.

5. List the techniques used by farmers to feed small ruminants.

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Module 7: Economics of small ruminant production

7.1 Performance objectives

Module 7 is intended to enable you to:

1. List basic production function relationships.
2. Write the functions for factor–product, factor–factor and product–product relationships.
3. Describe the production relationships as they relate to small ruminant production.
4. Define partial budget analysis.
5. Describe the logic behind partial budgets.
6. Describe the framework for partial budget analysis.
7. List the essential data required for computing partial budget analysis.
8. Given production parameters data, corresponding cost and prices data, compute partial budgets.
9. Given computed partial budgets, interpret the results.

7.2 Introduction to production relationships

Agricultural economists are usually members of multidisciplinary teams solving problems of livestock agriculture. The economist applies economic concepts and tools to estimate economic profitability of a technology. This input can be done during any phase of the research process: technology development, testing and evaluation on-farm. Details of economic theories and tools are beyond the scope of this module. In sub-Saharan Africa most research teams lack an economist because only a few people have specialised in this field. Since the majority of the audience for this manual are non-economists, this module will briefly touch on relevant economic concepts and focus on partial budgeting, a tool that we think can be used by non-economists to quickly gain insight into the profitability of the technologies without having to wait until an economist conducts detailed analysis of the data. Farmers need to make decisions about allocation of their resources on a day-to-day basis as well as on a long-term basis. This includes decisions related to the whole farm such as what crops to grow, what animals to raise, what type of system, what inputs to use and how to market. A farmer has to answer four basic questions:

- What should the farm produce?
- How should it be produced?
- How much should be produced?
- How should it be marketed?

To effectively evaluate a technology, we need to know the resources available to the farmer and his risk considerations. Farmers take into account: the family subsistence requirements, marketing opportunities and availability of resources (land and labour). It is important also to consider factors related to a farmer's choice of production technologies. New technologies are not automatically superior to traditional practices. The farmer wants to produce at the least cost and with little deviation from traditional practices. Marketing factors, such as prices, transportation and storage facilities need to be considered into our analysis. We will concentrate on how economics helps to answer the first three questions since we are interested in raising the productivity of small ruminants and will concentrate therefore on technological change.

7.2.1 Production relationships

Farmers obtain outputs when they use inputs (factors of production). The farmer decides the amount of inputs he will use to meet his output goals. The relationship between factors of production and output are best described by the following equation:

$$Y = f(X_1, X_2, X_3 ... X_n),$$

where Y is the output (e.g. meat yield, milk yield) that is obtained as a result of using inputs X_1,X_2,X_3 etc (e.g. tons of hay, vaccination, fertiliser) and f is the symbol for function. The output and production factors are called variables. Variation in one of these quantities will lead to variation in the other. The equation Y=f(X) is termed the production function which means Y is a function (f) of X. We will describe the three basic relationships that involve these variables:

- Factor–product relationship: how output is related to a single variable input holding other inputs fixed.
- Factor–factor relationship: how output (held constant) is related to two or more variable inputs.
- Product–product relationship: how the relative quantity of two or more outputs is related to a fixed quantity of inputs.

Factor–product relationship

In this relationship one input is varied and the level of other inputs is kept constant. The production function to express this is:

$$Y = f(X_1 \mid X_2, X_3 ... X_n),$$

where the symbol $\mid$ means that only X_1 is varied while X_2 to X_n are fixed. This relationship could lead to constant output, increasing output or decreasing output. The concepts marginal product, constant marginal product, increasing marginal product, decreasing marginal product and average product will be used to describe the factor–product relationship.

Marginal product. Marginal product is the change in output due to a change in variable input. The following function describes it:

$$\text{Marginal product} = \Delta Y \div \Delta X$$

The symbol Δ means change and is known as ‘delta’. For example:

$$\text{Milk} = f(\text{feed} \mid \text{land})$$

where the change in milk output is ΔY and the change in feed ΔX. $\Delta Y \div \Delta X$ means the change in amount of milk due to a specified change in amount of feed; the factor land is held constant. This relationship is used in agricultural decision making. This relationship compares the value of an additional quantity of output to the cost of the additional input required to produce the marginal product.

$$MP_{milk} = \Delta\text{milk produced} \div \Delta\text{feed quantity}$$

Thus the farmer will choose an input and decide what quantity of this input to use and how much output to produce.

The marginal product can be constant and this happens when, within a range of input levels, the application of each additional unit of input, yields equal increments in output (Figure 7.1). This relationship is rare in agriculture. Sometimes, for a range of input levels, each additional unit of input results in increasing increments of output (Figure 7.2). This is possible when the fixed input is in excess in relation to the variable resource. This situation is also rare in agriculture. The most typical relationship in agricultural production is decreasing marginal product (Figure 7.3). For a range of input levels, each additional unit of input yields an incremental output which is less than that from the previous increment in input.

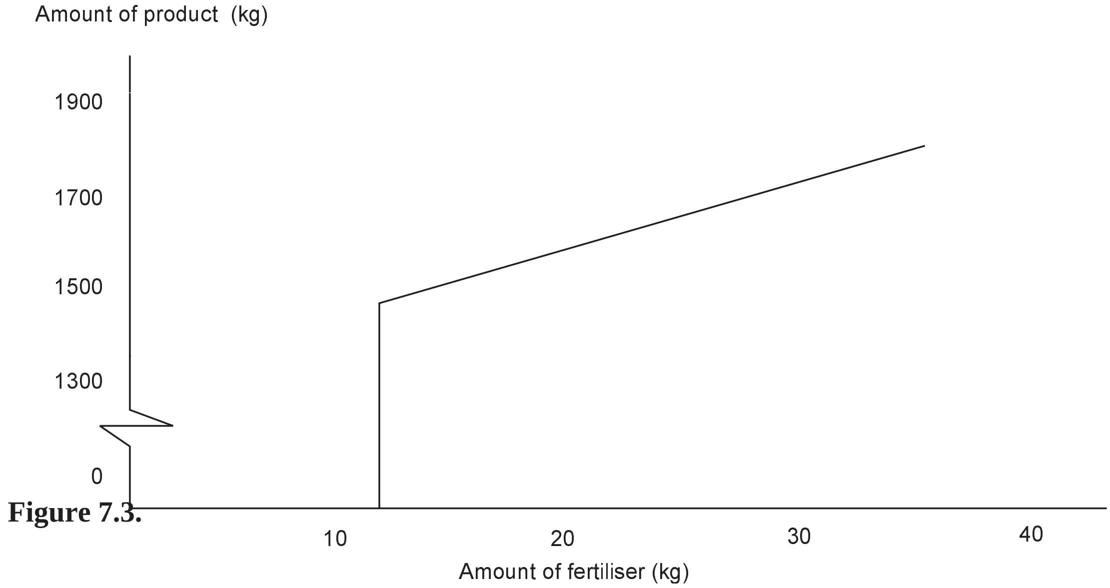


Figure 7.1. *Constant marginal productivity.*

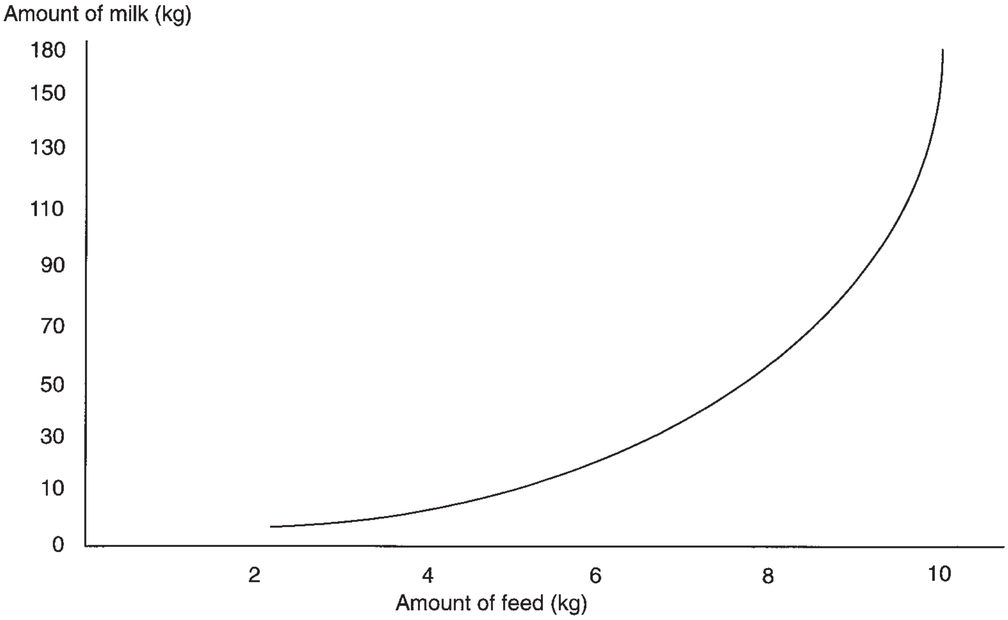
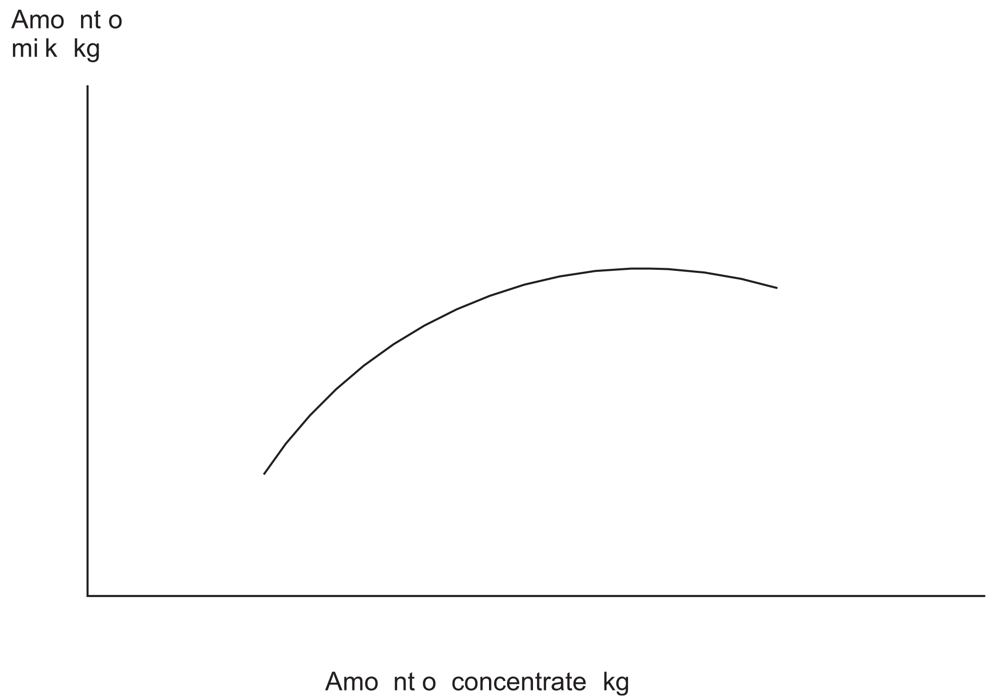


Figure 7.2. *Increasing marginal productivity.*



Decreasing marginal productivity.

Average product. This is the ratio of output to input, i.e. Y÷X, where Y is the total output and X is the total input. The following relationships exist between average product (AP) and marginal product (MP):

- when MP>AP, AP is increasing
- when MP=AP, AP is at maximum
- when MP<AP, AP is decreasing.

AP measures the technical efficiency of a process of production.

Relationships between marginal product and total product. The following relationships hold between marginal product and total product as the level of input increases:

- when total product is increasing at an increasing rate, marginal product is positive and increasing
- when total product is increasing at a decreasing rate, marginal product is positive and decreasing
- when total product is maximum, marginal product is zero
- when total product is decreasing, marginal product is negative.

The production relationship (Figure 7.4) is divided into stages I, II and III. The use of resources in stage I only is uneconomical. In such a case the farmer is using too little of the variable input given the level of fixed inputs that are available. One can increase the level of variable input up to the border between stage I and stage II to reach higher AP. If this is not possible, then some of the fixed inputs can be shifted to other uses to produce more products. It is also irrational to add inputs beyond the point of maximum TP (8X in Figure 7.4) since the marginal product is negative, i.e. too much input is used relative to the fixed inputs. In this case it is advisable to use less of the variable resources. Stage II represents the area of rational production, i.e. economic relevance. We need to know the production function and input/output price ratio to be able to locate the precise economically efficient level of variable input.

Do farmers maximise production? No, farmers maximise profit but they do not necessarily maximise production. When TP is maximum (Figure 7.4) MP is zero, i.e. Y=0 and MP=Y/X=0. Do farmers stop at the border between stage I and stage II, i.e. at X=5? No. Depending on the price, farmers keep using additional input even though MP is decreasing.

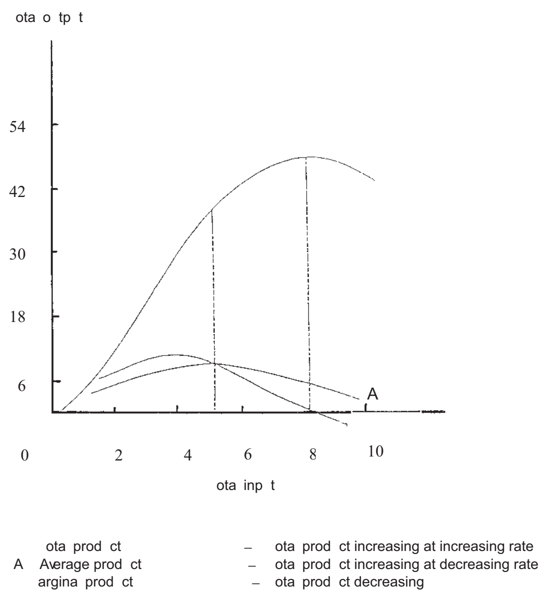


Figure 7.4. *Stages of production and the relationships between marginal product (MP) and average product (AP).*

Hypothesis: Farmers maximise profit

Prices of inputs – costs

Prices of outputs – revenue

Profit is the difference between revenue and cost:

Profit = Revenue – Cost

Revenue = Output (Y) × Pricey (Py)

Cost = Input (X) × Pricex (Px)

Profit = (Y × Py) – (X × Px)

Maximum profit = Revenue – Cost

(Production within stage II)

Maximum profit = Marginal revenue (MR)

= Marginal cost (MC)

Maximum profit occurs when added return (marginal revenue) equals added cost (marginal cost) and production is occurring within stage II:

MR = MC

$MR = \Delta Y \times Py$

$MC = \Delta X \times P_x$

where P_y is the price of output and Px is the price of input,

$$\Delta Y \times P_y = \Delta X \times P_x$$

$$\Delta Y \div \Delta X = P_{x/}P_y$$

$$Px \div P_y = \text{input/output price ratio}$$

MAX profit = MR = MC

In real farm situations farmers do not use levels of inputs that maximise profits because:

- the farmer's knowledge of the value of resources is imperfect and he/she is unsure of input/output relations
- the farmer is faced with risk such as uncertainty in future prices or future yields; to reduce the risk, the farmer discounts future returns
- the farmer is short on capital to buy the necessary inputs that will maximise profit.

Factor–factor relationship

In this production relationship we have a number of variable inputs (factors). The following function is used to express this relationship:

$$Y = f(X_1,X_2/X_3,X_4...Xn),$$

where X1 and X2 are variable. The aim in this relationship is to get the least-cost combination of inputs that give the desired level of output. A farmer can use different combinations that produce the same level of output. The substitution process has limits as a minimum of certain inputs are needed for a given output. Factor–factor relationships can be increasing, constant or decreasing. The only rational economic relationship is when the marginal rate of substitution between inputs is decreasing. The farmer will need to know the relative price differences of the inputs and the output prices. This will help to decide which combination of inputs to use to produce a certain level of output, i.e. the farmer desires the least-cost combination of inputs that maximise profit. This can be obtained when the marginal rate of factor substitution equals the inverse factor price ratio:

MR = MC, i.e. MR – MC = 0

(MC is at the minimum cost)

$$MC = \Delta X_1.P_{x1} + \Delta X_2.Px_2 = 0$$

$$\Delta X_1.P_{x1} = \Delta X_{2.}P_{x2}$$

$$\text{Slope} = \Delta X_1 \div \Delta X_2 = PX_2 \div PX_1$$

That is when the value of the marginal input added ($\Delta X_{2.}P_{x2}$) equals the value of the marginal input reduced ($\Delta X_1.P_{x1}$), the resource combination is optimal. Figure 7.5 shows this relationship: when the slope of isocost line (PX_2/PX_1) touches the isoproduct curve ($\Delta X_1/\Delta X_2$).

Product–product relationship

In this relationship two outputs are produced when the level of inputs is fixed. The farmer desires to produce optimal combination of outputs for a number of fixed inputs. The farmer aims at maximising revenue since the cost is fixed. The two outputs can be complementary, supplementary or competing for the fixed resources. Therefore, marginal analysis is used to decide on the best combination of outputs. Figure 7.6 shows a hypothetical transformation curve describing the three possible combinations. The slope of the product transformation curve is $\Delta Y_1/\Delta Y_2$. The two outputs generate different revenues. The equation for total revenue from the two outputs:

$$R = Y_1P_{Y1} + Y_2P_{Y2}$$

where R is total revenue, P_{Y1} is the price of output Y_1 and P_{Y2} is the price of output Y_2. The optimum output combination is reached when $\Delta Y_1/\Delta Y_2 = P_{Y2}/P_{Y1}$. This occurs when the slope of the isorevenue line PY_2/PY_1 is equal to the slope of the product transformation curve, $\Delta Y_1/\Delta Y_2$ (see Figure 7.6). The combination is complementary in region A–B, i.e. increasing the production of Y_1 will increase the production of Y_2. For example legume crops fix nitrogen which is used by the other intercrop (a non-legume). Region B–C is for outputs that are supplementary, i.e. increasing the production of Y_1 does not affect the production of Y_2. For example keeping a few milking goats on the farm does not affect the productivity of producing corn as the sources of labour are not competitive. As long as both products have positive prices, it is not economical to produce in region A–B or B–C. It is advisable to keep producing until we reach the competitive point, i.e. the point where the isorevenue line touches the product transformation curve.

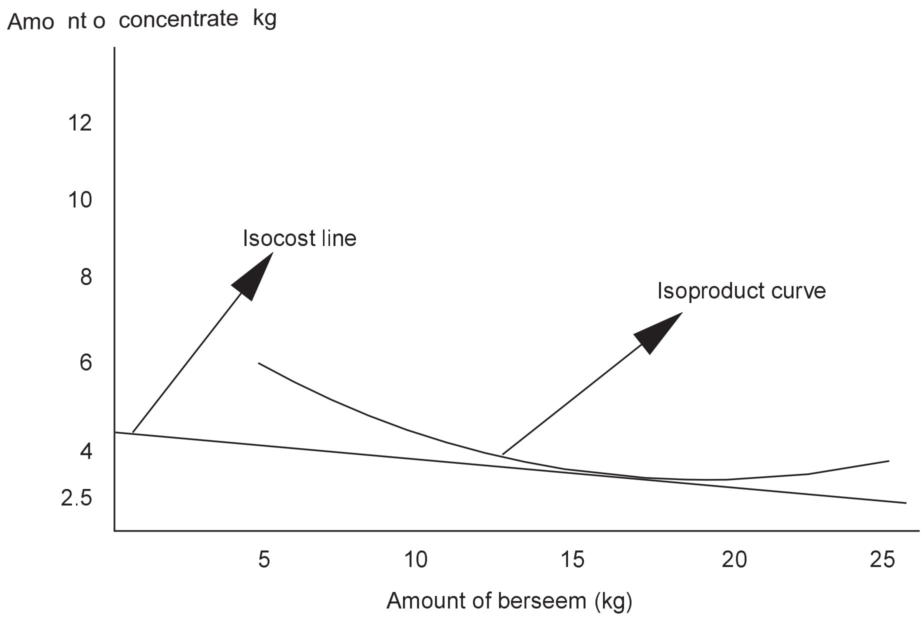


Figure 7.5. *Least cost combination of two inputs.*

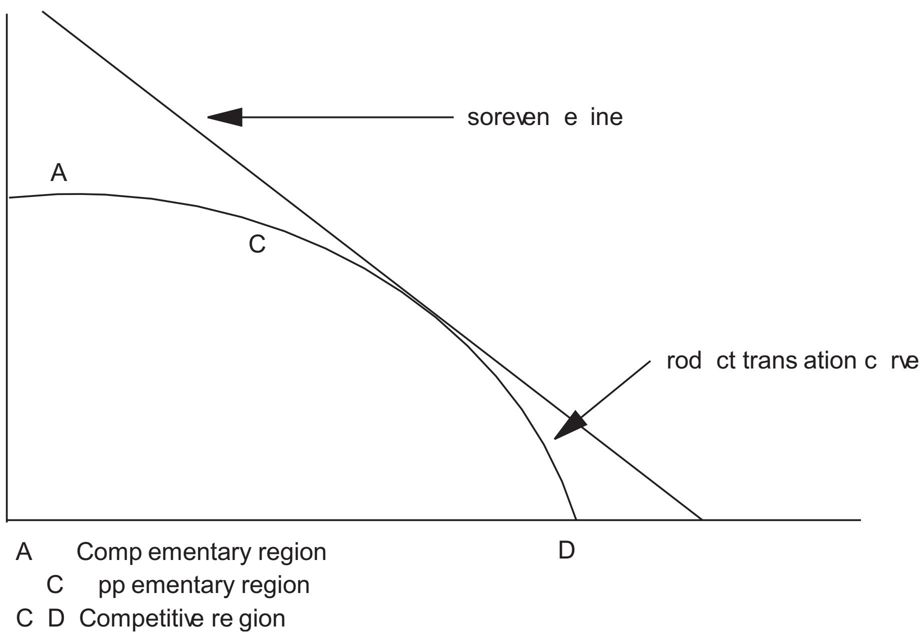


Figure 7.6. *Hypothetical product transformation curve.*

7.3 Partial budget analysis

Partial budget analysis is the tabulation of expected gains and losses due to a relatively minor change (marginal) in farming method or technology, e.g. feeding concentrates to sheep. The new technology could be technically feasible but this is not a necessary condition for adoption by farmers; the new technology must be profitable. Therefore it is important for the team of scientists developing the new technology or improving the existing one to determine the profitability of the technology. However, most national research systems do not have enough economists, and biological scientists often lack the ability to conduct economic analysis. This module therefore aims at describing a simple technique to determine the profitability of technologies at farmer level—the partial budget analysis. Livestock scientists need to be equipped with basic economic tools to evaluate small ruminant technologies. Partial budget analysis can be used to estimate the likely economic impact of a technology, before it has been tested (ex ante analysis), and after the trial has been completed, when actual data is available.

Partial budgets list only those items of income and expenses that change. They (i) measure change in income and returns to limited resources (ii) provide a limited assessment of risk and (iii) suggest a range of prices or costs at which a technology is profitable. After the changes are determined, the relationship is shown by the following equation:

[Added returns + Reduced costs] – [Added costs + Reduced returns] = [Profit or loss]

As stated earlier, the farmer's goal is to maximise profit and not necessarily only productivity. Determining the farmer’s goal is a good start. For example the household may set as a goal increasing income during drought periods and achieve this goal by introducing sheep in addition to cropping. The advantages and disadvantages of partial budgeting are listed in Box 7.1.

7.3.1 Logic behind partial budget analysis

The farmer's goal is to maximise returns. The following equation describes this relationship:

$$NI = TR - TC$$

where NI is the net income (e.g. from sale of sheep), i.e. the amount of money left when total costs (TC) are subtracted from total returns (TR). Total cost (TC) is composed of the cost of all inputs: variable costs (VC) and fixed costs (FC). Since FC are the same for comparing the new technology and the technology practised by the farmer, then:

$$TC = VC$$

The farmer wants to know if the new technology will increase his income while the researcher wants to know which technology is potentially more attractive economically. The change in income can be expressed as follows:

$$\Delta NI = TR - \Delta TC$$

$$\Delta NI = TR - \Delta VC$$

This relationship can be used as a rule of thumb for partial budgeting, since $\Delta FC = 0$ because by definition fixed costs do not vary.

If capital is not a constraint, choose the highest ΔNI. Since higher benefits require higher costs, it is necessary to compare the extra (or marginal) costs with the extra (or marginal) benefits.

Marginal rate of return (MRR) is another way of taking the cost factor into account. It measures the ΔNI which is generated by each additional unit of expenditure (ΔVC):

$$MRR = \Delta NI/\Delta VC$$

MRR is also a measure of additional capital invested in a new technology and its effect on net return.

Box 7.1. Advantages, disadvantages and appropriate situations for partial budget analysis

Advantages

- The technique is simple (it can be performed with a hand calculator) and easy to learn for non-economists.
- It examines only net changes in costs and benefits, therefore it is effective for assessing economic viability of single intervention technologies.
- It requires less data than whole-farm budgeting since fixed costs are not examined.
- The data required for partial budget analysis are collected for almost all other economic analyses.
- It allows early conclusions about the adaptability of a new technology.

Disadvantages

- There is a danger of neglecting the fact that farmers' resources are limited and sometimes knowledge about the resource base may be lacking.
- Often scientists do not understand the farmer's objectives; the partial view of a farming system might obscure the secondary character of a given farm component.
- The time for various farming activities which may overlap with or contradict a new schedule is often overlooked.
- Linearity of factors is assumed by using small-scale input/output data for a large-scale operation. The assumption that an increase in a unit of resource will increase the profit proportionally is questionable. Similarly, assuming that most new technologies do not require additional management skills is also questionable.

Appropriate situations for partial budget analysis

Partial budget analysis is appropriate where:

- a single component must be analysed
- inputs and outputs are measurable and easy to price
- animal yields vary little between farms
- profitability is the major concern rather than issues such as equity and income distribution
- fixed costs do not change
- economic evaluation is required for new technologies which are not yet well developed.

Researchers make recommendations to farmers about what to adopt. To make these recommendations, the following economic criteria should be observed (provided the technology is in line with the farmer's goal, sustainable etc):

- If net income remains the same or decreases, the new technology should not be recommended as it is not more profitable than the farmer's current technology.
- If net income increases and variable costs remain the same or decrease, the new technology should be recommended as it is more profitable than the farmer's current technology.
- If both net income and variable cost increase (the most common case), the MRR should be considered. The greater the increase in ΔNI and the higher the MRR, the new technology is more economically attractive.

Partial budgets for animal enterprises are essential because:

- animals have a longer life cycle than food crops
- animals use non-market inputs (crop residues, native pastures, labour and land) and market prices often do not exist
- animals have multiple outputs (e.g. meat, milk and manure)
- the life cycle of animals is not synchronised which makes it difficult to measure.

7.3.2 Data required for partial budget analysis

The most important step in performing partial budget analysis is the proper identification of data on the costs and benefits associated with the alternative technologies. Generally the following are essential data that must be collected:

- quantities of inputs which vary between alternative technologies
- prices of these variable inputs
- yields or productivity levels resulting from the alternative technologies
- prices of the outputs valuing non-market inputs or products opportunity cost (the value of the resource or product in its next best alternative use, e.g. family labour vs market labour wages).

Important products of small ruminants include reproductive capacity (offspring), milk yield, meat yield (weight gain), manure, skins and wool.

Inputs depend on the technology being used. Input costs should include cash costs (e.g. feed) and non-cash costs (family labour, capital costs, depreciation costs, crop residues and household wastes).

A logical framework for the steps of the partial budget analysis is given in Box 7.2. All benefits and costs should be calculated using farm-gate prices (the actual price which the farmer pays for the inputs or receives for his products). Input prices should account for all costs, a farmer selling animals will encounter transportation costs, storage charges and marketing costs. If a technology affects the quality of the sheep and goats, market prices should reflect the quality factor.

Box 7.2. Partial budgeting format

1. Additional income: list the items of income from the alternative plan that will increase or not be received from the base plan.
2. Reduced expenses: list the items of expense for the base plan that will be avoided or reduced with the alternative plan.
3. SUBTOTAL (ΔTR): 1 + 2
4. Reduced income: list the items of income from the base plan that will decline or not be received from the alternative.
5. Additional expenses: list the items of expense from the alternative plan that are not present in the base plan.
6. SUBTOTAL (ΔVC): 4 + 5
7. NI difference (ΔTR–ΔVC): 3–6: A positive (negative) difference indicates that the net income of the alternative exceeds (is less than) the net income of the base plan by the amount shown.
8. If there is capital constraint: MRR = ΔNI ÷ ΔVC

Table 7.1 shows the breakdown of the benefits and costs for economic analysis of small ruminants. Care should be taken in determining the value to assign to inputs and output when calculating partial budgets. In some cases opportunity cost needs to be used. For example, manure provides a low cost fertiliser for crops and in this case it can be given the cost of reduction in fertiliser use. Family labour is another example. Rural wages for hired labour can be used to evaluate family labour. When labour is not an option for household members, it is difficult to evaluate. Animals or animal products that are consumed by the household can be valued against the purchase value in the market. Tables 7.2 and 7.3 present checklists of costs of and benefits from producing ruminants and pigs which must be considered when computing partial budgets.

Table 7.1. *Breakdown of benefits and costs for economic analysis of small ruminants.*

Benefits	Costs
Primary	Primary
Increase milk yield	Cash costs
Increase litter size	Feed costs: hay, salt and minerals, concentrates, grains, feeds for the young
Culls (ewes, rams, does and bucks)	Non-feed costs: veterinary medicine and drugs, vaccine
Goat meat and lamb or mutton	Wages for hired labour
Mohair and wool	Pasture rent
Hides	Non-cash costs
Manure	Family labour
Horn and hooves for processing into feed supplements and other products	Depreciation of facilities, equipment etc
Meat and milk by-products	Other non-market feed costs
Secondary	Secondary
Urine	Carry disease
Weight increase (realised when theanimal is sold)	Destruction of crops, trees, trampling of land (which causes ecological damage)
Weeding–grazing	
Farmers’ preference	
Attractiveness of colour and appearance	
Seed distribution	
Research	

Table 7.2. *Checklist of costs involved in producing ruminants.*

Type of cost	Form of cost
Primary costs	
Variable costs	
Feed costs	
Concentrates	Cash
Grass and hay	Cash/non-cash
Mineral/supplements	Cash
Grain	Cash/non-cash
Water	Cash
Other costs	
Medicines/vaccines	Cash
Veterinary services	Cash
Breeding fees	Cash/non-cash
Supplies	Cash
Milk hauling/marketing	Cash/non-cash
Transportation	Cash/non-cash
Utilities	Cash
Hired labour	Cash
Other labour(family/exchange)	Non-cash
Stock replacement	Cash/non-cash
Fixed costs	
Housing/bedding	Cash/non-cash
Beginning stock	Cash
Land rent	Cash/non-cash
Depreciation	
Taxes, interest	
Secondary costs	
Destruction of crops	Cash/non-cash
Trampling of land	Non-cash
Noise, disease	Non-cash
Foul odour (animal and/or manure)	Non-cash
Threat to safety of small children	Non-cash

Table 7.3. *Checklist of benefits of producing ruminants.*

Type of benefit	Form of benefit
Primary benefit	
Milk	Cash/non-cash
Meat	Cash/non-cash
Work (large ruminants)	Cash/non-cash
Hides	Cash/non-cash
Manure	Cash/non-cash
Horn and/or hooves for feeds	Cash/non-cash
Horn and/or hooves for art	Cash/non-cash

Table 7.3. cont...

Table 7.3 cont...

Meat and milk by-products	Cash/non-cash
Transport (large ruminants)	Cash/non-cash
Capital asset	Cash
Reproduction	Cash/non-cash
Secondary benefit	
Urine	Non-cash
Weeding/grazing	Non-cash
Aesthetic value	Non-cash
Religious value	Non-cash
Pet value	Non-cash
Entertainment and sports	Non-cash
Research	Non-cash

7.3.3 An example of partial budget analysis for small ruminants

We will use an example to illustrate the steps used to calculate and interpret the results of partial budget analysis. The example will use data from experiments conducted in the Ethiopian highlands (Ehui and Rey 1992). The goal of the experiment was to solve nutritional and health problems faced by sheep in the Ethiopian highlands. Four treatments were used with 50 ewes:

- Treatment I (control): animals were under normal grazing, no drenching or feed supplementation
- Treatment II: animals were drenched with anthelmintics (Ranide and Panacur) three times per year
- Treatment III: animals were supplemented with 300 g wheat bran/ewe per day and 150 g noug cake/ewe per day in addition to normal grazing.
- Treatment IV: animals were both drenched and given feed supplementation

The results indicated that:

- nutritional supplementation leads to reduced mortality, heavier animals and higher lambing rates
- control of endoparasites leads to reduced mortality but had no significant effect on lambing rates or weight.

Production parameters for each treatment are listed in Table 7.4. The variable costs were found to be feeds, anthelmintics, labour for administering drenching, breeding stock depreciation charges and capital costs. The cost items and prices were as follows:

Cost item	Price (EB)
Drenching	3.00/50 ewes
Radine	0.41/treatment
Panacur	1.23/treatment
Wheat bran	6.38/100 kg
Noug cake	16.33/100 kg.

1. US$ 1 = EB 2.07

Table 7.4. *Small ruminant production parameters under four treatments in the Ethiopian highlands, 1989.*

Production parameters	Treatment I	Treatment II	Treatment III	Treatment IV
Annual reproduction rate (%)	1.02	1.02	1.35	1.35
Survival (%)				
0–4 months	0.75	0.85	0.85	0.85
4–8 months	0.85	0.90	0.90	0.90
8–12 months	0.95	0.95	0.95	0.95
Effective lambing rate (%)	0.62	0.74	0.98	0.98
Live weight at 12 months (kg)	17.48	17.88	18.78	18.78
Liveweight productivity per ewe (kg)	10.80	13.25	18.43	18.43
Number of ewes/ram	16.0	16.0	16.0	16.0
Average weight/head	24.77	24.77	28.67	30.37
Breeding stock mortality rate (%)	0.18	0.16	0.16	0.16

Treatment I = normal grazing; Treatment II = drenching with anthelmintics; Treatment III = feed supplementation; Treatment IV = both drenching and feed supplementation.

Using the data in Table 7.4, the cost and prices listed above, the gross and net return and marginal rate of return (MRR) were calculated for each treatment. The summary of results are shown in Tables 7.5 and 7.6. As an example, the marginal rate of return for Treatment II over Treatment I was computed as follows:

$$\Delta VC = VC\ (TII) - VC\ (TI) = 13.81 - 12.35 = 1.46$$

$$\Delta NI = NP\ (TII) - NP\ (TI) = 83.92 - 79.06 = 4.86$$

$$MPP = NI \div VC = 4.86 \div 1.46 = 3.34 = 334\%$$

Table 7.5. *Gross return (EB/ewe) of feeding and health management experiments for sheep, Debre Birhan, Ethiopia, 1989.*

	Treatment I	Treatment II	Treatment III	Treatment IV
Mean price/kg LW (EB)	2.57	2.57	2.57	2.57
Mean liveweight productivity at 12 months (kg/ewe)	10.80	13.25	18.42	18.42
Average weight/head (kg)	24.77	24.77	28.67	30.37
Gross return (EB)/ewe[1]	91.4	97.72	121.03	125.40

Treatment I = normal grazing; Treatment II = drenching with anthelmintics; Treatment III = feed supplementation; Treatment IV = both drenching and feed supplementation; EB = Ethiopian Birr.

1. [(Mean liveweight productivity at 12 months (kg/ewe) × 2.57)+(Average weight/head (kg) × 2.57)].

Table 7.6. *Results of feeding and health management experiments for sheep, Debre Birhan, Ethiopia, 1989.*

	Treatment I	Treatment II	Treatment III	Treatment IV
Gross returns (EB)	91.41	97.72	121.03	125.40
Cash costs				
Feed				
Noug cake	–	–	8.94	8.94
Wheat bran	–	–	6.98	6.98
Veterinary	–	0.41	–	0.41
Ranide	–	1.23	–	1.23
Panacur	–	0.54	–	0.54
Labour				
Non-cash costs				
Capital cost (at 30% per annum)	–	0.65	4.78	5.43
Breeding stock depreciation charges	12.35	10.98	12.7	13.46
Total costs that vary (VC)	12.35	13.81	33.41	36.99
Net return (NR)	79.06	83.92	87.62	88.41
Net return over control	–	4.86	8.56	9.35
Marginal rate of return (MRR) (%)	–	334.00	19.00	22.00

Treatment I = normal grazing; Treatment II = drenching with anthelmintics; Treatment III = feed supplementation; Treatment IV = both drenching and feed supplementation; EB = Ethiopian Birr.

Figure 7.7 illustrates the net benefit curve for the data. The figure also shows the values for MRR for the added benefits of TII over I, TIII over II, and for TIV over III. The following are interpretations of the partial budget analysis results:

- Treatment IV yields the highest return over the control followed by Treatment III.
- If cash is not a constraint, feed supplementation would be recommended to farmers.
- The increase in benefit is accompanied by an increase in cost; farmers would not adopt this technology if it were recommended to them.
- The added benefits from Treatment II are EB 4.86 and a 334% marginal rate of return.
- The added benefits from Treatment III are EB 3.71 and a 19% marginal rate of return.
- The added benefits from Treatment IV are EB 0.78 and a 22% marginal rate of return.

We can conclude that:

- treatments with supplemental feeding (Treatment III) and supplemental feeding with drenching (Treatment IV) cannot be recommended to the farmers
- drenching (Treatment II) can be suggested for on-farm testing as it yielded a very high marginal rate of return (334%) on station.

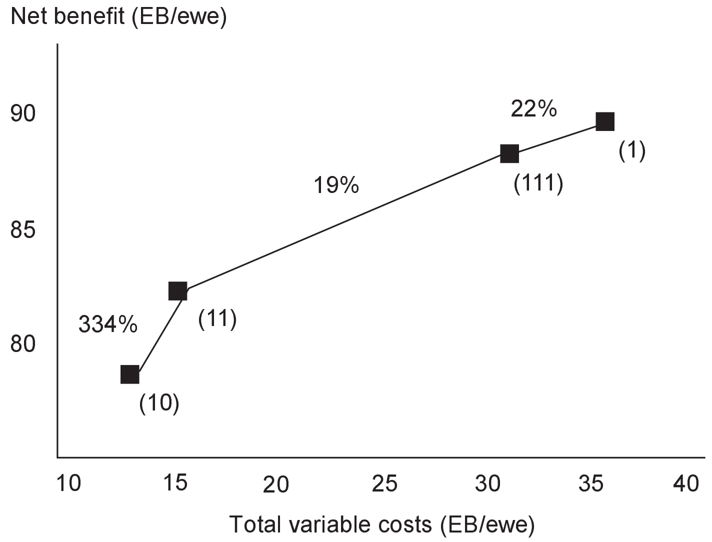


Figure 7.7. *Net benefit curve, feeding and health management trials, Ethiopian highlands, 1989.*

7.4 Exercises

1. The following table shows data for variable amounts of feed used by a farmer and the corresponding milk output.

Feed		Milk		Marginal product
X	ΔX	Y	ΔY	( )*
(kg)	(kg)	(kg)	(kg)	
2	( )*	10	( )*	( )*
4	( )*	30	( )*	( )*
6	( )*	60	( )*	( )*
8	( )*	100	( )*	( )*
10	( )*	150	( )*	( )*

( )* : Fill in the parenthesis with the appropriate figures.

Make the necessary computations and use your knowledge on production relationships to fill in the ( )* with the missing words, letters and numbers.

2. Complete the partial budget for on-farm fattening sheep experiment at Hidi/Debre Zeit, Ethiopia, in the wet season during 1991.

Treatments

- Treatment 1: Grazing (plus 400 g teff straw per head/day)
- Treatment 2: Grazing plus supplementation (100 g Sesbania, 50 g noug cake, 8 g salt, 5 g bone meal and 50 g wheat bran per head/day)
- Treatment 3: Pen-feeding (700 g teff straw, 100 g Sesbania leaves, 50 g noug cake, 8 g salt, 5 g bone meal and 50 g wheat bran per head/day)

Data (Ethiopian Birr/sheep) for variable costs, revenue from sales are given below:

	Treatment group*					
	1		2		3	
	NVT	VT	NVT	VT	NVT	VT
Revenue from sales	73.50	97.34	154.11	131.26	120.48	114.48
Total variable costs	44.36	71.65	101.11	90.50	90.00	87.00
Sheep purchase	28.50	29.10	29.40	28.65	29.65	28.85
Feed						
Teff straw	5.76	5.76	–	–	10.08	10.08
Sesbania	–	–	6.19	6.19	6.19	6.19
Noug cake	–	–	1.54	1.54	1.54	1.54
Wheat bran	–	–	0.76	0.76	0.76	0.76
Salt	–	–	0.76	0.76	0.76	0.76
Bone meal	–	–	0.24	0.24	0.24	0.24
Labour						
Per diem	1.0	1.0	1.0	1.0	1.0	1.0
Labour	8.0	8.0	8.0	8.0	8.0	8.0
Veterinary drugs (Ranide)	–	1.10	–	1.10	–	1.10
Transportation (sheep)	1.10	1.10	1.10	1.10	1.10	1.10
Net return						
Net return over Control						
Marginal rate of return (%)						

*NVT = no veterinary intervention; VT = veterinary intervention.

(A) Calculate: (i) net return (ii) net return over control and (iii) marginal rate of return (%).

(B) Draw conclusions in relation to (i) what the most profitable treatment is (ii) your recommendation to the farmers concerning feeds (iii) your recommendation to the farmers concerning veterinary services.

7.5 References and reading materials

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Module 8: Biometrics techniques

8.1 Performance objectives

Module 8 is intended to enable you to:

1. Define the basic concepts of biometry.
2. Define descriptive statistical parameters.
3. Compute variance, standard deviation, coefficient of variation, standard error, confidence interval of normal, binomial and Poisson variables.
4. Write statistical models to fit a set of data.
5. Compute analysis of variance.
6. Use the t-test.
7. Compute regression analysis.
8. Compute analysis of covariance.
9. Use the Chi square (χ^2) test.
10. Plan experiments.
11. Use randomisation techniques.
12. Know how to design sample surveys.
13. Compute sample sizes for experiments or sureys.
14. Present results.

8.2 Introduction

Animal research comprises both experiments and surveys conducted either on a station, on a farm or in the field. Such research has to be properly designed and conducted, and the results must be statistically analysed and interpreted. Typically, comparable groups of animals are subjected to specified treatments for some predetermined period and the results of these imposed treatments, as measured by one or more variables, are used to estimate different types of responses.

The scope of this course is to introduce some of the basic principles of experimental design and statistical analysis. The purpose of good experimental design is to ensure that the results obtained are free of bias and that interpretations can be made which are uncomplicated by the existence of uncontrolled factors. Statistical analysis, from calculation of treatment means and standard errors to the more elaborate techniques of analysis of variance, is a useful and necessary tool for researchers. However, only experiments of sound design permit sound statistical analysis and interpretation.

The data set that will be used throughout much of this module is from an experiment carried out to study the effect of supplementation of weaned lambs on their health and growth rate (Table 8.1). Sixteen

Table 8.1. *Data set for the effect of supplementation on health and growth rate of weaned Red Maasai and Dorper lambs.*

Record	ID No.	Breed	Sex	Supplement	Block	Weaning weight	Weigtht at 6 mo. (kg)	PCV (%)	FEC (epg)	Weight gain (kg)
1	349	1	2	1	1	8.0	8.4	10	6500	0.4
2	326	1	2	1	1	9.0	9.6	11	2650	0.6
3	393	1	1	1	2	12.0	12.1	22	750	0.1
4	71	1	1	1	2	12.3	14.1	15	5200	1.8
5	271	1	1	1	3	13.0	13.2	19	4800	0.2
6	382	1	2	1	3	15.5	16.3	24	2450	0.8
7	85	1	2	1	4	16.3	17.7	27	200	1.4
8	176	1	2	2	4	15.9	17.2	21	3000	1.3
9	286	1	2	2	1	11.0	13.1	21	1600	2.1
10	183	1	1	2	1	9.9	11.2	21	450	1.3
11	21	1	2	2	2	11.6	12.6	25	2900	1.0
12	122	1	1	2	2	12.5	14.3	25	300	1.8
13	374	1	1	2	3	14.6	17.4	19	2250	2.8
14	32	1	2	2	3	14.2	16.4	22	2800	2.2
15	282	1	2	2	4	16.3	19.7	20	750	3.4
16	94	1	1	2	4	16.7	17.2	13	5600	0.5
17	127	2	2	1	1	8.5	9.1	26	1350	0.6
18	216	2	2	1	1	9.5	10.3	19	1150	1.1
19	133	2	1	1	2	11.1	12.7	30	200	1.6
20	249	2	1	1	2	9.8	11.4	28	0	1.6
21	123	2	2	1	3	12.6	13.6	23	600	1.0
22	222	2	2	1	3	12.3	14.5	24	1500	2.2
23	290	2	2	1	4	13.3	15.3	22	1950	2.0
24	148	2	1	1	4	14.1	15.9	26	500	1.8
25	142	2	2	2	1	9.2	12.5	25	850	3.3
26	154	2	2	2	1	9.5	13.2	35	700	3.7
27	166	2	1	2	2	10.7	13.8	29	400	3.1
28	322	2	1	2	2	9.6	13.0	26	800	3.4
29	156	2	1	2	3	11.2	14.0	28	1550	2.8
30	161	2	2	2	3	12.2	15.6	22	550	3.4
31	321	2	1	2	4	13.1	16.9	25	1250	3.8
32	324	2	1	2	4	14.8	19.1	24	1100	4.3

Red Maasai and 16 Dorper lambs were treated with an anthelmintic at weaning (approximately 3 months of age) and assigned at random to supplemented and non-supplemented groups (eight lambs in each group). All lambs grazed on pasture for a further 3 months. At night they were housed and lambs in the supplemented group were fed cottonseed cake and bran meal. Data recorded included body weight at weaning and at six months of age, packed red cell volume (PCV) and faecal egg count (FEC) at 6 months of age.

Some of the questions we will attempt to answer will be:

- Did supplementation improve weight gain?
- Did supplementation affect PCV and FEC?
- Were there any differences in weight gain, PCV or FEC between breeds?
- Is the experiment well designed?
- Is the size of experiment (number of animals per group) sufficient to detect differences between breeds and diets?

8.3 Background to basic biometry

8.3.1 Methods of describing data

Research data consist of recorded observations or measurements made on **experimental units**, e.g. animals. We shall discuss later how to decide what should be the basic experimental unit in a statistical analysis. Measured characteristics such as body weight, growth rate, PCVand FEC are called **variables**.

One of the first steps in analysing research data should be to examine the frequencies of different values recorded for the variables measured. This will help organise the data in some way and summarise their main features and may also help to spot data errors or extreme values.

Frequency table

A useful starting point is to examine the range spanned by the data. To do this, one finds the lowest and highest value of a variable (e.g. PCV) and divides the range into a reasonable number of intervals. The numbers of data values that occur within each interval are counted and made into a table (Table 8.2). After calculating the number of animals in each class interval, the relative frequency, which is the percentage of values contained in each interval, can then be calculated. This shows how the data are distributed. Table 8.2 shows that a majority of animals have PCVs between 19 and 30. Four animals have PCVs below and one animal has a PCV above this range. The frequency distribution for FEC is very different with the majority of values at the lower end of the range (Table 8.3).

Table 8.2. *Number of animals grouped by packed cell volume (PCV) category.*

PCV class interval (%)	Frequency of animals	Relative frequency (%)
10–12	2	6
13–15	2	6
16–18	0	0
19–21	7	22
22–24	8	25
25–27	8	25
28–30	4	12
31–33	0	0
34–36	1	3
Total	32	100

Table 8.3. *Number of animals grouped by faecal egg count (FEC) category.*

FEC class interval (epg)	Frequency of animals	Relative frequency (%)
0–700	12	38
800–1500	8	25
1600–2300	3	9
2400–3100	5	16
3200–3900	0	0
4000–4700	0	0
4800–5500	2	6
5600–6300	1	3
6400–7100	1	3
Total	32	100

Histogram

Tables can be presented pictorially by means of a diagram, known as a histogram. A histogram helps identify the shape of the distribution. Sometimes the histogram is more or less symmetrical, with the bulk of the data gathered near the centre and the proportions of data on each side roughly balancing each other. Sometimes the histogram is **skewed**. This means that the data are rather bunched up to one side. Figure 8.1 gives an example of the skewed distribution of FEC. There are more data values to the left than the right. Biological data often belong to a **normal distribution**; the frequency distribution is '**bell-shaped**'**; the distribution of PCV approximates to this shape.**

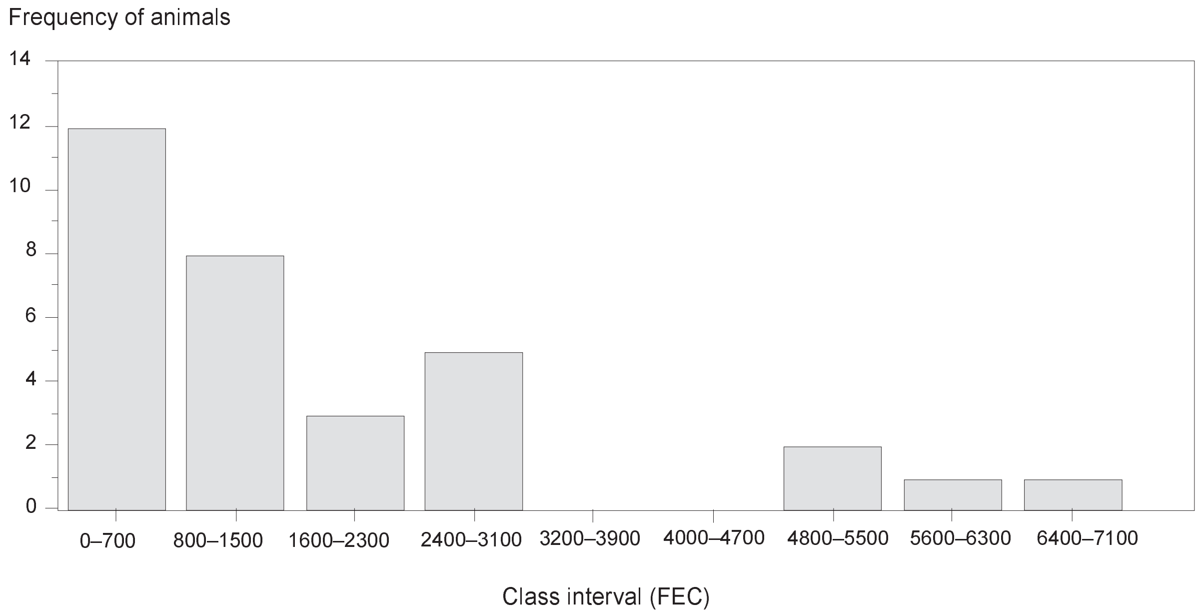

Figure 8.1. *Histogram of frequency distribution of faecal egg counts (FEC).*

Scatter plots

Graphs derived by plotting one variable against another are commonly used to examine relationships between two variables. Figure 8.2 shows a scatter plot of PCV and FEC. Such a scatter plot can also indicate outliers (i.e. data values which are rather extreme and appear different from the others). Such outliers may be due to data errors. Figure 8.2 shows one possible outlier. Let us assume that during data entry lamb 94 has had its PCV digits transposed by mistake from 13 (see Table 8.1) to 31. With such a high FEC its PCV value is somewhat away from the others towards the top right corner of the diagram. Examination of the input data shows that a mistake has been made in data entry.

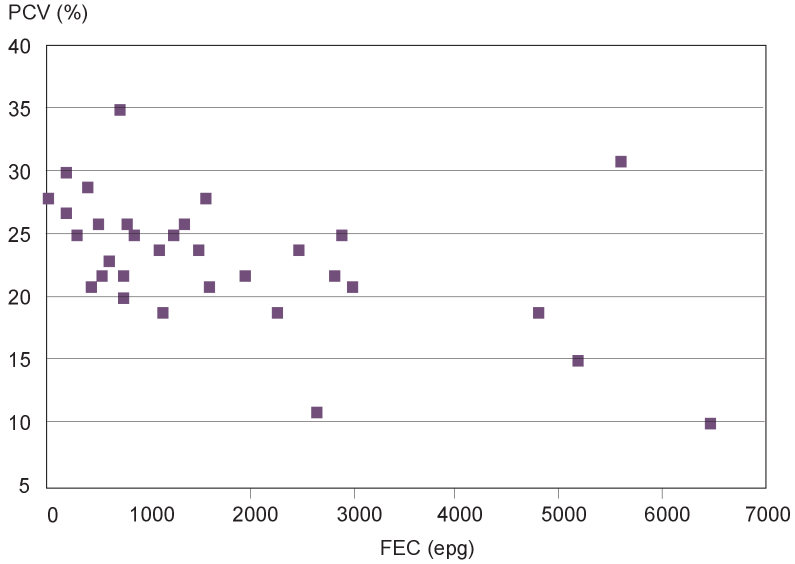

Figure 8.2. *Scatter plot of packed cell volume (PCV) versus faecal egg count (FEC) with mistake in PCV value (31 rather than 13%) for lamb 94.*

Of course, when all the data are described together like this, variations due to diet and breed are hidden. If possible, it is best to summarise the data in each group separately. Quite a nice way is to use what is known as Tukey's box and whisker plot (Figure 8.3), which displays the range, median and quartiles (with the middle half of the data contained within the box and the remainder described by the vertical lines) for each group alongside each other.

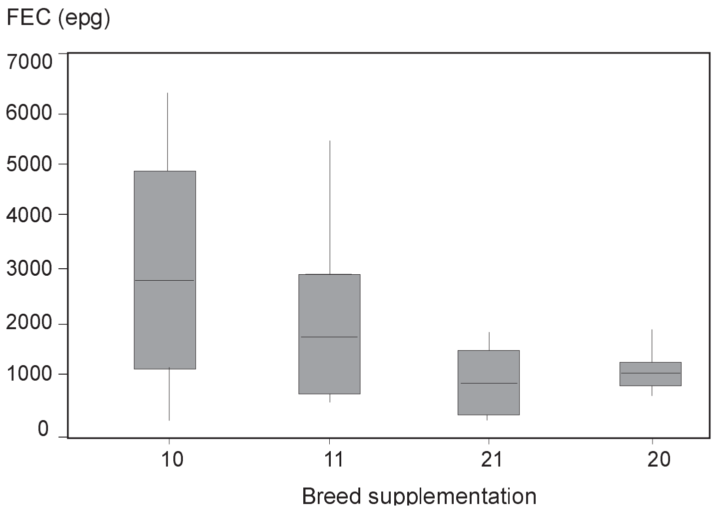

Figure 8.3. *Box plot of faecal egg count (FEC) for each breed–supplementation group.*

8.3.2 Descriptive statistics

Mean

Tables and graphs, such as those already described, are often useful and revealing. They are always the first step in attempting to summarise a set of data and to look at its structure. One of the first items of interest is a measure of a central or representative overall value.

The most commonly used measure is the **arithmetic mean** (usually referred to simply as the **mean**). The mean is obtained by dividing the sum of all the observations by the number of observations. The calculation of the arithmetic mean may be demonstrated for the Dorper lambs (breed 1) that were non-supplemented (diet 1) by using their weights at 6 months.

mean = (8.4 + 9.6. + ...+ 17.2)/8 = 108.6/8 = 13.575 kg

The mean is a kind of central value. However, the mean can be somewhat misleading if the distribution is skewed, i.e. if there is a high proportion of large values or a high proportion of small values. The problem is that a few extreme values unduly influence the value of the mean. In these situations the median may be a very useful alternative. The median is the value lying in the middle, such that one half of the values are above and one half below. Putting the 6-month body weights in order, we get 8.4, 9.6, 12.1, 13.2, 14.1, 16.3, 17.2, 17.7; the median value is therefore 13.65 kg. If there is an odd number of values, the median is the middle value. In both cases, the numbers must be arranged in ascending order (from smallest to largest) before calculating the median.

These two values (for mean and median) are in this case very similar. For FEC, however, we might expect the mean and median to be more different. Thus, if we put FECs for the same animals in order, we get 200, 750, 2450, 2650, 3000, 4800, 5200, 6500. Thus, the median is 2775 while the mean is 3194, which is somewhat higher. For a variable such as FEC, for which the frequency is skewed, the mean will often be greater than the median.

Variance and standard deviation

Biological processes yield variable data. The most common measures of variability are the **variance** and **standard deviation.** The variance of a group of observations is calculated as the sum of squares of deviations from the mean divided by one fewer than the number of observations. Thus the variance of the 6-month body weights for breed 1, diet 1 is calculated as:

$[(8.4 - 13.575)^2 + (9.6 - 13.575)^2 + ... + (17.2 - 13.575)^2]/7$

$= [(-5.175)^2 + (-3.975)^2 + ...+(3.635)^2]/7 = 82.755/7 = 11.8221 \text{ kg}^2$

An alternative formula, which is easier to use with a large number of observations, is to calculate the sum of each value squared, subtract the total squared divided by the number of observations, and divide the answer by the number of observations less one. Using this method the variance becomes:

$[8.4^2 + 9.6^2 + ... + 17.2^2 - (108.62/8)]/7$

$= (1557.0 - 1474.245)/7 = 82.755/7 = 11.8221 \text{ kg}^2$ and the answer is the same.

While it is often convenient to use the variance based on squared deviations as a measure of dispersion or variation of the data, it is often usual also to think of this variation in terms of the original units. By taking the square root of the variance one returns to the original scale of measurement. The square root of the variance is known as the **standard deviation (SD).**

Thus the standard deviation = $\sqrt{11.8221}$ = 3.438 kg.

Coefficient of variation

We have shown that the variation among a set of observations can be measured using the variance or the standard deviation. There are occasions when we wish to compare the relative variation between two variables having different means, e.g. birth weights of calves and adult weights of cows. Since the adult weights would be expected to have a larger standard deviation because of the larger values involved, a comparison of the two standard deviations may not be very helpful. We might also be interested in comparing the relative variation between different characteristics or traits of the same animals, e.g. weaning weights and PCV of calves. For such comparisons the **coefficient of variation (CV)** is calculated as the standard deviation expressed as a percentage of the mean. Thus, for 6-month body weight for breed 1, diet 1, the coefficient of variation:

$$CV = (SD \div \text{mean}) \times 100 = (3.438/13.575) \times 100 = 25.3\%$$

The CV is independent of the unit of measurement. For body weight or PCV, for example, coefficients of variation of the order of 10% might normally be expected. Growth rates, however, often have higher coefficients of variation. This example shows that the spread of 6-month weights in this group of lambs is wider than one would normally expect.

The descriptive statistics for the 32 animals in the example data set are summarised in Table 8.4. Note the high CVs for all variables, particularly for weight gain and FEC. The comparatively large CVs for body weight and PCV may have been due to the exposure of these lambs to high levels of helminth infestation.

Table 8.4. *Descriptive statistics of variables measured in the example data set.*

Variable	Mean	Median	Standard deviation	Coefficient of variation
Weaning weight (kg)	12.19	12.25	2.49	20.4
6-month weight (kg)	14.11	13.90	2.82	20.0
Weight gain (kg)	1.92	1.80	1.18	61.4
Packed cell volume (%)	22.72	23.50	5.35	23.6
Faecal egg count (epg)	1770	1200	1686	95.3

Number of animals = 32.

8.3.3 Precision of estimated parameters

Standard error

Suppose the experiment were repeated several times. Each time we would calculate a mean, say for breed 1, diet 1, each mean would be different. Thus there would be variability among means just as there is variability among individual observations in each sample. However, since each mean is averaged over eight observations, the variation among means would be smaller than the variation among individual observations. The variance of a mean can be calculated as the average of the variances calculated each time the experiment is conducted divided by the number of observations used for calculating each mean. The standard deviation of the mean is known as the **standard error.**

The standard deviation is a useful measure of the variation of an individual observation. The standard error is a useful measure of the variation of a mean. Normally we would not repeat an experiment to calculate the average variation of the mean. Instead, we pretend that the variance of individual observations will remain constant from experiment to experiment (in practice it will not vary much) and use the value already calculated as an estimate of this average. Thus, we can then calculate, for the 6-month body weights of sheep in breed 1 fed diet 1:

$$\text{variance of mean} = 11.8221/8 = 1.4778 \text{ kg}^2$$

$$\text{standard error} = \sqrt{1.4778} = 1.22 \text{ kg}$$

The standard error or variance of a mean decreases as the number of observations increases. Thus, for example, if 24 sheep were used for each breed, then, for breed 1 diet 1:

variance of mean = 11.8212/12 = 0.9926 kg^2

standard error = 1.00 kg

Note that this standard error is lower than the value calculated above with 8 sheep.

Confidence interval

The standard error can be used to develop what is known as a **confidence interval.** A confidence interval is a range between upper and lower limits, which is expected to include at a given level of probability the true (or population) mean value. This is the value for which the sample in the experiment provides an unbiased estimate.

Usually we talk about the 95% confidence interval. This is the interval in which the true mean should lie with a 95%, or 19 times in 20, chance of being correct. Similarly, the 99% confidence interval gives the range within which we expect the true mean to lie with a 99%, or 99 times in 100, chance of being correct. The approximate 95% confidence interval can be calculated as the sample mean plus or minus twice the standard error. Similarly, the 99% confidence interval is the sample mean plus or minus approximately 2.6 times the standard error. Thus the approximate 95% confidence interval for the mean 6-month body weight of lambs of breed 1 fed diet 1 is:

$13.58 \pm 2 \times 1.22 = (11.14 \text{ to } 16.02)$ kg

Similarly, the approximate 99% confidence interval is:

$13.58 \pm 2.6 \times 1.22 = (10.41 \text{ to } 16.75)$ kg

As one might expect, the 99% confidence interval is wider than the 95% one. Another way of thinking about this is to say that if the experiment were repeated 100 times then we would expect that on 99 occasions the sample mean would fall within the range 10.41 to 16.75 kg, and on the other occasion it would fall outside.

It should be emphasised that the above formula is only approximate; instead of 2 or 2.6 we should strictly use a t-value with the appropriate degrees of freedom; t-values will be discussed later.

Binomial and Poisson variable

Sometimes response variables take on the values 0 or 1. These could be, for example, mortality or disease. The variables are sometimes described as **discrete** variables, i.e. they can only take on discrete values. Variables such as body weight are known as **continuous** variables, i.e. they can take on any value within a reasonable range to a given degree of accuracy. Discrete variables such as mortality and disease often belong to distributions that are not normal, but **binomial** or **Poisson** distributions. Discrete variables taking on values 0 or 1 are also sometimes called **binary** variables. For example, suppose that 4 lambs in a sample of 20 die before weaning. We can record a death as 1, a lamb that survived as 0. The proportion of lambs that died is p = 4/20 = 0.2. This is simply the mean of the 0s and 1s, i.e. (1+1+1+1+0....+0)/20 = 4/20 = 0.2. Mortality is typical of a variable that is associated with a probability of occurrence, p. Such variables typically belong to a binomial distribution.

We have seen that the mean = p, and that this can be calculated in an analogous way to that of a normally distributed variable. The binomial distribution, however, has a special expression for the variance, namely $p(1 - p)$. Thus if p = 0.2, then variance = $0.2 \times 0.8 = 0.16$.

The standard deviation and standard error are similarly calculated, i.e.

standard deviation = $\sqrt{0.16} = 0.4$

standard error = $\sqrt{(0.16/20)} = 0.089$

The distribution of certain binary data is often closer to that of a Poisson distribution, a distribution associated with rare events. Incidence of trypansomosis, for example, can often be considered as being associated with a Poisson distribution, particularly if the prevalence is very low (e.g.<10%). The mean is the same as that for the binomial distribution, namely p. The variance, however, is different from that of the binomial distribution and is also p. Thus, if the prevalence of trypanosome infections is 0.06 in a sample of 100 cattle, (i.e. 6/100 are detected parasitaemic), then the variance is also 0.06 and

standard deviation $= \sqrt{0.16} = 0.24$

standard error $= (\sqrt{0.06/100}) = 0.024$

In practice when p is small (<0.1), it does not matter whether one assumes a binomial or Poisson distribution.

8.3.4 Analysis of variance

Statistical models

So far these course notes have been prepared without using mathematical, algebraic equations. This has been deliberate. However, statistical concepts are often presented mathematically and it is important for biologists not to be frightened by the formulae that sometimes appear in scientific papers. Formulae are often the easiest way to describe the statistical methods that have been applied.

If we look at the structure of our example data set we can see that each variable, weaning weight, 6-month body weight, PCV, FEC and weight gain, can be characterised by other attributes. For example, records 1–8 all refer to lambs from breed 1. They are also characterised by the fact that these lambs were not supplemented. Thus, we can say that each record is made up of a component due to breed and a component due to diet. We shall use a letter to refer to each of these components, namely b (breed), d (diet). These components are often referred to as factors or parameters. It is common to give a subscript to each parameter level. For example, we have 2 breeds. Let us refer to them as b_1, b_2. Similarly, we have 2 diets, d_1, d_2. Thus, for example, records 1–8 are each made up of $b_1 + d_1$.

Similarly, records 9–16 are made up of b1 + d2 and records 25–32 of $b_2 + d_2$. It is usual to use the letter y to refer to the variable to be analysed and to use a combination of subscripts to refer to the particular data value. Thus:

$y_{111} = b_1 + d_1$ for record 1

$y_{124} = b_1 + d_2$ for record 12

$y_{225} = b_2 + d_2$ for record 29

Note that the first subscript refers to breed, the second to diet and third to lamb number (1–8) within each breed–diet category.

Normally b and d are defined as deviations from the overall mean for which the symbol μ is normally used. Also, since there are fewer factor levels (2 + 2) than there are lambs (32), each observation will deviate from the sum of the 2 parameter levels by an amount usually described by the letter e or ε, known as the **error** or **residual** term.

Thus, the above equations are written in full as:

$$y_{111} = \mu + b_1 + d_1 + e_{111}$$

$$y_{124} = \mu + b_1 + d_2 + e_{124}$$

$$y_{225} = \mu + b_2 + d_2 + e_{225}$$

Thus, each observation is made up of an overall mean, a term for breed, a term for diet and a residual. These equations can be written more generally as:

$$y_{ijk} = \mu + b_i + d_j + e_{ijk} \ (i = 1, 2; j = 1, 2; k = 1....8)$$

The purpose of analysis of variance is to estimate the overall significance of differences among each set of parameter means. It separates variations due to breed and diet from each other, and compares the magnitudes of these different sources of variation with the variation which is left over among residual terms. In using analysis of variance, two main assumptions are used: firstly, that the eijks have the same distribution for each parameter or factor (i.e. are not more variable for one than another) and, secondly, they are distributed normally. Thus, it is not strictly valid to use analysis of variance for discrete variables that are associated with binomial or Poisson distributions.

In developing the idea of analysis of variance it will be simplest to start with a model based on just the four groups of lambs categorised by breed and diet in the data set, but ignoring the breed–diet structure. The model we shall first use, with g signifying group, is:

$$y_{ij} = \mu + g_i + e_{ij} \ (i = 1....4; j = 1....8)$$

It is important to emphasise the need for writing down the statistical model to be fitted to a set of data before embarking on a statistical analysis. It helps the researcher decide the form the analysis of variance should take.

One-way analysis of variance

The model:

$$y_{ij} = \mu + g_1 + e_{ij}$$

is an example of a **one-way analysis of variance.** Such an experiment is often referred to as a completely randomised design.

The **degrees of freedom (df)** for the variation among groups is calculated as one fewer than the number of groups (i.e. 4–1). The total degrees of freedom = 32 (number of lambs)–1. The residual degrees of freedom is calculated by subtracting the among groups df from the total df.

The following calculations calculate the **sums of squares (SS)** and **mean squares (MS).**
Total. This is the same calculation as used previously for the variance, i.e. the sum of squares of individual observations minus the square of the total divided by the number of observations. Mathematically we can write this as:

$$\Sigma y_{ij}^2 - (\Sigma y_{ij})^2/32$$

Thus, if we apply this formula to the weight gains of the 32 lambs, we obtain:

$$\text{total SS} = 160.78 - 61.4^2/32 = 160.78 - 117.8112 = 42.9688$$

Groups. The formula for the among group sums of squares uses the totals for each group divided by the number of lambs in each group. It is:

$$\Sigma Y_{i.}^2/8 - (\Sigma Y_{ij})^2/32$$

The capital letter Y, together with the dot, means the sum of the individual yijs summed over the subscript that the dot is replacing, in this case, j. Thus:

$$Y_{i.} = y_{11} + y_{12} + ... + y_{18}$$

The among group SS for weight gain is therefore:

$$(6.6^2 + 15.1^2 + 11.9^2 + 27.8^2)/8 - 61.4^2/32 = 148.2525 - 117.8112 = 30.4413$$

The among group mean square equals the among group sum of squares divided by the among group degrees of freedom. Thus:

Among group MS = 30.4413/3 = 10.1471

Residual. We calculate the residual sum of squares by subtracting the among group sum of squares from the total sum of squares. Thus:

Residual SS = 42.9688 – 30.4413 = 12.5275

Residual MS = residual SS/residual df = 12.5275/28 = 0.4474

Putting the results of these calculations into the analysis of variance we get:

Source of variation	df	SS	MS	F
Among groups	3	30.4413	10.1471	22.7
Residual	28	12.5275	0.4474	
Total	31	42.9688		

The residual MS estimates the average variation among individuals within groups and is an estimate of the average within group variance of weight gains. The among group MS represents the additional variation brought about by the differences in mean weight gains among the four groups. The magnitude of this additional variation can be assessed by dividing the among group MS by the residual MS to give what is known as the **F-value**. Thus:

F = 10.1471/0.4474 = 22.7

We use this value to compare with values in F-tables with 3 and 28 degrees of freedom. If we look at the column headed 3 df at the top of each of the F-tables and then come down this column until we reach 28 df on the left hand side, we find the values 2.95, 4.57, and 7.19 for 5%, 1% and 0.1% levels of probability, respectively. If our observed F-value exceeds any of these values, then we say it is statistically significant. The value of 22.7 exceeds the value of 7.19. Thus, the analysis of variance shows that there is a highly significant variation in liveweight gain among the four groups of lambs at the 0.1% level of statistical significance. This is normally described using the notation ($P<0.001$). In other words, the probability of there being no differences among the 4 groups of lambs is less than 1 in 1000.

Factorial analysis of variance

The groups of lambs in the experiment have been assigned a particular structure. In other words the 4 groups are composed of combinations of 2 diets and 2 breeds, namely:

	Supplementation	
Breed	Yes	No
1	1	2
2	3	4

This design, sometimes described as a 2×2 factorial design, is a very useful way of getting as much information from an experiment as possible. Thus we can look at the effects of dietary supplementation on weight gain of two breeds at the same time. What is more, we can look at the way that dietary supplementation and breed may interact. If there is no **interaction** then we mean that any effect of dietary supplementation is the same for each breed. If there is an interaction then the effect of supplementation is different for different breeds.

We can rewrite our statistical model as follows:

$$y_{ijk} = \mu + b_i + d_j + (bd)_{ij} + e_{ijk}$$

where $(bd)_{ij}$ is a notation used to signify the interaction of breed and diet.

If the analysis shows there to be no significant interaction then we could express the model as:

$$y_{ijk} = \mu + b_i + d_j + e_{ijk}$$

In other words, the model simply adds to breed the same estimate for diet irrespective of breed. Sometimes we refer to such effects as being **additive**.

To estimate sums of squares for breed and diet we split the sums of squares we have already obtained for groups, namely:

$$\Sigma Y_{ij.}{}^2/8 - (\Sigma yijk)^2/32$$

into a component for breed:

$$\Sigma Y_{i..}{}^2/16 - (\Sigma_{yijk})^2/32$$

and a component for diet:

$$\Sigma Y_{.j.}{}^2/16 - (\Sigma_{ijk})^2/32$$

The expression we had earlier for the among group SS was:

$$(6.6^2 + 15.1^2 + 11.9^2 + 27.8^2)/8 - 61.4^2/32 = 30.4413$$

The between breed SS becomes:

$$(21.7^2 + 39.7^2)/16 - 61.4^2/32 = 10.1250$$

(where 21.7 and 39.7 are total weight gains for breed 1 and breed 2, respectively).

The between diet SS becomes:

$$(18.5^2 + 42.9^2)/16 - 61.4^2/32 = 18.6050$$

(where 18.5 and 42.9 are total weight gains for diet 1 and diet 2, respectively).

This results in sums of squares of 30.4413, 10.1250 and 18.6050 for group, breed and diet, respectively. The sum of squares for the interaction can be obtained by subtraction of the last two numbers from the first, i.e. 30.4413 – 10.1250 – 18.6050 = 1.7113. We can then complete the analysis of variance table as follows:

Source of variation	df	SS	MS	F	Probability
Breed (B)	1	10.1250	10.1250	22.63	<0.001
Diet (D)	1	18.6050	18.6050	41.58	<0.001
Interaction (B×D)	1	1.7113	1.7113	3.82	0.06
Residual	28	12.5275	0.4474		
Total	31	42.9688			

This analysis demonstrates a highly significant difference between breeds in average weight gain, a highly significant effect of supplementation with cottonseed cake and bran meal and an interaction approaching statistical significance. But how precisely were these effects manifested? We need to look at the mean values and calculate their standard errors to determine the precision with which they are estimated. We can then apply earlier knowledge to calculate confidence limits for each mean.

Mean values for weight gain (kg) are as follows:

	Supplementation		
Breed	No	Yes	Mean
1	0.82	1.89	1.36
2	1.49	3.48	2.48
Mean	1.16	2.68	1.92

Standard errors (SE) can be calculated as the square root of the residual variance divided by the number of observations. From the analysis of variance the residual variance = 0.4474 kg^2. Therefore, SE of any mean in the body of Table 8.1 = $\sqrt{(0.4474/8)}$ = 0.236. Similarly, SE of overall mean of supplementation (yes or no) = $\sqrt{(0.4474/16)}$ = 0.167; SE of overall breed mean = $\sqrt{(0.4474/16)}$ = 0.167 kg.

8.3.5 t-test

We now have a good idea from the last section that there are highly significant differences between breeds and diets. We shall now formalise the method for analysing differences between residual means when there are more than two breeds or diets. Instead of the F-test, which considers the variation among any number of levels of a factor, we use the **t-test** which looks at the variation between just two levels. The formula for the t-test is:

t = (difference between two means)/(SE of difference between two means)

The **SE of the difference between two means (SED)** is calculated as the square root of the variance multiplied by $(1/n_1 + 1/n_2)$ where n_1 and n_2 are the numbers of observations respectively making up the two means to be compared. Thus:

$$SED = [\text{variance} \times (1/n_1 + 1/n_2)]$$

When $n_1 = n_2$ the formula reduces to:

$$SED = \sqrt{(2 \times \text{variance of mean})} \text{ or } \sqrt{2} \times SE.$$

To better illustrate the use of the t-test let us return to the one-way analysis of variance and pretend that the four group means now represent sheep fed four different legume species. Thus to compare the difference between weight gains for legume species 1 and 2 we get:

$$t = (1.89 - 0.82)/(\sqrt{2} \times 0.236) = 1.07/0.334 = 3.20$$

We compare this value with t-values in the t-table using the number of degrees of freedom, namely 28, for the residual variance. With 28 df we get t-values of 2.05, 2.76 and 3.67 at 5%, 1% and 0.1% levels of significance, respectively. The value of 3.20 is less than 3.67 but greater than 2.76, and so the difference in weight gain for these two species is significant ($P<0.01$). However, if we compare species 2 and 3 we get:

$$t = (1.89 - 1.49)/(\sqrt{2} \times 0.236) = 1.20$$

which is not significant.

Least significant difference

It is sometimes more convenient to calculate the **least significant difference (LSD)** needed for the difference between two means to be significant. This is calculated as:

$$LSD = t \times SED$$

Thus, for the 4 legume species means

LSD = 2.05 × 0.334 = 0.68 at the 5% level of significance

= 2.76 × 0.334 = 0.92 at the 1% level of significance

= 3.67 × 0.334 = 1.23 at the 0.1% level of significance

We can then compare differences between the respective means with these values to determine their significance. Thus, for example,

1.89 − 0.82 = 1.07 : significance level $P<0.01$

3.48 – 1.89 = 1.59 : significance level P<0.01

1.49 – 0.82 = 0.67 : not significant

8.3.6 Blocking

One aim of good experimental design is to ensure that the residual mean square is as small as possible. One way to do this is to ensure that animals are as uniform as possible before the experiment starts. Another is to ensure that animals with similar attributes are assigned equally to the different factors being compared. The most common type of design is a **randomised block** for which animals might be blocked or grouped, for example, on the basis of body weight, age, lactation, pregnancy status or herd. An experiment might also be replicated in time. Each replicate then constitutes a block.

Because of the wide range of weaning weights among lambs in this experiment it might be sensible to group the lambs on the basis of weaning weight. This in fact is what was done (see Table 8.1). Lambs in each breed were sorted into weaning weight order and formed into four blocks of four with the lightest four in the first and heaviest four in the fourth block. Lambs were then randomly assigned to the two levels of diet within each block. This assignment is shown in the data set in Table 8.1. When this is done, the model formula becomes (with r for block):

$$Y_{ijk} = \mu + b_i + r_{ik} + d_j + (bd)_{ij} + e_{ijkm} \quad (i = 1, 2;\ j = 1, 2;\ k = 1, 2, 3, 4;\ m = 1, 2)$$

Note that there are eight possible values of rik: r_{11}, r_{12}, r_{13}, r_{14} for breed 1 and r_{21}, r_{22}, r_{23}, r_{24} for breed 2. The subscript m has two values, one for each of the two lambs assigned to each of the two diets in each block.

The formula for calculating the among block within breed sum of squares is the sum of:

$\Sigma Y_{1jk1}{}^2/4 \ - \ (\Sigma y_{ljkm})^2/16$ calculated for lambs of breed 1

$\Sigma Y_{2jk1}{}^2/4 \ - \ (\Sigma y_{2jkm})^2/16$ calculated for lambs of breed 2

The new residual sum of squares is then calculated by subtracting this sum of squares from the residual sum of squares previously calculated. The completed analysis of variance for weight gain then becomes:

Source of variation	df	SS	MS	F	Probability
Breeds (B)	1	10.1250		21.68	<0.001
Blocks/breeds	6	2.2538	10.1250	0.80	NS
Diet (D)	1	18.6050	0.3756	39.84	<0.001
B × D	1	1.7113	18.6050	3.66	0.07
Residual	22	10.2737	1.71113		
Total	31	42.9688			

This table shows us something about the design of the experiment. If we compare the F-value of 0.80 for among blocks with the 5% value in the F-table with 6 and 22 degrees of freedom, namely 2.55, we see it is much smaller. In other words, differences among blocks were not significant. In this experiment, therefore, assignment of lambs to blocks was of no benefit in reducing, in terms of weight gain, the residual variance. In other words, weight gain post-weaning was unrelated to weaning weight. This does not mean that it was a bad thing to assign sheep to diets on the basis of their initial weight, for in other instances we may find that blocking by initial weight is beneficial.

8.3.7 Heterogeneity of variance

The variances for weight gains among individuals can be calculated separately for each breed–diet group and should be 0.3793, 0.9041, 0.2955, 0.2107 kg^2, respectively. The residual variance used in the analysis of variance is the average of these. Examination of these different estimates shows that the variance was smaller for groups 1, 3 and 4 than for group 2. The analysis of variance we have undertaken assumes that each variance calculated for each group estimates the same ‘population’ variance. This may not be true. In this example the differences in variances are not much to worry about, and one can assume that the weight gains of lambs in group 2 were by chance more variable than in the other groups. The conclusions are clear. The analysis of variance technique is robust. In other words it handles data for which assumptions, such as homogeneity of variance of symmetric, normal distributions, do not strictly apply. But what alternative methods are at our disposal? Faecal egg count (FEC), for instance, has a very skewed, non-normal distribution and an analysis of variance undertaken on these data may not be justified.

Transformations

Firstly we could transform FEC to a different scale by using a calculation such as log (y), log (k+y) or $\sqrt{y}$. Each of these calculations reduces the skewness of the data and makes the residual variance less dependent on the mean. The logarithm transformation is stronger than the square root one. The log (k+y) transformation, where k is a constant >0, is used instead of log (y) when individual values of y occur which equal 0. The disadvantage of this method is that, although it may produce a more valid statistical analysis, it is often not so easy to present the results. This is because the means and standard errors calculated in the statistical analysis are now on a different scale.

Sometimes a transformation is not appropriate and an alternative method would be to split the data into separate parts and to do a separate analysis of variance on each part. It is conventional, however, to analyse FEC on the log scale. An arcsin ($\sin^{-1}\sqrt{y}$) or square root transformation is more appropriate for disease prevalence data, the square root for when the prevalence is low. However, there are now new methods using what is known as **logistic regression** or **log linear models** which are more suitable for such data. These methods are too advanced for this module.

Results can be expressed on the original scale by calculating the geometric mean (antilog of the transformed mean) and the antilog of the 95% confidence limits for the transformed mean. Take, for example, the Dorper lambs (breed 1) supplemented with cottonseed cake and bran meal. The mean and standard error for FEC calculated on the log scale (loge y) are 7.26 and 0.36, respectively. The 95% confidence range for this mean is $7.26 \pm t \times 0.36$ where t, with 7 degrees of freedom = 2.36. Thus, 95% confidence interval for mean = (6.41, 8.11). If we transform these values back to the original scale using the antilog (or e^x) transformation, then mean = 1422, range = (608 to 3327).

Thus, we can say that the geometric mean is 1422 eggs per gram (epg) and that the 95% confidence interval within which the true ‘population’ mean lies is between 608 and 3327 epg. Three important points need to be highlighted:

- it is not permitted to calculate an antilog for the standard error to produce a standard error on the original scale
- the upper and lower confidence interval values are not equidistant from the mean
- if $\log_e (50 + y)$ is used for the transformation, then 50 must be taken off the antilogs after transformation back to the original scale in order to calculate the correct geometric mean and range.

Another variable that is often transformed to logarithms is antibody titre. Serum is usually diluted in a geometric series, i.e. with a constant ratio between successive dilutions, e.g. 1/2, 1/4, 1/8, 1/16 etc. Thus, frequency distributions of titres tend to be lognormal and so the logarithmic transformation is to be desired.

8.3.8 Regression analysis and analysis of covariance

Regression analysis

Regression analysis is a form of analysis of variance. The only difference is that the statistical model is written in a form that is based on the relationship between a y variable and one or more other continuous variables, say x, z...., often referred to as **independent variables**, rather than with discrete sets of parameter or factor levels.

Thus $y_i = a + bx_i + e_i$ fits a straight line between the y_i and x_i values with slope b, known as the **regression coefficient**, and crossing the y-axis at the point a, known as the **intercept**. We shall not consider methods of calculation here, but they result in a similar analysis of variance table to those derived previously. For example, consider the relationship between PCV and loge (50 + FEC) and ignore the fact that lambs were from different breeds and fed different diets. Statistical analysis of these data (using calculations not described) lead to the following analysis of variance:

Source of variation	df	SS	MS	F	Probability
Regression	1	374.5087	374.5087	21.9	<0.001
Residual	30	513.9600	17.1320		
Total	31	888.4688			

Regression equation is $y = 46.0 - 3.297x$

Regression coefficient = –3.297

SE of regression coefficient = 0.705

Correlation coefficient (r or p) = 0.65

We can test for the statistical significance of the regression coefficient by using the t-test:

$t = b/SE = -3.297/0.705 = 4.68$

Comparing with t-values in the t-table with 30 degrees of freedom, we see that the regression coefficient is significant ($P<0.001$). We come to the same conclusion using the F-value in the analysis of variance table. Thus, there is a highly significant association between PCV and FEC. The degree of this association is described by the correlation coefficient. A correlation coefficient can vary between 0 (no correlation at all) and 1 (perfect association, i.e. the points lie on a straight line). In this case r = 0.65. The scatter diagram of PCV and loge (FEC + 50) is illustrated in Figure 8.4 with the regression line imposed. The spread of points illustrates a reasonable association between PCV and logarithm of FEC, although the association between PCV and FEC untransformed (Figure 8.2) may be slightly better.

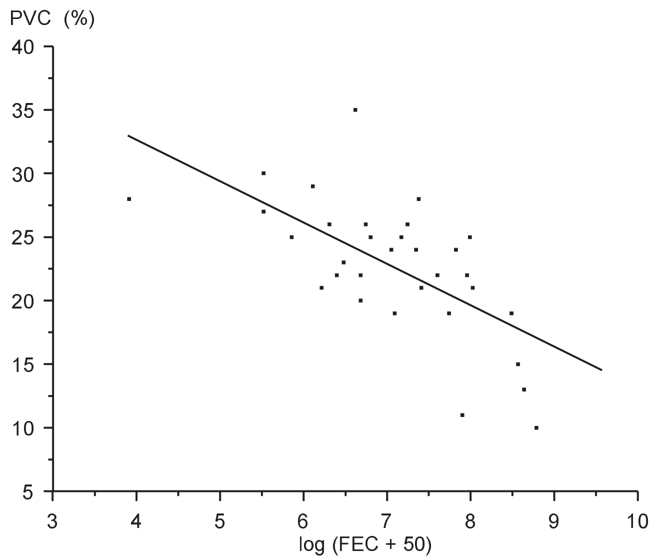

Figure 8.4. *Regression line of packed cell volume (PCV) on log (FEC+50).*

Analysis of covariance

Analysis of covariance is a simple extension of analysis of variance. Independent variables not incorporated in the design of the experiment are included as **covariates**. Thus, in the study of the effect of supplementation on the weight gains of the two breeds of sheep, weaning weight was taken into account in the definition of blocks.

Sex, however, was not. We can, however, include sex in the model as a covariate with values 1 or 2 for males and females, respectively (Table 8.1). Covariates may also be continuous variables. The full model appears as follows:

$$y_{ijkm} = \mu + b_i + r_{ik} + d_j + (bd)_{ij} + ßx_{ijkm} + e_{ijkm}$$

where ß is the regression coefficient of weight gain (yijkm) on sex (xijkm). The analysis of covariance appears as follows:

Source of variation	df	SS	MS	F	Possibility
Breeds (B)	1	10.5302	10.5302	23.31	<0.001
Blocks within breed	6	2.9192	0.4865	1.08	NS
Diet (D)	1	19.3548	19.3548	42.82	<0.001
B × D	1	1.8982	1.8982	4.20	0.05
Sex	1	0.7870	0.7870	1.74	NS
Residual	21	0.4518	0.4518		
Total	31	42.9688			

The analysis adjusts, or corrects, individual parameter level means for the differences in numbers of males and females making up the means. The regression on sex, whilst not significant, has nevertheless reduced the residual mean square. Interestingly, when adjusted for sex, the F-value for blocks is now also greater than 1. Note that the total sum of squares is no longer the sum of the individual squares in the analysis of variance table. This is because each sum of squares is now corrected for differences between sexes.

When there is a choice to use an independent variable as a covariate or to define it as a blocking factor in a designed experiment, the second option is usually preferred, provided adequate numbers of degrees of freedom are retained for the residual term. If there had been equal numbers of females and males for each breed in Table 8.1, then it would have been possible to block lambs on the basis of body weight for each sex.

8.3.9 Analysis of discrete data

Sometimes response variables measured in an experiment may be discrete, not continuous. Such variables, often referred to as **binary** variables, can take two values, 0 or 1. One example is mortality; others are proportions of animals conceiving, proportions lambing, or proportions with a given disease etc. This module briefly mentions the simplest method of handling such data.

Chi-square (χ^2) test

For simple experiments one can group the data into a two-way table and perform a χ^2 test. Thus, for example, if the lambs used in this experiment were drawn from a group of 55 Dorper and 42 Red Maasai lambs and 14 and 4, respectively, died before weaning, then we can compare differences in mortality by forming a table, often known as a **contingency table**, as follows:

	Alive at weaning		
Breed	No	Yes	Total
Dorper	14	41	55
Red Maasai	4	38	42
Total	18	79	97

The above values are the ones observed. The next step is to calculate the values that would have occurred had the mortality rates in the two breeds been the same. These are known as expected values. To do this calculation, expected values for each of the four cells in the body of table are obtained by multiplying together the two totals in the corresponding row and column and dividing by the grand total. Thus, expected values are:

$55 \times 18/97$	$55 \times 79/97$
$42 \times 18/97$	$42 \times 79/97$
10.2	44.8
7.8	34.2

The formula for the χ^2 test is:

$$\Sigma(o_i - e_i)2/e_i$$

where o_i = observed value and e_i = expected value (i = 1, 2, 3, 4).

$$\text{Thus } \chi^2 = (14 - 10.2)^2/10.2\ (41 - 44.8)^2/44.8 + (4 - 7.8)^2/7.8 + (38 - 34.2)^2/34.2$$

$$= 1.416 + 0.322 + 1.851 + 0.422$$

$$= 4.01$$

The number of degrees of freedom = $(2 - 1) \times (2 - 1) = 1$

The 5% and 1% values for χ^2 with 1 degree of freedom are 3.84 and 6.63, respectively. Thus we can say that the mortality rate before weaning in the Dorpers of 14/55 (25%) was significantly higher than that of 4/42 (10%) in the Red Maasai ($P<0.05$).

When any value of ei is less than 5, the above formula should be replaced by:

$$\Sigma(|\,o_i - e_i| - 0.5)^2/e_i$$

where $|o_i - e_i|$ is the positive value of the difference between o_i and e_i. This is because the χ^2 test is only an approximation to the distribution of numbers in a contingency table when the numbers are small.

8.4 Planning experiments

So far we have considered in some detail the statistical analysis of experimental results. We have encountered the concept of blocking to help improve the precision of an experiment. Now we shall discuss in more detail the general aspects of good experimental design. Careful planning of any experiment is obviously important, but it is even more essential for certain types of livestock trials and for on-farm experiments. Experiments involving calving, lambing or kidding may be particularly awkward since it may be difficult to control birth dates. This means that different animals may enter the experiment at different times. In addition, livestock trials are often fairly long term, when compared to crop trials, and need intensive data recording. Animals are also valuable. This makes detailed planning essential.

8.4.1 Stages in planning experiments

Objectives

All experiments should have clear, well-defined and realistic objectives. This may seem obvious, but is frequently overlooked. An example of a vague objective is: 'To examine the effect of nutrition on reproductive performance'. More precise objectives might be: 'To quantify the response to treatment with the trypanocidal drug Samorin in early pregnancy on conception rates of goats exposed to a high trypanosomosis risk', or 'To determine the effect of anthelmintic treatment on weight gains of lambs to weaning in different breeds of sheep'. The scope of the experiment should also be clear: which breed(s) will be used, what weight and age/parity ranges will be studied, what management system will be followed etc.

Data collection

At the planning stage, one needs to decide what data to collect and how they should be measured. For example, sera samples may need to be stored and frozen. Is this practically feasible in an on-farm trial? With large on-farm trials in particular, it might be useful to run a small pilot study before the main trial to reveal and resolve any unexpected problems in data collection. Data recording sheets should be designed before data are collected. They should ideally allow for both easy field recording and easy statistical analysis without the need to copy data from one sheet to another. The main methods of statistical analysis should be decided before the trial is started. There is little point in collecting a mass of data if you do not know how you are going to analyse them.

Some guidelines (not necessarily rules) for good practice in data recording are as follows:

1. As far as possible data that are collected manually should be entered on the same recording sheet, i.e. do not put body weight on one sheet, PCV on another etc. Results of subsequent automated analysis (e.g. ELISA antigens) should not, however, be copied to this sheet. It is better to devise a system for entering these data separately and merging with the manually recorded data in the computer.
2. Do not transcribe data from one sheet to another. This is a time when many errors occur.
3. Try to involve two people in measurement and recording so that they can cross-check each other.
4. Decide beforehand on accuracy required for data recording (e.g. to the nearest kg, 0.5 of a kg etc), and take care when reading values from an instrument recorder. Values of 25 or 30% for PCV, for example, are, in practice more often recorded than values of 26 or 29% when using a gauge to measure the height of the packed red cell volume read from a straw after centrifugation.
5. Enter animal identification on the recording sheet in the order in which animals are weighed and the samples collected. This may be preferable, particularly in large field trials, to using recording sheets on which animal numbers have already been written.
6. When recording information on breed, age etc, think how you might want to use it. Information is usually better recorded numerically when the numerical code is easy to remember (e.g. 1 – male; 2 – female). Remember, however, that the computer can easily recalculate values, so do not do mental arithmetic in converting names to numbers if you are likely to make mistakes.
7. Do not do calculations by hand that the computer can do for you, e.g. calculation of weight gain.
8. If entering data into the computer, preferably get someone else to verify the data you have entered.

The way a recording sheet might be produced is illustrated in Table 8.5. Note that numbers have been used where possible. Age is a difficult variable to record in a mixed age population. One way around the problem is illustrated in the table. It might be preferable to separate trypanosome species in the recording sheet as shown, rather than list species under one column headed 'trypanosomes'. This is easy to do and means that you do not have to get the computer to separate species later. The value 2 represents a score for intensity of infection (1–5), in this case for *Trypanosoma vivax*. Note that all variables and attributes are entered together in columns on the same sheet with animals listed down the left hand side of the page.

Table 8.5. *Example of a recording sheet.*

Sample no.	Animal ID	Breed	Calf/ adult	Age	PCV	*T. congolense*	*T. vivax*	*T. brucei*
1	301	1	1	12 mo.	26	0	0	0
2	126	1	2	4 y	24	0	2	0
3	313	2	2	6 y	29	0	0	0
4	219	2	1	9 mo.	27	0	0	0

Experimental design

You will need to decide how many animals or farms to use based on previous knowledge of the likely variation you might expect. If you do not have sufficient resources you will have to consider either a modification of your objectives, carrying out the trial in stages over a number of years, or abandoning the trial altogether. There is little point in proceeding with a trial if you are fairly sure that it cannot meet your objectives!

Experiments should be kept as simple as possible in terms of design, execution and analysis. The most efficient designs are often the most simple to analyse. For simplicity of analysis there should be equal numbers of experimental units assigned to each treatment. Such designs are known as **balanced** designs. While this is usually relatively easy to organise for crops, it is not always so easy with livestock and on-farm trials. Unbalanced experiments need sophisticated statistical analysis which cannot readily be done without statistical computer software. Sometimes the analysis has to be done that way, either because it was not possible to make the experiment completely balanced in the first place, or because animals may have died during the course of the experiment.

Assignment of animals. Practical arrangements should be simple to avoid problems, confusion and errors when implementing an experiment. However, this should not be at the expense of other considerations, such as avoiding systematic errors. For example, with an on-station trial in individual pens, it might be convenient to put all animals on the same diet in adjacent pens. Animals on different diets will then be in different parts of the barn. However, the barn may not be a uniform environment; some regions may be more exposed to, say, wind and cold air. The differences between diets may be confounded with differences in environment, making the results impossible to interpret. Randomisation should be used to overcome these sorts of problems, even though it may introduce some practical complications.

Precision. An experiment will give an estimate of the difference between two treatments, e.g. the difference in their effects on mean growth rate. The precision of an estimate reflects how close the estimate is likely to be to the true or population value and, as we have already seen, this is measured in statistical terms by its standard error. The smaller the standard error the greater the precision.

The precision of an experiment will depend on the size of the experiment (e.g. the number of animals involved). Precision increases as the number of experimental units per treatment increases. It also depends on the inherent variability of the experimental material. An experiment with large variation among experimental units will have less precise estimates than one for which there is very little variation among units.

Replication or blocking. Estimating the precision of an experiment depends on the amount of random variation. Therefore, it is essential to be able to calculate the standard deviation of the data. In order to do this there must be data from more than one experimental unit in each treatment. Thus the treatments must be replicated.

Very low levels of replication such as two experimental units per treatment may not be sufficient to give an adequate estimate of the standard deviation nor to give reliable estimates of treatment means. As a general guide one should always try to ensure that at least six degrees of freedom are available for estimating the residual variance in the analysis of variance. The precision of an experiment is also increased by increasing the number of times each treatment is replicated.

It has previously been explained that a good choice of blocks will make the variation among blocks greater than the residual variation within blocks. This is also a good way of improving the precision. In the data example (Table 8.1), blocking based on initial weight did not reduce the residual variance. In other situations, however, blocking based on body weight will be beneficial and, therefore, is a good principle to adopt. Sometimes there may be several choices for suitable replicates or blocks, e.g. body weight, age, sex. Research workers are often tempted to make treatment groups similar in all respects by balancing such attributes across treatments. This is wrong and can introduce systematic errors. This method gives no scope for randomisation of animals to treatments.

It is essential to allocate treatments at random to experimental units. This is to eliminate any subjective bias which may occur (no matter how honest one tries to be). Randomisation minimises the risk of systematic errors and helps to ensure that each treatment is represented fairly in the trial. The aim of randomisation is to give each experimental unit an equal chance of being allocated to any of the treatments.

8.4.2 Experimental units

The best formal definition of an **experimental unit** is that it corresponds to the smallest division of the experimental material such that any two units may receive different treatments in the actual experiment. For example, in an on-station feeding trial, if animals can be fed individually then any one animal can receive any of the feeds. An animal is the experimental unit in this case, and animals are randomised to treatments. However, if individual pens are not available, then animals must be group fed. Any animal must then be given the same diet as its pen-mates, will compete with its pen-mates for food and therefore cannot be considered independent of them. In this case, a pen is the experimental unit, the pen is randomised to treatments and all statistical calculations to compare treatments should be carried out on a pen basis. Group feeding may have the advantage, though, of being closer to farm practice.

Experimental units need to be carefully thought about and defined in on-farm trials. With many types of treatments it will not be possible for a farmer to give one treatment to some animals and a different treatment to others. All animals in one herd or flock will be given the same treatment. In many such cases a herd or flock will be the experimental unit. Data will have to be summarised on a herd or flock basis before statistical analysis is undertaken. The correct definition of the experimental unit is crucial for the validity of most statistical analyses.

Split-plot designs

These are more common in crop than in animal experiments. They involve two levels of experimental units, a ‘main plot’and a ‘subplot’. Thus, for example, an experiment might use a number of flocks, half of which receive regular anthelmintic treatments. Within each flock, sheep might be randomised into two groups, one receiving trypanocidal prophylaxis, the other not. For anthelmintic comparisons, flock is the experimental unit, for trypanocidal comparisons, the individual animal is the experimental unit. When using split-plot designs one has to be careful to ensure that adequate numbers of replicates are available at the main-plot level since there is more variation among flocks than among sheep within flocks.

8.4.3 Randomisation

Once a suitable method of blocking has been decided, one needs to design an adequate number of blocks which can allow equal numbers of experimental units to be assigned to each treatment. Thus, in the example, lambs were ranked in order of body weight and eight sets or blocks of four lambs formed. The four lambs in each block were then assigned at random to each of the two diets. There are different mechanisms for assigning experimental units at random.

Drawing lots

A card or piece of paper can be prepared for each treatment, or cards can be taken from a pack of playing cards. The cards can then be shuffled and drawn like raffle tickets. The treatment marked on the first card drawn is allocated to the first animal and so on.

Using tables of random digits

Many statistics books give tables of random numbers. Alternatively, the digits from telephone numbers in a telephone directory, for example, could be used. As an example, suppose we wish to allocate six treatments to six animals in a block, and suppose the sequence of random digits listed in a table is:

6 7 3 8 2 2 9 0 8 5 6 9 8 3 1 4 7 0 5 8 0 8 1 8 6 1 5 4 3 2....

The first animal in the block would have treatment 6, the next number, 7, would be ignored since there is no treatment 7. The second animal would get treatment 3, 8 is ignored and the next animal would receive treatment 2. The next 2 in the sequence would be ignored because treatment 2 has already been allocated, and so on. The full randomisation for the first block would then be:

animal	1 2 3 4 5 6
treatment	6 3 2 5 1 4

Continuing, we get for the second block:

animal	1 2 3 4 5 6
treatment	5 1 6 4 3 2

The lines below show again the random sequence; the digits that are ignored either because a digit is not in the range 1 to 6 or it has been used before in the block are underlined.

6 7 3 8 2 2 9 0 8 5 6 9 8 3 1 4	7 0 5 8 0 8 1 8 6 1 5 4 3 2
Block 1	Block 2

With five or fewer treatments, one can use two or more digits to represent a treatment. For example, with three treatments, digits 1, 4, and 7 could represent treatment 1, digits 2, 5 and 8 treatment 2 and digits 3, 6 and 9 treatment 3. Then only 0 would be ignored. With more than ten treatments, random digits can be taken in pairs giving random numbers from 0 to 99. Again different pairs of digits can be used to represent the same treatment.

Other methods

A dice used in children's games can be used instead of random digits for six or fewer treatments. Note though that one should not use two dice for up to twelve treatments, since numbers such as 7 (3+4, 2+5 or 1+6) are far more likely to occur than 12 (6+6), and the number 1 cannot occur at all.

8.4.4 Designing surveys

An essential component of a survey is a sound sample design. In most cases it is impractical to collect data on all individuals of a population, but a representative subset or sample of the population can allow one to draw inferences about the characteristics of the population. There are several methods to select animals for sampling. The methods can be classified in two types, one type that does not and one type that does rely on random sampling techniques.

Objectives

As in designing experiments it is important to clearly state the objectives and to list the variables to be estimated. It is also important to define the target population and to ensure that the sampled population is representative of the target population. It would be inappropriate to use data from diagnostic laboratories or abattoirs, for example, and then to make inferences about the occurrence of disease in an animal population of a country.

Sampling frame

The population to be sampled must be divided into **sampling units** before selecting the sample. A unit can vary from an individual animal to an aggregate of individuals, such as pens, farms, dip tanks, villages etc. The list of all sampling units in the sampled population is called the **sampling frame**.

Non-random sampling

Two methods can be used: convenience sampling and purposive sampling. In convenience sampling, a sample is selected because it is easy to obtain, e.g. a herd near the investigator. In purposive sampling, the selection of units is based on known exposure or disease status. It is thus an inadequate technique for obtaining data to estimate the occurrence of the disease in a population. Both methods may create serious biases.

These methods are not based on probability sampling techniques and therefore, it is not possible to give a level of confidence to the mean. These methods are not usually encouraged since they may produce inaccurate population estimates and are often as expensive to perform as random sampling methods. There may be good reasons on occasions for using such methods, but the experimenter needs to be aware of their limitations.

Random sampling

A number of methods are available, e.g. simple random sampling, systematic random sampling, stratified sampling and cluster sampling. Confidence limits of the population values can be calculated. These designs are more complex to analyse but the validity of the results is worth the investment in time and money.

The objective of random sampling is to select a percentage of the population using a formal randomisation process as has already been described. Such a selection procedure is required for the investigator to calculate the precision of the sample estimate as measured by the standard error of the mean. In practice, random sampling provides the investigator with the assurance that his sample will be representative of the population being investigated.

To obtain a simple random sample of n from a population of N animals to determine the prevalence of trypanosomosis by antigen-ELISA analysis, for example, one would randomly select n numbers from between 1 and N, each number identifying an animal in the sampling frame. Thus, the animals selected would be distributed randomly throughout the sample population.

The estimated standard error of the sample mean:

$$= s/\sqrt{n} \times \sqrt{(1 - n/N)}$$

where s is the calculated standard deviation, which equals $\sqrt{p(1 - p)}$ for a binary variable.

Note that this is different from the standard error used previously in the analysis of designed experiments. It has the additional value $\sqrt{(1 - n/N)}$ which is included to take into account the fact that the sample is from a population of finite size N. If the population is infinite (or very large), this term can be ignored.

Systematic random sampling

In systematic sampling the n sampling units are selected from the sampling frame at regular intervals (e.g. every 10 animals). The interval k between animals (in this case 10) is the integer closest to N/n. When systematic methods are used, the starting point in the first interval is selected at random. Systematic sampling is a practical way to obtain a representative sample, and it ensures that the sampling units are distributed evenly over the entire population. It is particularly useful for sampling animals arriving at a dip tank. Then, we can assume that the sample is random and a standard error can be calculated. When sampling animals at a crush on a farm, however, the systematic sample may give an accurate estimate of the mean, but it may not be strictly random because the weaker animals may arrive last at the crush. If there is any doubt about whether one can pretend that a sample is random or not, and the sampling frame is known in detail in advance, then it will usually be advisable to select the whole sample at random.

Stratified random sampling

With this technique, the sampling frame is divided into blocks known as **strata** based on factors (e.g. herd, area, age of animal) likely to influence the level of the primary variable (e.g. prevalence of helminthosis) being estimated. A simple random or systematic random sample is then selected within each stratum. Stratified random sampling improves the precision of the sample estimate, because only the within stratum variation contributes to the variation (standard error) of the mean. Different sampling percentages can be used in the various strata. For example, if 60% of animals are from the Red Maasai breed and 40% from the Dorper breed, then the sample of size n can be selected from the breeds in the same ratio (e.g. 60:40).

When stratified sampling is used, information on all sampling units, with respect to the factors forming the strata, must be known before drawing the sample. In general, the number of factors used for stratification should be limited to those likely to have a major impact on the mean value of the primary variable to be estimated (e.g. prevalence of helminthosis).

An estimate of the population mean is given by the formula:

$$\overline{y} = \Sigma N_i \overline{y}_i / N = \Sigma N_i / N$$

where $\overline{y}_i$ is the sample mean in stratum i of size N_i.

The standard error of $\overline{y} = (1/N) \times \sqrt{\Sigma[N_i^2 \times s_i^2 / n_i \times (1 - n_i/N_i)]}$.

Cluster sampling

In cluster sampling, the first sampling unit is larger than the particular unit of interest, and sampling takes place at several stages. For example, cluster sampling in two stages could include a sample of primary units (e.g. farms) and then, within the farms, a sample of secondary units (e.g. animals).

Cluster sampling is often used because of its practical advantages and flexibility. The number of primary (n_1) and secondary (n_2) units may be varied to account for different costs of sampling primary versus secondary units, as well as the variability among primary units and among secondary units within primary units.

Whenever possible one should select sampling units at each stage with probability proportional to the number of population individuals in the stratum or cluster. This minimises the standard error and stabilises the sample size. Usually cluster sampling generally requires more animals to achieve the same precision as simple random sampling, but the costs will be lower. The formulae for estimates of means and standard errors can be found in statistical text books.

8.4.5 Sizes of experiments and sample surveys

Experiment

Before conducting an experiment it is important to decide on how many animals, flocks, herds etc one may need in order to estimate treatment means to a desired precision. In other words, we need to know how many replicates or blocks we need in order to have a reasonable chance of detecting a real difference at a given level of statistical significance.

We have already seen that the standard error of the difference between two means, each of n observations, is given by the formula:

$$SED = \sqrt{(2 \times \text{variance}/n)} = \sqrt{2}\ SE$$

One might have a preconceived idea of the approximate size of the standard deviation or variance to be expected. Thus, if the experiment described in our example were to be repeated using two different breeds, we could assume that we might expect a residual variance of about 0.5 (it was 0.4518 in the experiment). Suppose we decided that we needed to determine a difference of 1.0 kg in weight gain between two groups to be statistically significant ($P<0.05$). We can then apply the formula.

$$LSD = t \times SED = t \times \sqrt{(2 \times variance/n)}$$

Squaring both sides and manipulating terms we get:

$$n = 2t^2 \times variance/LSD^2$$

Substituting t = 2 (approximate value with large number of degrees of freedom) we get:

$$n = (2 \times 4 \times 0.5)/1.0^2 = 4.0$$

Therefore we can expect to require four animals per group to show a difference in weight gain of 1.0 kg as significant between diets (P<0.05).

With a completely randomised design with 4 groups (breed × diet) we would have 12 (i.e. 4 × 3) degrees of freedom for the residual mean square. $t_{12} = 2.18$ where t_{12} is the t-value with 12 degrees of freedom. Replacing t^2 with 2.18^2 in the above formula we can revise our sample size estimate to:

$$n = (2 \times 2.18^2 \times 0.5)/1.0^2 = 4.75.$$

Therefore we would in fact need five animals per diet.

Surveys

Suppose we wish to carry out a survey to estimate the trypanosome prevalence in a given population of cattle. To estimate the size of a random sample we follow the same steps as in the previous section. First we decide how accurately we need to determine the population mean μ, i.e. how close to μ we want our sample to be. Approximating to a normal distribution, we can write:

$$t = (\bar{y} - \mu)/se(\bar{y} - \mu)$$

Write $\bar{y} - \mu = L$

Then:

$SE(L) = SE(\bar{y})$ since μ is fixed, i.e. it is the mean of the population) $= \sqrt{[p(1- p)/n]}$

Therefore:

$$t = L/\sqrt{[p(1 - p)/n]}$$

Squaring both sides and manipulating the equation we get:

$$n = [t^2 p(1 - p)]/L^2$$

As before we first substitute t = 2 for level of significance P<0.05. It is clear that in order to estimate n we need to have some idea of p beforehand. If we are sampling from a finite population of size N then a further step is needed. In this step we adjust the required sample size to n1 using the formula:

$$1/n^1 = 1/n+1/N$$

To demonstrate how to calculate L, suppose p = 0.4. If we decide that we want our sample to provide an estimate within 10% of this value then:

$$L = 0.4 \times 0.1 = 0.04$$

Then:

$$n = 2^2 \times 0.4 \times 0.6/0.04^2 = 600$$

If the population size is 1200, then:

$$1/n^1 = 1/600 + 1/1200$$

and so $n^1 = 400$.

8.5 Presenting results

A set of numerical results should usually be presented as a table or graph rather than be included in text. Text becomes difficult to read if too many numbers are included. Well presented tables and graphs can concisely summarise information which would be difficult to describe in words alone. Poorly presented tables and graphs, however, can be confusing or irrelevant. In general, tables are better than graphs for giving detailed numeric information, whereas graphs are better for indicating trends and making broad comparisons.

Tables and graphs should, ideally, be self-explanatory. In other words, the reader should be able to understand them without detailed reference to the text. The title should be informative and rows and columns of tables and axes of graphs should be clearly labelled. Graphs and tables should be as simple as possible, while having sufficient detail to be useful and informative.

In scientific papers statistical information, such as standard errors and significance levels, is usually required. This may not be necessary for articles for a more general readership or for slides or transparencies for use in a lecture. Such statistical information should always be presented in such a way that it will not obscure the main message of the table or graph.

One often finds tables in scientific papers clustered with little superscripts a, b, c etc, or symbols *, *** to signify significant differences. Authors need to ask themselves whether these are really necessary, as they tend to obscure the main ingredients of the table. In some cases they will feel they are necessary and help with the understanding of the table. Think twice, however, before doing this. Normally tables are much better if they are simple and present the data at their face value. Often only means and standard errors are required. The summary values given in Table 8.6 are all that are needed to present the mean results for the breed/dietary supplementation example, and, provided the reader understands standard errors, he/she will be able to draw his/her own conclusions on how biologically significant the results are. Significance levels can be quoted in the text as a guide to the reader, but the reader should be able to draw his own conclusion on how ‘significant’ he/she feels the results are.

Table 8.6. *Weight gains (kg) of lambs.*

	Supplementation		
Breed	No	Yes	Mean
1	0.82	1.89	1.36
2	1.49	3.48	2.48
Mean	1.16	2.8	1.92

SE of differences between means in body of table = 0.24.
SE of differences between overall breed and dietary means = 0.17.

The number of digits and decimal places presented in a table should be the minimum number that is compatible with the purpose of the table. Thus, in this example three decimal places for weight gain, e.g. 0.825 may be too many, since the third decimal place may have little practical significance; conversely, one decimal place, e.g. 0.8, 1.9, could lose too much information. As a general rule, standard errors should be written with the same or one more decimal place than the mean.

The data in Table 8.6 are presented in the form of a bar chart in Figure 8.5. Graphical presentation often helps to highlight certain aspects of the results. Individual standard errors for each diet can be presented as a vertical line above a bar. If it is necessary to include standard errors of differences between means, these can be included as a footnote or in the text. A graph should never duplicate the results displayed in a table in the same report.

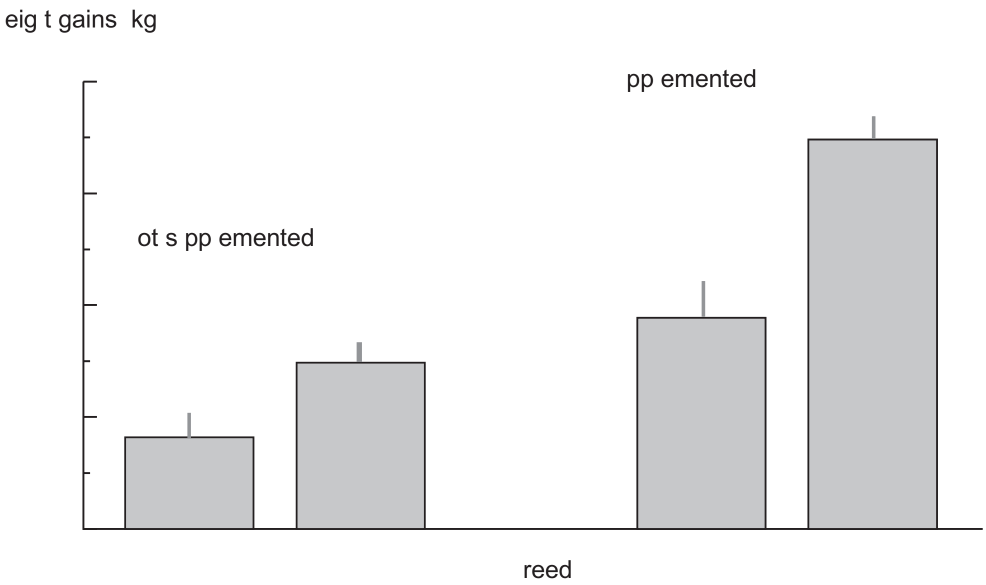

Figure 8.5. *Weight gains (kg) of sheep in the form of a bar chart.*

8.6 Exercises

1. Calculate the mean, median, standard deviation and coefficient of variation of the PCVs of the eight lambs in breed 1 in Table 8.1 fed diet 1.
2. Using the results of Exercise 1, calculate the standard error and 95% confidence interval for mean PCV of breed 1 lambs fed diet 1.
3. In a sample of 80 sheep 5 are detected with trypanosomes. Calculate the standard error of the prevalence of trypanosomes assuming first a Poisson distribution and second a binomial distribution. Calculate the 95% confidence interval using the formula given for the normal distribution.
4. Write down a statistical model to describe the factors which you might expect to affect incidence of helminthosis during a 3-year study of 10 flocks of sheep.
5. Calculate the variance for weight gain of the eight lambs within each breed–supplementation group in Table 8.1 and show that the average of these variances is the same as the residual mean square (0.4474) calculated in the one-way analysis of variance by group.
6. Using the following means and standard errors calculated for weight gain:

	Supplementation		
Breed	No	Yes	Mean
1	0.82	1.89	1.36
2	1.49	3.48	2.48
Mean	1.16	2.68	1.92

SE of mean in body of table = 0.236
SE of overall mean by supplementation or by breed = 0.167

Calculate approximate 95% confidence intervals for the various means. For example, for breed 1, non-supplemented, you should get a 95% confidence interval of 0.82 2 $\times$ 0.236 = (0.35 – 1.29). Briefly explain what these results show you.

7. Complete the following analysis of variance table for PCV using the data in Table 8.1.

Source of variation	df	SS	MS	F
Breed (B)	1			
Diet (D)	1			
B × D	1			
Residual	28	560.3750		
Total	31	888.4688		

Interpret the findings.

8. Using the results of Exercise 7, calculate SED for comparing mean PCVs of breeds 1 and 2, calculate the t-value and show that t^2 = F value for breed in the analysis of variance table.

9. Using only data for non-supplemented lambs (in Table 8.1) carry out a t-test to compare FEC between breeds, firstly using values on their original scale, secondly transforming FEC (y) to loge (50+y). The value of 50 is used because it is the least detectable FEC.

10. Two flocks were sampled for trypanosomosis. In one flock 12 of 32 animals were found to be parasitaemic (38%), and in the other 4 of 19 were parasitaemic (21%). Are these trypanosome prevalences significantly different?

11. Two hundred and forty breeding does (120 Mashona type and 120 Matebele type) purchased from communal areas are being used in a 6-year continuous mating study. Does were randomly allocated to eight treatment groups within breed. A 2 × 2 × 2 factorial design was used. Two levels of feed supplementation (no supplementation and supplementation), dosing (no dosing and dosing with anthelmintics) and dipping (no dipping and dipping at regular intervals) were evaluated. After three years of study deaths within one of the treatment groups for the Mashona breed have resulted in no does or kids remaining in that group. The experiment has another three years to run. Should the researcher fill this group with new does or continue to analyse the experiment with one treatment group missing? Write down any questions you would like to address to the researcher.

12. You plan to carry out a farm trial to assess the effect of anthelmintic treatment on growth rate of lambs to weaning. You have 10 flocks, each on a different farm, at your disposal. It will be possible to divide the flocks on four of the farms so that each half grazes in a different area. The flocks on the other farms cannot be subdivided in this way. It has been decided that it would not be desirable to mix treated and untreated sheep in the same grazing pasture. Design two experiments, one based on just the 4 flocks which can be divided, the other based on all 10 flocks to carry out the objective. Write down the statistical models in each case and sketch the form of the analysis of variance table. Which are the experimental units in each case?

13. Suppose that the lambs in the example data set (Table 8.1) do not belong to two breeds but that they are all Red Maasai and the code used for breed is instead anthelmintic treatment (yes or no). Redesign the experiment to investigate the effect of supplementation in the presence or absence of treatment and reassign the lambs to treatment and supplementation using the table of random numbers at the end of these notes.

14. Suppose a stratified random sample of 40 cattle is chosen: 20 from 180 zebu and 20 from 120 N'Dama cattle. Suppose 10 of the zebu and 2 of the N'Dama are found with trypanosomes in their blood. Calculate the estimated mean trypanosome prevalence in the population of 300 cattle and its standard error.

15. The mean trypanosome prevalence is to be estimated from 200 cattle in 20 herds, which range in size from 36 to 180 animals. It has been decided to select 10 herds at random with probability proportional to their size and then to select 20 animals at random from each herd. Describe how you would select the 10 herds.

16. Calculate how many replicates you would need to determine a difference of 0.5 kg as significant ($P<0.05$) between any group in the breed x diet experiment described in Table 8.1 if your estimated standard deviation was 0.8 kg.
17. Suppose you wish to estimate the size of the sample needed to estimate antigen prevalence rates of Theileria parva in zebu calves. We estimate that the likely prevalence is 50%. Calculate how many calves you will need to sample if the population mean prevalence in a group of 400 calves is to be estimated to within a 10% prevalence range in accuracy (namely 45–55%). What will be the predicted accuracy of this sample if the actual prevalence turns out to be 80%?
18. There are at least three ways that Table 8.6 could be improved for publication in a scientific paper. List these. Are there any changes that you would make to this table if you were to present it as a transparency in a talk?
19. Using the following analysis of variance table:

Source of variation	df	SS	MS	F	Probability
Breeds (B)	1	10.1250	10.1250	21.68	<0.001
Blocks/breeds	6	2.2538	0.3756	0.80	NS
Diet (D)	1	18.6050	18.6050	39.84	<0.001
B × D	1	1.7112	1.7112	3.l66	0.07
Residual	22	10.2738	0.4670		
Total	31	42.9288			

and applying the t-test to the means and standard errors summarised in exercise 6, write, in no more than three sentences, a report of the results.

8.7. References and reading materials

Cochran W.G. and Cox G.M. 1992. *Experimental Designs.* John Wiley and Sons, Inc., New York, USA. 634 pp.

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Module 9: Research project protocols

9.1 Performance objectives

Module 9 is intended to enable you to:

1. List components of a protocol.
2. Plan for writing a protocol.
3. Write a protocol.
4. Co-ordinate the review process for your protocol.

9.2 Introduction

As a scientist working on small ruminant production, your goal is to solve the problems of resource-poor farmers through research. This research should focus on the farmers' problems and needs to be an integral part of the research of your institution and maybe the region you are in. You may also be a member of a network, e.g. the Small Ruminant Network (SRNET). In all these situations, you need to plan, develop and submit your research ideas in a format that can be reviewed and approved by the appropriate body. To achieve this objective, you need to plan your research and develop a project protocol. Funds for research are becoming scarce and scientists have to compete for the few resources available. This competition can be for resources provided by your national research institution or a donor agency; in both cases you need to develop and write a protocol that will convince the donors to fund your research. This module will enable you to develop the skills to do so. This module will also cover a few topics related to implementation when your protocol is approved: administration, financial information and reporting. These topics are usually not part of a protocol unless the supporting institution wishes them to be.

9.3 Research project protocols

What is a research protocol? It is an instrument that describes your intentions to conduct research to solve a problem. It is a document that details what needs to be done:

- It can have one or several proposals.
- It is a project portfolio (including one proposal or several proposals).

In countries where funding is mostly obtained from donor institutions, it can be called a grant proposal. A protocol is more inclusive than a proposal, a term that is used by many in place of protocol. A protocol can contain one or more proposals, e.g. ILRI submitted to the EU a protocol with three grant proposals, one for small ruminants, one for cattle and one for nutrition.

9.4 Planning

Several prerequisites will help you in planning, developing and finally writing a good protocol:

- You have good research skills, are experienced and have published articles on previous research.
- You are committed to implementing the research.
- You are linked to a stable multidisciplinary team and/or network.
- Your institution is committed to research.

When planning your research, you should:

- be innovative
- provide a clear rationale
- be focused
- be timely
- address specific problems that farmers have.

If the proposal has many experiments, then the experiments should be feasible and in a logical sequence. You should know the resources available to you before writing a protocol: personnel, equipment, supplies, land, animals etc. You should also know the study area and the needs of the farmers. Knowledge about other institutions is important as joint protocols may be called for by the complex nature of the problems.

The planning process states:

- the problem: the why
- the importance of the problem
- what needs to be done
- how the problem will be addressed: the work plan
- resources (human and financial) needed to accomplish the plan.

9.5 Components of a protocol

The attributes of a good project protocol:

- Well defined problem statement.
- Clear, well focused and realistic objectives.
- The work plan must not address too many questions.
- The budget must be realistic and adequate for the intended purpose.

This section will give guidelines on what goes into each component of a protocol. Only experience will teach you to perfect your protocol. Different institutions (e.g. your research organisation, a network or a donor) may require more components or break down the components into more categories. The attributes of a protocol listed above are the main components that are usually required for most protocols.

9.5.1 Background and justification

This section of the protocol should:

- state the problem and rationale for solving it
- clearly describe the problem
- state what we already know
- state what needs to be done.

This section is used to demonstrate your understanding of the subject and to justify the need to conduct the proposed research. You should show why the information that will be obtained through research will be useful; this means explaining how the information can be used to solve the problems of the farmer. Work done by others that is relevant to your work should be clarified; avoid controversial issues in this section.

9.5.2 Objectives

This section lists and the overall objective and the specific objectives. The specific objectives are items in a list that will contribute towards attaining the overall objective. You should describe:

- the research that you intend to accomplish
- the hypotheses that you will test.

Remember that your success will be evaluated against the objectives you have set out to achieve.

Example:

Let us use the project 'Gastro-intestinal parasitism in small ruminants' to illustrate the two types of objectives:

- An example of an overall objective of the project: *To characterise breeds of sheep and goats in sub-Saharan Africa for genetic resistance to internal parasites*
- An example of a specific objective that contributes towards the overall goal: *Determine the specificity of genetic variation for resistance in terms of different parasite genera*

9.5.3 Expected outputs

Expected outputs are indicators used to verify whether the objectives have been achieved. To illustrate how outputs should be written here are two examples from a protocol submitted by ILRI to the European Union to fund the Small Ruminant Network (SRNET):

- Output i : Three issues of newsletter published
- Output ii: Training manual for the small ruminant production technique course will be published and distributed

Outputs constitute the terms of reference of the project. They should be written to reflect the results for which the project is held directly accountable and for which it is given resources. When outputs are achieved, the project is complete.

9.5.4 Work plan

The work plan describes the materials needed and the methods to be used. It sets out what will be done and how to achieve it. The description should be clear and detailed for every experiment. There are two different types of work plans:

- A work plan that describes a single experiment.
- A work plan that describes more than one experiment.

The second type of work plan could be constituted of sequential trials. It could also describe an umbrella project that will cover a series of trials.

Each trial included in the work plan should have the following attributes:

- Objectives: The objective(s) of each trial should relate to the overall and specific objectives of the protocol.
- Expectations: Expectations relate to information on how the objectives will achieve the overall output.
- Time frame: The time frame shows the timetable for the activities in each trial (see Table 9.1 for an example). The targets should be treated as flexible dates but it is important to set such a timetable to guide the team implementing the experiment(s). In such a framework, activities should be listed in chronological order for every year of the lifetime of the protocol. You should be as specific as possible, e.g. feeding schedule, blood sampling dates etc should be listed.
- Materials and methods: The work plan will include the materials needed in every experiment. What goes into this part? In a nutshell it should describe what is to be done and how it will be done. You may find the following terms used but they all mean the same thing:

  Materials and methods ↔ *Methodology* ↔ *Procedures* ↔ *Activities*

  The materials and methods can be described together or separately. The main guideline is that no detail should be left out. The agency that you wish to sponsor your protocol will need to know what needs to be done, why and how.

- Statistical analyses: Experimental design refers to various biometrical designs used in experimentation (see Module 8). In the protocol you must:
  - outline the experimental design and procedures
  - for new methods, explain why they are better than the old ones
  - explain control treatments clearly
  - explain how data will be collected and analysed
  - state and describe/define the materials that will be used: crops, animals, feeds etc
  - list collaborators (scientists, institutions)

Table 9.1. *Schedule of experimental matings to generate genetic parameters in the endoparasite project, Debre Birhan, Ethiopia.*

Mating	Lambing in dry season	Lambing in wet season
1st mating	May 1992	January 1993
1st lambing	October 1992	June 1993
2nd mating	May 1993	January 1994
2nd lambing	October 1993	June 1994
3rd mating	May 1994	January 1995
3rd lambing	October 1994	June 1995
Last date of recording	October 1995	June 1996

9.5.5 Budget

- The budget section shows the resources that are needed to implement the protocol. Major features of the budget are:
- It has to be based on the real situation (i.e. be realistic). This can be done by surveying the market costs of items in the budget. Past experience can be of great help.
- Inflation rates should be included.
- A percentage for contingency should be included.

Items that are usually included in protocol budgets (Table 9.2) are:

- Personnel costs: This includes the list of principal and support staff and labour (permanent and casual). Consultants are listed in this section.
- Equipment costs: This can include laboratory, field and office (computers, audio-visuals) equipment and vehicles.
- Operation costs include experimental material (animals, feed, drugs etc), travel, training, communication, information, workshops and office supplies.
- Contingencies
- Administrative costs (overheads)
- Budget explanatory notes: This part is placed below the budget table. It explains items in the budget that may need further details or qualification.

Table 9.2. *Budget format for a protocol.*

Budget category	Year 1	Year 2	Year 3	Total
Personnel costs				
1. Professional staff				
2. Support staff				
3. Consultants				
Subtotal				
Equipment costs				
1. Lab equipment				
2. Animal handling facility				
3. Audio-visual equipment				
4. Vehicles				
5. Computers				
Subtotal				
Operational costs				
1. Animals				
2. Feeds				
3. Drugs				
4. Travel				
5. Training				
6. Communication				
7. Information				
8. Workshops				
9. Office supplies				
Subtotal				
Administration cost				
Subtotal				
Contingencies				
Subtotal				
Total				

Budget explanatory notes.

9.5.6 Logical framework

Many donors require a logical framework to accompany the protocol. The logical framework serves to improve the planning, implementation and performance appraisal processes by clarifying project design and making it transparent to the borrower (the project team) and lender (the source of funding). The logical framework is a table of information about the protocol that:

- stimulates you to think of what you want to do and how
- can be used as reference to monitor the progress of the project as it provides the indicators to use and the means of verification
- shows the basic assumptions you made before the project started.

The logical framework consists of a 4 × 4 matrix, with a vertical hierarchy of objectives:

- goal
- purpose
- output
- activity.

The horizontal components are:

- summaries of the objectives at each level
- performance indicators for achievement of those objectives
- the sources needed to verify the indicators
- the important assumptions for moving from one level of objectives to the next higher level.

The 'pre-conditions' is an extra box at bottom right describing important factors which must be in place for the project to be initiated. Examples are: a. DNA sequencer available (for a genomics project) b. liquid nitrogen available (for an animal breeding project) c. country statistics available (for a policy analysis or economics project). An example of a logical framework is given in Box 9.1.

Box. 9.1. An example of a logical framework: Logical framework for the Small Ruminant Network Project

Narrative summary	Measurable indicators	Means of verification	Important assumptions
Goal Improve and sustain small ruminant research and enhance human resource capacities in the region	1. Increase in new small ruminant production technologies and research methodologies 2. Increase in national support for small ruminant research	1. Final project report 2. Level of small ruminant activities in the participating NARS 3. Level of national support for small ruminant research	1. Commitment to regional collaboration continues 2. Small ruminant research and development remains a priority in the region 3. Networking remains an acceptable mechanism for regional collaboration
Purpose 1. Build small ruminant research capacity and competence in the NARS Strengthen collaboration between and within NARS 3. Promote national small ruminant network formation 4. Optimise use of available human and other resources.	1. Better small ruminant research programmes 2. Better management of research projects 3. Strong NARS–NARS and NARS–ILRI linkages 4. Active small ruminant network activities 5. Better utilised resources (human and infrastructure)	1. Project annual reports 2. Project evaluation reports 3. Increased network activities 4. Level of institutional collaboration and interaction	1. Existence of enabling policy environment 2. National government's investment in small ruminant research continues 3. Support for networking is sustained at regional and national levels

Box 9.1. cont...

Box 9. 1. cont...

Output 1. Well-established regional collaborative research activities 2. Strong research capacity in the NARS 3. Relevant and adoptable research methodologies and technologies developed 4. Large volume of georeferenced data base on small ruminant genetic resources in the region 5. Strong institutional linkages 6. Enhanced research leadership capacity	1. Eighteen on-going research projects in participating countries 2. Number of technologies and research tools developed and tested 3. Level of interaction between collaborating institutions and scientists 4. Level and quality of information accumulated on small ruminant genetic resources 5. Level of management of research and accountability 6. Established national small ruminant networks	1. Number of research grants awarded 2. Research project reports 3. Research portfolios 4. Publications at local and international levels 5. Level of NARS participation in network activities 6. Level of interaction between and within institutions and scientists 7. Number of active national Small Ruminant networks in the region	1. Research programmes are scientifically sound and well managed 2. All collaborators are committed 3. There is an enabling environment 4. Funds allocated for project implementation are available on time
Activities/inputs 1. Steering Committee meetings to plan and sanction network activities 2. Research planning and development meetings 3. Implementation of approved research protocols 4. Documentation and publication 5. Counselling and training 6. Co-ordination	1. Steering Committee to hold two meetings 2. Number of research planning and development meetings 3. Number of on-going research projects 4. Research reports and published papers 5. Training programmes completed or on-going 6. Planned network activities implemented	1. Records of committee meetings 2. Reports on project activities 3. Newsletters, proceedings and published papers 4. Number of training courses and scientists trained 5. Completed network activities	1. Effect of natural disasters is minimal 2. Infrastructure (laboratories, farms etc) is available 3. Inputs/resources are available Project Budget (S) 1. Personnel 168,090 2. Services 4,250 3. Supplies 12,500 4. General expenses 12,100 5. Travel 14,500 6. Capital 3,700 Total 215,140

Suggestions for developing a logical framework

1. Involve as many stakeholders as possible in preliminary discussions.
2. Devote adequate time to develop a first draft of the log frame. It is important and deserves the team's best efforts.
3. Regard it as a very useful exercise which is essential for the success of the project and an absolute requirement for obtaining funding.

4. Begin with purpose as this is the objective of the project/programme. In developing purpose, ensure it will contribute to goal (which should be pre-defined). Remember, success is purpose achieved.
5. Identify important assumptions, i.e. those which must be fulfilled in order for the project to achieve the goal.This provides an indication of the feasibility of the project.
6. Define outputs required to achieve purpose. Remember you are contractually obliged to produce these. When outputs are achieved, the project is completed.
7. Define activities required to achieve outputs.
8. Identify important assumptions at the activities, outputs and goal levels. Do not underestimate the value of this step as it can lead to a revision of outputs and/or activities.
9. Detail objectively verifiable indicators (OVIs) for goal, purpose and output and show a budget summary at the activity level
10. Identify means of verifying at all levels.
11. Use a first draft as a basis for further discussion with all stakeholders.
12. Revise draft.
13. Send to selected independent reviewers for comment before finalising.

9.6 Writing strategies

Protocols differ depending on the nature of the problem that needs to be addressed and the format requested by the institution to which you will submit the proposal. This section will provide you with general rules to help you write a good, well presented protocol.

- Step 1: Begin to write your protocol early as it takes time to write a good protocol
- Step 2: Set a time outline for yourself. This will leave you ample time to think, plan, prepare, outline, write, revise, have colleagues review, revise, polish, get administrative approval, and mail the protocol.
- Step 3: Use the checklist provided by the donor or network.

9.6.1 Some writing guidelines

1. Make an outline for each component of the protocol to safeguard against missing important points.
2. Include well designed and labelled tables and figures.
3. Be accurate, clear and consistent:

- Use a logical sequence of presentation of the ideas.
- It is advisable to avoid big words and jargon. Your donor reviewer may not have time to go to the dictionary.
- Avoid ambiguity.
- Terminology and abbreviation should be the same throughout the text.
- Appropriate sections of the protocol should agree with each other.

4. Do not include irrelevant information.
5. Use simple words, short, direct sentences and short paragraphs.
6. Try to be positive but do not overstate your case.

If editing facilities are available in your institution, it is a good idea to use them.

9.7 The review process

Discussing your ideas and sharing the first or second drafts of your protocol with colleagues is a good step to help you avoid pitfalls. It will give you an idea of whether others understand what you want to convey. It is helpful if your institution has a review system for all protocols before they reach their destination. It is a good idea to set some guidelines for your reviewers on the feedback you need. We suggest the following points:

- scientific and technical significance of the research
- originality
- adequacy of methodology
- suitability of the facilities
- appropriateness of the budget
- appropriateness of time to carry out the research.

Request the reviewers to summarise the strengths and weaknesses of the protocol and provide recommendations.

9.8 Exercises

1. To write your protocol, the following are the main components:
   - Background and justification
   - Objectives
   - Expected outputs
   - Work plan
   - Budget
   - Logical framework

To practice, start with your ideas for a research project and answer the following questions for all of the above sections:

- What is the purpose of this section of the protocol?
- What should the scope of this section of the protocol be?
- How should the subject be introduced?
- What are the main ideas to be included in this section?
- Which of the items are essential? not essential?

9.9 References and reading materials

Reif-Lehrer Liane. 1989. *Writing a Successful Grant Application.* Jones and Bartlett Publishers, London, UK. 283 pp.

Module 10: Guidelines to communication

10.1 Performance objectives

Module 10 is intended to enable you to:

1. List the steps for planning the communication requirements of your research project.
2. Use guidelines for (i) oral communication, (ii) interpersonal communication, (iii) visuals and (iv) writing and editing.
3. Write papers for publication in refereed journals.
4. Write review articles.
5. Prepare posters.
6. Prepare overhead projection transparencies.

10.2 Introduction

Scientific research to solve the problems of livestock systems is a prerequisite to generating technologies. It is then the duty of the researcher, extension agent and others in government and non-governmental organisations to communicate this research to farmers, development agents, other researchers, donors and the general public.

This module is written for the livestock researcher. It broadly describes ways to communicate and provides reading materials that can be consulted for more details. Since the field of communication is wide, researchers are encouraged to seek information on skills not covered in this module from communication text books.

10.3 Planning communication in a research project

We have illustrated how to write protocols in Module 9. Communication of results should be part of the research plan. Communication activities must be planned at the onset of your research project. Most researchers think of communicating their results on an ad hoc basis and this usually happens near the end of the project. This behaviour results in poor communication of the results.

- As part of the plan for your project, develop the plan of communication activities. For example: seminars, annual reports, newsletter articles, refereed journal articles, workshop proceedings and project reports.
- Write the objectives for each communication activity.
- Define the expectations and agree on the role of each member of the research team in the project.
- Discuss issues with professional communicators (if you have them in your institution).
- List the agenda for action in order of priority.
- Agree on the deadlines for outputs.
- Implement the plan.
- Monitor the implementation of the plan.
- At the end of project evaluate the outputs of the communication plan as part of the overall evaluation exercise.

10.4 Communication guidelines

In order to communicate properly you need to acquire the necessary skills. In this module we will focus on guidelines for oral presentation, interpersonal communication, visual communication and writing and editing. We hope you learn and use these guidelines to communicate your research results to the various audiences (farmers, general public, researchers, extension agents, other development agents and donors). Depending on the situation, you may find yourself in need of other skills. Since it is beyond the scope of this manual to cover all communication skills a list of reading materials is included at the end of this module.

10.4.1 Guidelines to oral presentation

To communicate the results of your research, you often need to present your results in scientific meetings or to farmers. In both cases you need to acquire oral presentation skills. You need not fear speaking in scientific meetings or in meetings with farmers provided you learn the skills needed for this purpose (see Tripathi 1991).

What do we mean by presentation? Presentation means communicating your message by sight and sound via the co-ordinated act of mind, body, language and voice. Presentation skills can be divided into stage craft and delivery.

Stage craft

Stage craft is the effective management of stage devices. The stage is the place from where you make your presentation.

- The stage can be set into different configurations. For effective presentations, the front centre and the left side of the stage are the strongest. Movement on the stage should be co-ordinated for the most effective relay of the message. You should move forward if you want to stress a point, backward to show rejection and laterally to signal change in topics.
- The speaking platform in the stage is a table or podium. It is placed on the stage to facilitate placement of notes, transparencies and other material that you may need for the presentation.
- A public address system, composed of speakers and microphones, is sometimes available. If the system is not functioning well, raise the tone of your voice to keep the audience alert to your messages. Tips for using a microphone include:

- talk over the microphone, not to it.
- do not handle sheets of paper near the microphone.

- You may like to use a board (e.g. whiteboard) or flipcharts.
- You may need to use projection equipment. It is advisable to learn how to use the projection equipment (overhead or slide projector) before the meeting. You need to check that the equipment is functioning well before your presentation.

Delivery

Delivery is the communication of the message by verbal and non-verbal means. To master some measure of control over your delivery, you need to follow five simple rules:

- Preview the materials
- Practise your presentation
- Prepare the environment
- Prepare your audience
- Present

When you begin your presentation, approach the audience with a confident air. If the presentation is the first for you, you may feel nervous. Tips to feel at ease:

- Prepare or select your illustrations (slides or overhead transparencies) very well. Number your illustrations and arrange them in order before the meeting. Before the meeting, load the slides into the projector and do a trial run.
- Feel that the audience is there to learn from you and exchange information with you rather than evaluate you.
- Have no fear that you will lose your status.

It is advisable to show enthusiasm as this will pass to the audience. You need to observe the following tips in your delivery:

- Adopt a simple conversational style in a relaxed and confident composure. Look at the audience no matter how shy you may feel.
- Use an effective voice that is audible, intelligible, expressive and pleasant.
- Use simple and direct language; avoid jargon.
- Speak at a reasonable rate (100 to 125 words per minute) so that your audience can follow you.
- Present in a lively form; avoid dull, monotone presentation.
- Avoid distracting mannerisms (e.g. smoothing hair, playing with pens, too much body movement etc).
- At the beginning of your presentation thank the chair and the audience for giving you the chance to present and at the end thank them for their attention.

If unexpected events happen during your presentation (e.g. bulb of overhead projector burns), do not panic. Always have a contingency plan for such events. The audience will sympathise with you and probably admire you if you can continue the presentation in spite of the problem at hand.

After you deliver your presentation, allow time for discussion. A presentation without discussion will lack interaction with the audience. Tips for your conduct during this important part of the presentation:

- Keep calm while answering the questions.
- Do not evade questions; if you cannot answer the question or do not have the data to support your answer, say ‘I do not know’ which will gain you the respect of the audience.

- Treat every question or comment seriously even if they appear elementary to you; the listener has the right to learn.

10.4.2 Guidelines to interpersonal communication

Like all communication processes, interpersonal communication is a two-way process. To be successful in your career you need to understand and apply positive interpersonal methods. In this section we will deal with the following tools in interpersonal communication: verbal communication, non-verbal communication and active listening.

Verbal communication

You need verbal communication in every aspect of your career. You need to communicate verbally with your colleague scientists, farmers and development agents. A basic rule in verbal communication is simplicity. Simple language is more effective with most audiences. You can use jargon with listeners who understand it, otherwise it will distort your message. Your intention is to communicate and not intimidate. Tips for good verbal communication habits:

- Empathy: Try to put yourself in the other person's place. Do it with an open mind.
- Respect: Show respect to your listener and this will improve exchange of information.
- Eye contact: Establish eye contact with your listeners; this shows confidence and transparency.
- Grammar: Use correct grammar and avoid slang.
- Pace or speed: Speak at a reasonable rate as you may loose the listener if you speak too fast or too slow.

Your listeners often will hear what they want to hear. Factors that lead to this state are different attitudes, cultural and educational backgrounds and difficulties with language.

The best way is to keep trying until you get the proper feedback. Try to understand the factors that may hinder communication first and try to find ways to avoid the problems.

Non-verbal communication

In all cultures, people communicate with gestures, facial expression and body language. You can use non-verbal communication effectively if you understand the cultural background of the listener.

- Positive body language: relaxed appearance, body leaning forward, arms outspread and hands at side.
- Negative body language: tense appearance, chin in hand and hands hidden.
- Personal distance: If you happen to know the listeners you can speak to them at a distance of one metre, e.g. person-to-person communication with a colleague or a visiting farmer.
- Social distance: If you are involved in business or formal communication, maintain a distance of about two metres, e.g. conversation during a meeting or in group discussion.
- Public distance: During exhibitions or field days, you can maintain a longer distance while speaking without offending your listener. Use a microphone if available.

Active listening

To understand what the speaker is saying one must actively listen. Passive listening is good in certain circumstances, e.g. psychiatric treatments. Active listening is the active involvement of the listener (receiving the message) with the speaker (sending the message). Active listening can:

- show the speaker that you want to hear what he wants to say
- allow you to show the speaker that your are interested in open, honest communication
- lead to effective discussion

- assist in recognising problems
- aid in solving problems.

To be an active listener you should avoid the following behaviour:

- When giving feedback do not threaten, preach, blame, ridicule or interrogate.
- When listening, keep attentive and do not become distracted.

10.4.3 Guidelines to visual skills

This section of the module is targeted at scientists or extension/development agents who are not necessarily specialists in visuals. It is intended to help you grasp the concepts of visuals so that you may be able to:

- interact with artists while they are preparing visuals for you
- prepare simple visuals for written papers, posters and slides in the absence of visual specialists.

For more details about visual skills please refer to the reading materials especially Tripathi (1991).

Role of visuals

Visuals in your scientific writing or presentation can do one or all of the following:

- demonstrate a real situation
- highlight key points
- explain trends
- summarise information
- gain and hold the attention of an audience
- save time by avoiding excessive verbal explanation (a picture is worth a thousand words).

Visual format

There are two visual formats:

- Projected format which includes overhead transparencies and slides.
- Non-projected format which includes posters, flip charts and specimens.

In the following sections we will deal with preparation of overhead transparencies and posters. For more details on these or other formats please refer to the reading material.

Considerations in preparing visuals

The two main considerations are (i) clarity of the message and (ii) clarity of the image.

The following are tips for clear message and image visuals:

- Your message must be relevant and simple. The projected visual must show what is described. A good, effective visual has one fact or idea and is uncluttered. Divide complex information into chunks that are easily understood. It is better to show more visuals than to try and cram every concept into one or a few visuals.
- The recommended maximum number of text lines is nine including title and subtitle.
- The recommended number of words and/or data is 25 to 40.
- Try to use tables of maximum 6 rows $\times$ 6 columns.
- If you are to project tables or graphs from journal articles or books, try to produce your own version with summarised information; tables or graphs from books usually contain much information.

- Each visual must have a simple, short title that conveys the essence of the message and stimulates interest.

- Your image will be more visible if there is clear contrast between content (text, illustration) and background. One way you can achieve contrast is by using colour. You can use light colours for images (content) and dark colours for background. For text, white lettering on a blue background or yellow on a black background are recommended. You can use other combinations to avoid too many colours in one visual.
- Use lower case letters for the text as they are easier to read than capital letters. You can use capital letters at the beginning of sentences or in short titles.
- Select a readable typeface such as Times.
- The size of the letters depends on the viewing distance. You can check the legibility of a 35 mm slide by holding it at about 35 cm from your eyes. If you can read it, then the audience should be able to read it on the screen. To quickly check the legibility of an overhead transparency, lay it on the floor on a white paper and if you can read standing over it, then the audience should be able to read it from a screen.
- Sequence your visuals to flow from introduction to the body of your presentation to conclusion.

Graphic design for visuals

It is essential to understand the principles of graphic design for effective communication through visuals. Even though you may not be a graphics specialist, it is useful to learn and use principles of graphic design. For detailed information about graphic design consult Arntson (1988).

Nowadays it is easy to acquire, learn and use computer graphics software. The first step is to learn from good examples which are available in publications in the library.

- Start with a plan and a format.
- Consider the equipment you will use. We recommend computer programs such as Harvard Graphics and Freelance.
- Use simple typefaces.
- Learn to use vacant space to add to your message.
- Change the default space specifications between lines if you have different requirements.
- Keep your graphic design simple.
- Try to use illustrations if possible. You can use photos or select from the clip-art in the computer. Beware of copyrighted art material as it may get you into legal entanglement. If you need it badly, obtain copyright from the publisher.

10.4.4 Guidelines to writing/editing skills

This section will provide tips on writing and editing. For details refer to the reading material.

Writing tips

- Write short sentences.
- Keep the paragraphs short; editors do not like very long paragraphs.
- Use short, simple words in place of long words with the same meaning.
- Use personal words (like you and we, a person's name, direct quote etc) which will give your writing a human touch.

- Action verbs grab the interest of the reader better than to be verbs. Use verbs in the active rather than the passive voice.

When you have no access to an editor

- Check your paper or report before you submit it.
- Avoid mixed tenses. For example:

  Wrong sentence: He planted the seeds and milks the goat.

  Correct sentence: He planted the seeds and milked the goat.
- Avoid redundancy. For example:

  Wrong sentence: The farmer was growing the same identical cultivar as his neighbour.

  Correct sentence: The farmer's cultivar was identical to his neighbour's.
- Be careful of plural and singular verbs. For example:

  Wrong sentence: A mixture of fertiliser, herbicide and inert material are not available to the poor farmer.

  Correct sentence: A mixture of fertiliser, herbicide and inert material is not available to the poor farmer.
- Avoid careless repetition. For example:

  Wrong sentence: You want to emphasise a point, so you repeat it, using different words for emphasis.

  Correct sentence: You want to emphasise a point, so you repeat it using different words.
- Be careful about mixed construction. For example:

  Wrong sentence: We informed the farmer to prepare his field early, that he should plant at the onset of the rains, and he should weed in time.

  Correct sentence: We informed the farmer to prepare his field early, to plant at the onset of the rains and to weed in time.

10.5 Writing scientific papers

We do research to solve the problems of the resource-poor farmer. However, we need to communicate the research results to our colleagues. Communication channels to do so include newsletters, workshops and workshop proceedings, reviews and refereed journals. This section will deal briefly with how to write papers for refereed journals. For more details consult the reading materials section. We recommend you consult O'Conner (1991) and Stapleton et al (1995).

10.5.1 Planning the paper

The logical time to plan your paper is at the time you planned your research. When you complete the experiments, decide whether your results are suitable for publication. A good rule to follow: Aim to publish a few first-class articles than many mediocre ones. Quality will do you more good than quantity. How to know that a paper is worth publishing? A paper worth publishing meets one or all of the criteria listed below. It:

- contributes significantly to experimental or theoretical knowledge
- contributes significantly to observational knowledge
- translates known principles into applications.

If your work measures up to these criteria, then proceed with writing the paper. One way to test whether your results fulfill one of these requirements is to write down the conclusions you have reached. Measure these conclusions against what is known. Discuss them with a colleague. This preliminary exercise will show you whether there are gaps in your arguments and observations. When you reach this stage and are satisfied that your work meets the criteria, find time to write your paper. Simple rules to observe at this stage:

- Do not slice a piece of work into several short papers. Publishing several papers from the same work is suitable only for very large investigations.
- Use your own original work to write the paper. Using other people's work is plagiarism; this action is fraudulent and unacceptable.
- The paper must be original and the work should not have been published in another journal. This is another form of plagiarism. This rule does not prevent you from publishing a brief note or preliminary communication; if you have done so, you can still submit the work as a full paper.

Choice of journal

The following are important factors in choosing the journal:

- The scope of the journal: Does the journal publish research papers or review articles?
- What type of research papers does the journal publish? You are a specialist on small ruminants and you want to send your manuscripts to journals that deal with your research area.
- The audience: Is your work of interest to a wide general audience in your field of research or to a few specialists?
- Which journal is the audience you hope to reach likely to read?
- Which are the well established journals in your field?
- Which journals require authors to be members of the society that owns or sponsors the journal?
- Which journals provide reprints?
- How often is the journal published?
- Does the journal have page charges?

Once you answer the questions, make a list of possible journals. Choose the journal that will publish quickly and that has a style you can cope with. Once the journal is decided upon, obtain and read the 'instructions to the author'.

Outline

An outline will help you to write the paper systematically building it step by step. It is an essential part of the plan. The outline can be a topic outline or a sentence outline.

- Topic outline
  - List points under the main headings.
  - Sort the points you listed under the main headings into a logical order.
  - Give the points levels using numbers. Example:

    1.0 Introduction

    1.1 Agro-ecological regions

    1.2 Small ruminant distribution in agro-ecological regions
- Sentence outline

This style uses small, short sentences for the outline. Each sentence is then expanded. The example above in the topic outline can be transformed into a sentence outline as follows:

Agro-ecological regions in Africa are five. Distribution of small ruminants in agro-ecological regions depends on diseases, feed availability, policy issues and population pressure.

Authorship

Research on small ruminant productivity is best done by multidisciplinary teams. The contribution of the different members of the team differs. When it comes to publishing, the question of authorship is discussed. Sometimes it can lead to serious disagreements. The following criteria can be used to settle this issue:

- Each author should have participated sufficiently in the work to take public responsibility for the content.
- Credit for authorship should be based on substantial contributions to conception and design, analysis and interpretation of data, drafting the article, reviewing the manuscript critically for important intellectual content and giving final approval of the version to be published.
- Those who should not be included as authors are persons who:
  - participated only in the acquisition of funds
  - participated only in collecting data
  - only supplied you with research material
  - only performed general supervision of the research group.

To give due credit to such persons, you can mention them in the acknowledgment section.

All those listed as authors should give their consent. There is need to agree on the order of authors' names. The following guidelines may be used:

- The first author is the person who did most of the work and all or most of the writing.
- Co-authors' names are listed in an order that reflects the amount of work done by each.
- If the contribution of authors is equal, then list names alphabetically. Another solution to this situation is to assign the place of first author to the members of the team in turn for a series of papers that will be published from the work.
- If you are the first author, find out exactly how each co-author wants their name on the publication.

How to organise writing among the team of authors

The team should agree on the purpose, scope and outline of the paper before writing starts. The following are suggestions on how to handle the process:

- One person in the team should do the writing to be edited and reviewed by others.
- Another approach: Each member of the team should write a section. One person should edit the final draft so that the paper is consistent in style.
- The team can meet to discuss the draft; these meetings should be short.
- All authors should approve the final draft of the paper before it is submitted to the journal.

There is no one style of doing this and teams are free to develop the process that will suit their situation.

Preparing tables and figures

Readers often scan a paper quickly to assess whether they want to continue reading it or not. They most often refer to the abstract, the tables and figures. Therefore attention should be given to these important elements in your paper. Each table or figure must stand on its own and must contribute to the text. Decide whether the data will be presented as a table or a graph. Check the instructions which the journal provides for preparing tables and graphs before you do them. You should prepare the tables and figures before you start writing.

Tables are used to:

- report precise numerical information
- show data for component groups
- present numbers when they are not enough to make a graph.

A table consists of title, column headings, row headings, the rows and columns containing data and explanatory notes when needed.

Tips for designing tables:

- Keep the structure simple.
- Focus on what message you want the reader to get out of the table.
- Arrange the data from left to right and from top to bottom
- Make the width of the table suitable to fit the columns of the journal.
- Write concise titles for tables.
- Arrange the columns in each table in a way that will show the readers the conclusions you want them to draw.
- Make the column headings brief.
- The rows and columns containing the data should show numbers to accuracy. Numbers should be to the nearest significant figure. When the numbers are large and loaded with zeros, use appropriate factors or units for column headings, e.g. 1,000,000 can be written as 1000 in the field cell and the column heading read ×1000.
- Give the statistics such as probability values, standard error of mean etc. Follow the journal style.
- If there is a need, use footnotes to explain data.

Figures that are often used in papers include graphs, maps, photographs and algorithms and flow charts. For complex illustrations and photographs you need to use the services of a professional. If your institution lacks such services, hire freelance artists or photographers. Most computers have the software required to prepare graphs. Therefore we will provide you with tips on how to prepare graphs. If you want to attempt other types of figures on your own, we suggest you consult communication text books that deal with these techniques (see the reading material).

Caution: Producing professional quality maps and photographs requires expensive equipment and time to master the required skills.

Graphs are used to:

- illustrate trends and the relations between variables in data
- present numbers when there are too many of them.

There are different types of graphs:

- Line graphs are curves demonstrating the relationship between two variables. Line graphs are often used for comparison over time. They show trends more easily than other types of graphs.
- Bar graphs or bar charts show data for one variable. Use bar graphs when there is no continuum (e.g. time) between the experimental points. You can also use them when the results can be subdivided and compared.
- Histograms show the frequency of distribution of the data points for each class of a variable (e.g. weight).
- Pie charts show the size of component parts.

Tips for drawing a graph

- Try to use the services of a graphic specialist. If this service is not available to you, use computer software such as Harvard Graphics. You need to learn the skills necessary to perform this job.
- Do not try to cram your graph with too much data but do not waste space either.
- Three to four curves in one line graph figure should be the maximum.
- When the curves cross, use different line thickness to separate them.
- Draw your curves as straight lines between data points or curves (smooth) fitted by an equation (smooth curves do not have to pass through every point). The computer will fit the curve if instructed to do so.
- You should place the dependent variable on the y-axis (e.g. yield) and the independent variable on the x-axis (e.g. time or fertiliser input).
- Draft short but informative descriptions for the axes; use lower case lettering.
- Use the same symbols when the same entities occur in different graphs.
- Use the same x-axis co-ordinates for different figures if values in them are to be compared.
- Do not draw rectangles around graphs unless the journal instructs you to do so.
- If you extrapolate a curve beyond the observed point, draw the extrapolated part as a dotted line.
- To differentiate between curves of similar types of line (e.g. solid) and thickness, use different symbols for points joined by lines (e.g. ❍, •) or similar symbols for points joined by lines of different type or thickness (-, -). Use the symbols preferred by the journal.
- Draw a vertical line to show the standard deviation or the standard error of the mean. Make these lines thinner than the other lines. In the legend tell the reader what these lines represent.
- Whenever possible, label curves directly rather than using a key. Position the labels horizontally.
- Label the x and y axes briefly and simply. Use the labelling to show (i) the variable and (ii) the unit of measurement.
- Choose the scales of the axes carefully. If the axis does not start at zero, mark a break; mark calibrations clearly.

10.5.2 Writing the first draft

After you have prepared the outline, your notes and draft tables and figures, you are ready to write the body text. Leave wide margins and print in double spacing to allow corrections or comments to be written in the empty spaces.

You can start writing the sections in a systematic way or start with easy sections. Most people find the materials and methods to be the easiest place to start. Follow your outline, but it should only be used as an aid.

A typical scientific paper consists of:

- Title
- Authors
- Postal addresses
- Abstract
- Introduction
- Materials and methods
- Results

- Discussion
- Acknowledgment
- References

Most journals follow this order.

The main headings are the reference points that make the structure of paper clear to the reader. The conventional main headings (abbreviated as an acronym IMRAD) are Introduction, Methods or Materials and Methods, Results and Discussion. Results are often combined with discussion but it is better to keep these sections separate if you can.

Title

The title should answer the question: What is the paper about? Most people find it easier to write the title after they write the first draft. The final version of the title must help the reader and not you. The journal may have specific requirements for the maximum length of the title. Do not use trade names or jargon in your title. If you write a series of papers on the same subject, you can either give each paper a separate title or use a general title with numbered subtitles. Journals differ in their policy on this issue. Some journals may ask you for a shorter version of your title to use as a running head (header) or as a footer.

The title of your paper should describe the main subject. It is the part of the paper that is most often read by researchers when scanning the journals or when conducting a computerised literature search. It is used in abstract journals, citation index journals and in data bases. Therefore it is important to give it attention. A good title should:

- be brief (around 25 words)
- describe the contents of the papers accurately
- avoid jargon and formulae
- contain key words for indexing and retrieval.

Abstract

An abstract answers the following questions:

- Why did you start?
- What did you do?
- What did you find?
- What do your findings mean?

The abstract usually comes at the beginning of the paper unless the journal states otherwise. Even though the content of the abstract reflects the paper, it is written to stand on its own.

- It is an abbreviated, accurate representation of the contents of your paper, without added interpretation or criticism. It is usually not more than 250 words.
- It should be informative and should present as much of the quantitative and/or qualitative information contained in your paper as possible. It reports the objective of the research, its scope, the methods used, the main results and the principal conclusions.
- It uses short and simple sentences. Try to write the abstract as a single paragraph. If the abstract is long, you can split it into two or more paragraphs. Write it after you have completed the other sections of the paper.

Things not to do in the abstract:

- Do not include information that is not in the paper.
- Do not include tables or diagrams.
- Do not include citations.

Key words

Some journals may ask you to provide key words for indexing and cataloguing entries. Choose the most important and most specific terms you can find in the paper. If you are keen that your work reaches as many scientists as possible, write specific key words; remember that readers search in the libraries using these key words.

Introduction

Readers will first scan the figures and tables and read the abstract. They then move to the introduction. Therefore the introduction must convince them to continue reading.

The introduction answers the following question:

- Why did you do the work?

An introduction should be relatively short and should contain:

- Information on what is already known or in use supported by references to the most important publications on the subject.
- The hypothesis.
- Support for the arguments to do the research.
- Experiments you intend to do to test the hypothesis.

Materials and methods

This section answers the following questions:

- What materials did you use?
- How did you use them?
- Why did you choose these methods?

What do you include in the materials and methods section?

- Describe the experimental design.
- Describe what you did and how you did it. A basic rule to follow: Give enough information for your colleague scientists to repeat your experiment if they wish, or assess how reliable your methods are.
- If the methods are already published in widely circulated journals, give the reference instead of repeating all the details. If you use a new method, describe it in full. If you made changes to published methods, describe the changes you made.
- Describe the materials used.
- Describe briefly the geographical area.
- Use generic names for chemicals. Do not use trade or local names unless there is no generic name for them.
- Use the full taxonomic names for animals, plants and micro-organisms.
- For small ruminants, give the age, sex and genetic and physiological status.
- Describe the method in a logical order including the procedures.
- State which statistical methods you used. If you used complex statistical methods, explain them.
- Indicate which computer program you used, if any.

Results

The results section answers the question:

- What did you find or see?

What do you include in the results section?

- Write the section so that it can stand on its own.
- Present the results in a logical order. The best order is the one used for the protocol.
- Reduce the massive amount of data you have collected to means along with standard errors or standard deviations.
- Include results from controls as well as treatments.
- Include only results relevant to your argument; these can agree or disagree with your hypothesis. Suppressing negative results is unethical. A negative result is as important as a positive one as it may direct the reader to a new hypothesis.
- You may wish to combine the results and discussion sections. In this case results are to be presented briefly while stating what the findings mean.
- Repeat in text only the most important findings shown in tables and figures.
- Refer to every table and figure by number in the text.

Statistics, to be used in the results section, give estimates of variability or precision of the findings. Follow the journal's policy when presenting statistical parameters in the results section, in tables and figures. (See Module 8 for more details). The following are general tips:

- Use well known statistical tests.
- Report the data such that readers can assess the degree of experimental variation.
- Use standard deviation to show the variability among individuals. Use standard error of mean to show the precision of the sample mean. State the number of measurements used to arrive at the mean.
- If data are from a skewed distribution, give the median and the range.

Discussion

The discussion section answers the following questions:

- What do your findings mean?
- What are the implications of these findings for further study?

What do you write in the discussion section?

- Answer the specific questions you stated in the introduction.
- Show how your findings relate to existing knowledge.
- Describe what is new in your work.
- Discuss the results and hypotheses.
- Present facts and refrain from speculation.
- Focus on the main facts and avoid temptation to refer to every detail of your work.
- Use the end of the introduction as your starting point in the discussion section.
- Use past tense for results and present tense for the conclusions you draw from them.
- Conclude the section by stating the main results, conclusions and recommendations for future work.

Reference list

All references in the text should be included in the reference list and vice versa. Follow the reference style of the journal. Avoid secondary citation, i.e. Jones (1953), cited in Black (1994); cite only those publications you have read yourself. Do not rely on any other author's interpretation.

10.5.3 Style

The rules for grammar and style are well covered in CBE (1994) and Benjamin (1989).

Tips for style

- As often as possible use the first person (I or we).
- Try to use the active voice most of the time. You can still use the passive voice on rare occasions.
- Use the past tense for observations and results of completed actions. For example:

  Ewe nutrition influenced lamb birth weight.
- Use the present tense for generalisations and conclusions. For example:

  Losses are particularly high in lambs weighing 2.0 kg at birth.
- Avoid jargon.
- Be simple and concise.
- Be sure of the meaning of every word.
- Use verbs instead of abstract nouns. Abstract nouns end in -ion. For example:

  Wrong: Investigation of risk factors.

  Correct: The risk factors associated with these problems need to be investigated.

  Wrong: No exploration of this possibility has yet been carried out.

  Correct: Nobody has explored this possibility.
- Break up noun clusters and stacked modifiers. These are strings of nouns and adjectives which give no idea of which modifies what. For example:

  Wrong: Guidelines enforcement for laboratory worker safety is a management responsibility.

  Correct: Management is responsible for enforcing guidelines for the safety of laboratory workers.

10.5.4 Review by colleagues

Request your colleagues to review your paper before you submit it to the journal. The following are steps to do so:

- Present your work as a seminar. Feedback will pin-point the strengths and weaknesses in your arguments. Note that tables and figures for a seminar are different from those for a journal.
- Select two to three colleagues and ask them to review your paper. Give them a deadline as sometimes it takes a long time for busy colleagues to do the job. If your institute practises the review process routinely, follow the institute rules.
- You may send your paper to a reviewer from outside your institute.
- Incorporate the comments from the reviewers and then submit the final draft to the journal.

10.5.5 Submission to a journal

The following are steps that may help you submit your manuscript to the journal:

- Write a covering letter to the editor.
- Mail the required number of copies.
- Enquire if you hear nothing in about eight weeks.

- Reply to the editor appropriately when you receive one of the following answers: (i) paper accepted (ii) paper will be considered if you make the requested change or (iii) paper rejected.

If revision is requested

If you agree that the changes requested by the editor will improve the paper, then work on the manuscript to make the changes. Always work with your co-authors and get their agreement.

- Return the manuscript with changes incorporated.
- Send a covering letter thanking the editors and attach the list of the changes you have made. If you disagree with one of their suggestions, explain why you disagree. Your reasons must be compelling and clearly argued.
- If you feel the paper is good as it stands and you disagree with all their suggestions, there is no need to waste your time. Submit the paper to another journal.

If the paper is rejected

- If the editor rejects your paper because it is outside the scope of the journal, submit the manuscript to another journal.
- The editor may reject your paper because it is too long and needs changes. If you agree with this and the rejection letter includes an offer to reconsider the article, make the changes and resubmit the paper. Otherwise change the style and submit your manuscript to another journal.
- The editor may inform you that the paper is rejected because of serious flaws or lack of information. If you agree with this assessment, put the manuscript away and obtain more information to fill in the gaps. If you feel the editor is wrong, send the paper to another journal.
- If you are not convinced by the assessment of the editors, write a short, polite letter explaining why you think the paper should be reconsidered.

Copyright

You can use published or unpublished information. If the information is published by others you need to obtain written permission from whoever has the copyright to this material. If you fail to do so, your paper may not be published by the journal or you will be legally pursued. It is your responsibility to obtain permission.

10.6 Writing review articles

When you are advanced in your career, you may be requested or you may want to write a review article to synthesise information in your field and share your views with your colleagues in your field of specialisation. Review articles have a wider perspective than research papers and writing such articles will help your own development.

10.6.1 Types of review articles

Review articles are detailed summaries of the work published on a specific topic, e.g. feed utilisation by small ruminants. There are two types of review articles:

- Type I: Review articles that evaluate published work on the topic and provide an up-to-date synthesis of it.
- Type II: Review articles that summarise the work without evaluating it.

When you accept to write a review article, look at the journal's instructions to authors and at reviews in the current issue. The journal may define the scope of the review. You must be clear on whether you are asked to write type I or II.

10.6.2 Literature search

Once you have agreed with the journal on the topic, you need to conduct a literature search before you begin to write. The following are steps to do so:

- Decide on the main headings of the review.
- Make an outline of the article and plan your reading strategies.
- Make notes on your procedures, on the criteria you will use and facts of special interest.
- Use filing cards to keep your notes or you can use a computer. Guard these cards carefully.
- Start with background publications (text books and earlier general reviews).
- Do a computer search if the facility is available. In the case of small ruminants or livestock contact ILRI for assistance.

10.6.3 Writing the review article

- A basic rule is to keep the audience in mind.
- Write a clear introduction which can accommodate both the specialist and the non-specialist. In this section describe the background and state the question your review will examine.
- Write the body of the review which usually focuses on a description of the literature search and ends with conclusions and recommendations for future work. Unlike research papers, review articles do not have standard headings such as materials and methods, results and discussion. The headings in the body of the review depend on which aspects of the topic are being discussed. In this section inform the reader how you searched the literature: by conventional methods, a computer search or a combination. If the review is a synthesis and analysis of studies, explain how you assessed the reliability of the studies covered. Explain the methods you used to analyse the literature, e.g. statistical methods. Evaluate the selected articles objectively:
  - Analyse variations in the findings critically.
  - Present both sides of a controversy dispassionately and present your position.
- Write your conclusions clearly. In the conclusion section write the summary of the main findings and make recommendations for new research.
- Write the reference list. Observe accuracy by taking details from the original publications. This section is very valuable to researchers and mistakes may waste their time. Write the references in the style of the journal in which you will publish the review and ensure that all references which you cite in the text are included in the reference list and vice versa.
- If the review journal asks you to write an abstract, try to make it informative by describing briefly (i) the purpose of the review (ii) the search method (iii) the main findings (iv) the main conclusions and (v) the recommendations.

10.7 Posters and overhead transparencies

You may present your visual material using an overhead or a slide projector, e.g. flip charts, films, video clips or computer multimedia or a combination of these. In this section we will limit ourselves to preparing posters for scientific meetings and transparencies for overhead projectors.

10.7.1 Posters for scientific meetings

It is often necessary to communicate information in a display format. Posters will do this effectively. Posters are communication tools used for publicity and advertising. They are linked to meetings, shows and public sales. In meetings they are used to display brief information about a theme. The poster must attract onlookers to view it and stimulate them into further action. This section will deal with posters for scientific meetings.

The content of a poster

After you have decided on the topic for your poster, outline the content of your poster keeping the audience in mind. In general, the following are the main sections of an outline of a poster for livestock research:

- Title
- Introduction (it should be brief)
- Materials and methods used
- Results
- Conclusions

Posters for farmers or the general public will not necessarily have the same sections. They usually present a visual message accompanied by a few words. Whether the poster is for farmers or scientists, the title should be informative, short and meaningful.

Format and design of posters

The format and design of posters depend on:

- How much space is available? What are the vertical and horizontal lengths?
- What shape is the space?
- Are there restrictions on the size of lettering?

You must bear in mind that your audience will not have time to read too many words. So you should convey the meaning through visual means if possible, e.g. striking pictures, use of colour (strongly coloured cards make good background for text in white). There is no single design formula. A basic poster design should organise the shapes following the principles of design: balance, use of space, use of text type, dynamics of colour and layout (see Arntson 1988). If you need to break the rules for a good reason, go ahead. In all cases, the arrangement of the design elements (title, subheadings, body text, visuals) must be simple and pleasing to the eye. Steps for designing a poster:

- The first step is to find the information about the format before you embark on designing. Posters can have a horizontal (landscape) or vertical (portrait) format (Figure 10.1).

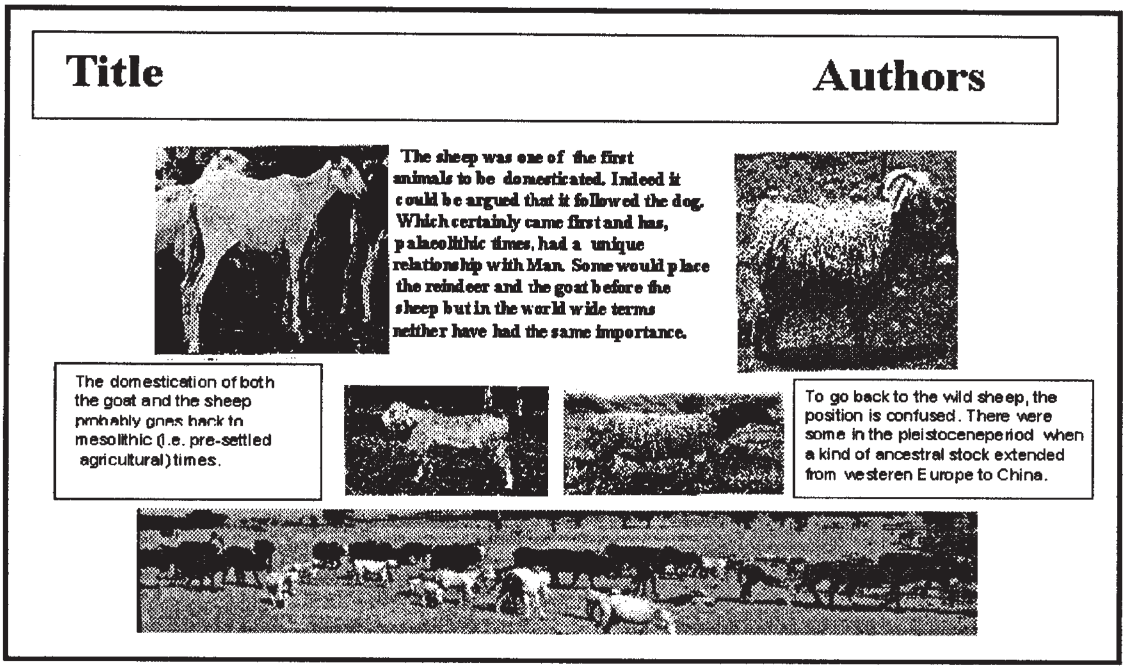

Figure 10.1. *Format determines how you design your poster.*

- Draw to scale a sketch plan of the presentation.
- The plan will guide you on how many illustrations and how much text you can fit into the allotted space.
- Make your display easy to carry especially if you have to travel to the meeting place. If you are allotted a space of 185 cm-wide by 120-cm long, you can have pages of text and figures fixed to 8 pieces of thin card (38 × 54 cm). The cards will occupy two rows of four pieces each and leave room for a title card. The title card should be large enough to be placed at the top left followed by your name and address (Figure 10.2).
- Number the text and illustration sheets on the upper right side (Figure 10.2); numbered sheets help readers to find their way quickly through information. It is a good idea also to number the sheets at the back to help you carry them in the right sequence to the conference site. The thin cards (38 × 54 cm) will each hold an A4 sheet containing text or illustrations. Use your own variations but for best results keep the number of different sizes of texts and illustrations to a minimum.
- Design an uncluttered display; this will help a reader who approaches the poster to stop, read, understand and move on in a very short period.
- When you arrive at the meeting place, fix the text and illustrations to the cards. Use glue or paste that does not dry too fast; this will allow you to adjust positions easily. You can also use double-sided adhesive tape to fix your sheets.
- Prepare a handout for interested viewers who may want to consult the information later. Design the handout to include the title, your name and address and a summary of the poster display. The handout should be short and as beautiful as the poster.

Design considerations for posters:

- The major design elements are the space occupied by the title, the body of text and the visual. One of the elements should be larger than the others to give contrast.
- Leave space around the design elements to avoid crowding. The open space area should be 30 to 40% of the poster area.

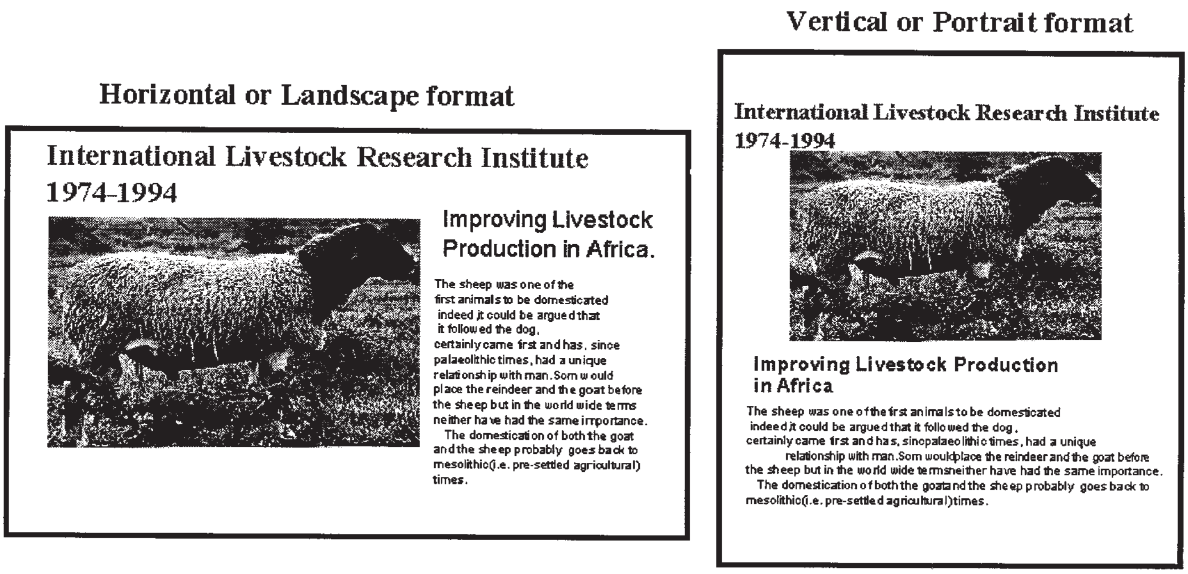

Figure 10.2. *Layout of posters.*

- Balance the elements, e.g. a large element on one side can be balanced by two smaller elements on the other. You can deviate by creating imbalance or stress which may be desirable to draw attention or direct the eye to certain elements of the design (Figure 10.3).
- Use horizontal lettering as vertical lettering is difficult to read. To create contrast, a large vertical line or illustration can be effective to attract the viewers' attention to the poster.

Materials for preparing posters:

- Select the best material you can afford to produce your poster.
- Smooth hard finish paper: You use this paper if you use ink. This combination will allow you to produce sharp finished lines.
- Heavy printing paper.
- Coverstock paper.
- Cardboard.
- Felt tipped markers for lettering.
- Commercially available letters: These include rub-down transfer letters and pressure-sensitive paper or vinyl letters. Transfer letters are expensive and rubbing them time consuming.

Tables and graphs for posters:

- Use figures rather than tables if you can.
- Write short and informative titles for figures and tables; these titles should be the same size as the subheadings.
- Keep legends short and place them below the figures.
- Make labels on graphs run horizontally.
- Lettering for posters:
- Produce lettering for the title and subheadings using a computer if you have the facility. If you do not have a computer, use dry-transfer or stenciled lettering. We suggest you use bold sans serif type

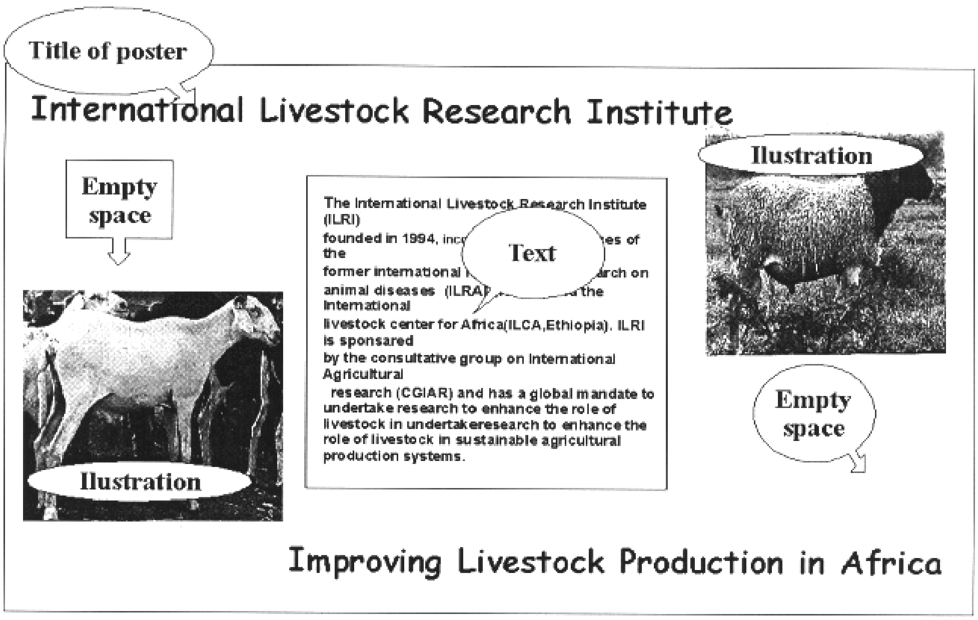

Figure 10.3. *Balance among elements in a poster.*

for these parts of the poster. Make the capital letters of the title at least 4 cm high and lower case letters at about 2.5 cm high.

- Use lower case (small) letters for the body of the text, except when it is necessary to use capital letters (start of sentence or genus). Make capitals 8 mm high and the small letters 4 mm to facilitate reading from 1 m away. Do not use capital letters for the body of the text because they cannot be easily read from a distance.
- Write your name and address with letters a little larger than the body of the text.
- For subheading titles, use capital letters of 1.0 to 1.6 cm high and lower case letters of 0.6 to 1.0 cm high.
- Line thickness for letters should be reasonably bold for good legibility. Rule of thumb: ideally line thickness should be one-sixth the height of the letter.

Visuals for posters:
The visual (illustration, photograph) is most often an important part of the poster. Posters for extension purposes usually contain visuals. The visual should:

- present an idea that will appeal to the audience
- be simple, compelling and to the point
- carry or reinforce the message.

Put yourself in place of the viewer and choose the most appealing and informative visual that will communicate the message.

Displaying posters

To display your poster:

- place it where it is highly visible, i.e. at eye level or above
- make sure there is adequate lighting.

10.7.2 Preparing overhead projection transparencies

Transparencies are large, transparent acetate sheets on which information can be written and projected. They are handy to use in presenting results during scientific meetings. The overhead projector is widely used and is available in most meeting rooms. It can be used with normal room lights. Tips for using the overhead projector:

- be sure that an electric outlet is available and working
- face the audience while using the projector
- switch the projector light off between transparencies to protect the audience from the glare.

Transparencies contain words or graphics (including illustrations). They are easy to prepare. They range from inexpensive, simply made transparencies to multicoloured transparencies with several parts (or overlays). Acetates of various quality are available to make transparencies. The equipment used to prepare transparencies ranges from specialised machines to inexpensive thermal and electrostatic copiers.

Preparing transparencies:

- Prepare the main points for each transparency.
- Use 10 lines or less with 7 words per line in each transparency.
- Use a legible typeface.
- Type text/data first on paper.

- Prepare illustrations (or obtain from clipart or other sources). Illustrations must be few.
- Design the layout of the transparency.
- Insert text/data and illustrations.
- Photocopy material onto the transparency using the equipment available to you.

10.8 Exercises

1. During your career you will be submitting papers to journals using different reference systems. Write the steps you will take to arrange the huge number of references that will accumulate. Indicae how you will do this using the computer and how you will do it manually.
2. When you start writing your paper, cut yourself off from the outside world. Do you agree with this statement? Elaborate on your reaction and write your own view of how you would go about it.
3. A newspaper editor approached you and asked you to write an article about your research for the newspaper. How would it differ from the style and format you use to write your research paper? Try to change this title of a research paper to a title for the newspaper article:

   Effects of restricting the water intake of dairy goats upon their milk yield

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Module 11: Transfer of technology

11.1 Performance objectives

Module 11 is intended to enable you to:

1. Define transfer of technology.
2. List the technology transfer systems.
3. Describe the role of research in the transfer of technology.
4. Explain extension needs of pastoralists and farmers in crop–livestock systems.
5. Describe at least one case study from your region.

11.2 Introduction

As a researcher your job is to develop technologies that will increase livestock productivity. But this effort will not have any impact unless the technologies are transferred to the farmers. Although your main function is research, you cannot afford to ignore linking your research to technology transfer efforts. This module outlines the mechanisms involved in linking your research to transfer of technologies to resource-poor farmers. In most countries of sub-Saharan Africa there has been little government support for the agricultural sector and, within this sector, small budgets have been allocated to research and extension services. This resulted in failure to transfer new technologies. A few success stories can be cited where extension programmes received good finance, were well structured and were targeted on high-value commodities. An example of a successful extension effort is dairy development in Kenya.

Many factors led to the poor transfer of technologies. Among these is the separation of extension from research programmes. As a consequence many extension agents have little information to share with the farmers. This module will focus on research–extension linkages. Your role in the research–transfer of technology continuum will be clarified.

11.2.1 Key concepts

Technology transfer is a two-way flow of technical information and materials among farmers, researchers and those who disseminate technologies. This definition extends the meaning of extension beyond association with the traditional public sector to involve services provided by other institutions such as non-governmental organisations (NGOs), private firms, educational institutions and producers' associations. Our definition also implies that technologies are generated by all parties and diffused by all. There is a continuum with no hard boundaries (Figure 11.1).

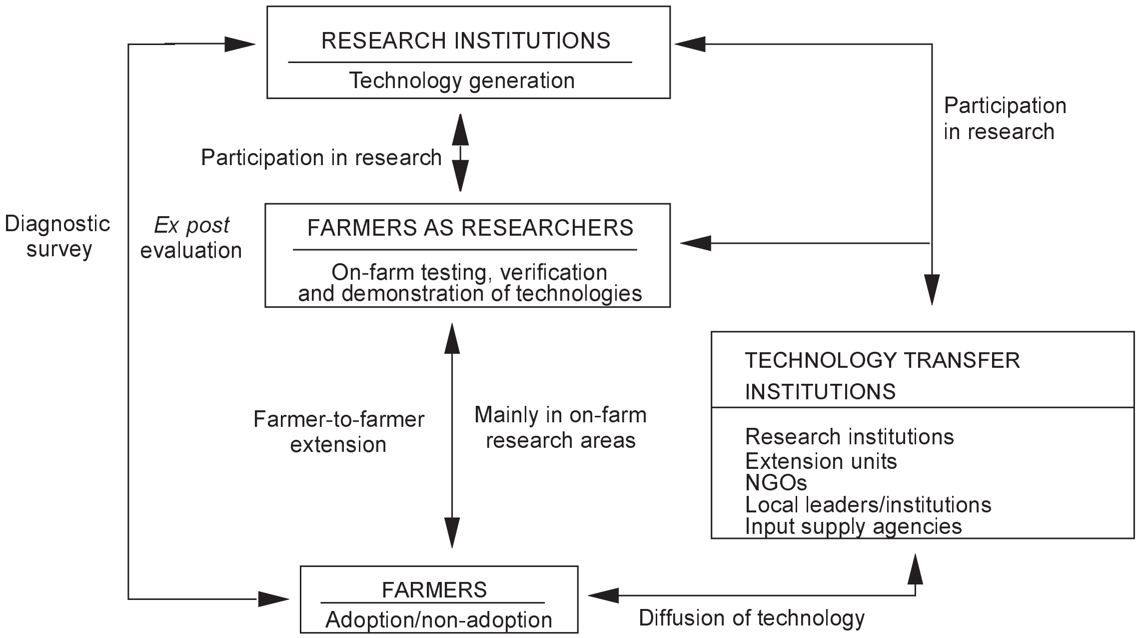

Figure 11.1. *Linking research and technology transfer agencies to farmers.*

The main processes of research are:

- Discovery: The process of collecting information and/or searching for relationships among variables. This process includes basic and/or strategic research.
- Exploratory development: The process of identifying, understanding and controlling the interaction between a proposed technology and the socio-economic and physical environments. This process includes applied research.
- Technology consolidation: Involves transforming the results of research into a new technology package. It includes adaptive research.

The main processes of technology transfer:

- Technology production: The process of providing materials (inputs and/or information) in sufficient quantities to those who are responsible for delivery.
- Delivery of technologies to farmers: The technology to the farmers; this can be done through many channels.
- Monitoring and evaluating the use of technologies: Studying the adoption rate by farmers and the impact of the technology.

Institutions involved in research and transfer of technology are many. Many researchers may be involved in transferring technology. In this module we will use information on research methodologies from Module 2. On-farm research:

- applies a problem-solving approach
- identifies and describes major farming systems in which the technology is needed
- adapts technology at farm level for farmers sharing the same problem
- involves farmers participating as partners
- obtains feedback to improve the relevance of research
- involves the collaboration of research, extension and development agencies for effective transfer of technologies.

We need to stress the point that technology transfer is used in this module in a broad sense to encompass extension activities. Transfer of technology differs from extension in the following ways:

- It provides inputs and services such as training on use of technologies or inputs, indigenous knowledge, credit, health services, infrastructure, entrepreneurship etc. Extension, the way it is applied in many countries, is mostly limited to information delivery.
- Government and non-governmental institutions can transfer technologies.
- Transfer of technology is a two-way flow of information. Farmers, development agents and researchers exchange information during the process.

Researchers should be involved in the process of technology transfer because:

- research is conducted to solve farming problems
- it is essential to translate research results into action at the farm level
- the researcher needs input from extension and development agents during research planning and implementation and for transfer of technology activities.

Therefore there is a continuum from research to transfer of technology that necessitates the participation of all parties: farmer, researcher and technology transfer agents (Table 11.1). Studies by ISNAR (Kaimowitz et al 1989) confirmed the hypothesis that the traditional weakness of the links between research and technology transfer was in part due to lack of awareness of their interdependence.

Table 11.1. *Areas of interdependence between research and technology transfer.*

Areas for interdependence	The need for interdependence*
Problem definition	Transfer agents > researchers – help them understand farmers' problems – facilitate contact with farmers Researchers > transfer agents – identify the scientific approaches to solve a specific problem
Experimentation	Transfer agents > researchers – identify representative location for trials – develop realistic experimental designs – explain objectives to farmers Researchers > transfer agents

Table 11.1 cont...

Table 11.1. cont...

	– establish proper procedures – provide advice during implementation
Technology adaptation	Transfer agents > researchers – help farmers choose the right option Researchers > transfer agents – propose the options for modifying technology to suit local conditions
Technology verification	– Transfer agents > researchers – help manage on-farm trials Researchers > transfer agents – ensure scientific rigour – process data from trials
Technology packaging	– Transfer agents + researchers > farmers – inputs required by new technology are available to farmers Researchers > transfer agents – explain the context in which a new technology should be applied
Provision of information	Transfer agents > researchers – produce and deliver effective messages to farmers Researchers > transfer agents – ensure that the messages are accurate
Provision of services	Transfer agents > researchers – provide specialised communication services to disseminate technologies Researchers > transfer agents – provide services such as soil testing, pest identification and seed certification
Provision of feedback	Transfer agents >researchers – provide the feedback of farmers about the new technology Researchers > transfer agents use feedback to research-identified problems

* > means contribution to.

11.3 Technology transfer systems

There is no agreement on the best way to transfer technologies in sub-Saharan Africa. The extension systems in the region differ widely because of differences in countries, prior colonial structures and the current interaction with international research and development agencies.

We can group the technology transfer systems practised in sub-Saharan Africa as follows:

- Conventional hierarchical approach. This system employs a large number of field staff who work directly with the farmers and are supported by subject-matter specialists.

- Co-operative organisations approach. In this system the organisations provide advice, services and inputs to the farmers.
- Profit-oriented agencies approach. In this system, the agencies provide specialist services of high value crops or livestock to farmers. The agencies make profit selling services or inputs.
- Farming systems research and extension approach. In this system a multidisciplinary approach is followed. The team looks at the total farm unit and technology development is a collaborative effort.

Most of the countries in sub-Saharan Africa use the conventional hierarchical approach. Some countries, through funding from the World Bank, modified this system by introducing the training-and-visit system. A common feature of the conventional hierarchical approach is the separation of crops and livestock technology transfer systems. If combined, there is bias towards crops. There is now pressure from farming communities and donor agencies to combine the different crop and livestock extension services into a single service. To achieve any impact, this service must link farmers with researchers.

11.4 Transfer of technology linkages with research

If you conduct research to develop technologies, you need to link your research to farmers and technology transfer groups. Researchers link to farmers through on-farm research (Figure 11.1) to ensure that the results of research solve farmers' priority problems. Researchers link to transfer of technology groups through validation of technologies and pilot production projects (Figure 11.1). The link ensures impact through a wider dissemination of technologies. The two links complement each other and one cannot replace the other.

11.4.1 Why do we need links?

Links between researchers, farmers and technology transfer groups ensure that:

- research is focused on priority needs and problems of farmers, therefore results from experiment stations are used to solve farmers' problems
- farmers and technology transfer workers keep up with research developments
- technologies are tailored to suit local conditions
- relevant technologies are widely promoted and adopted
- farmers have access to the information, inputs and services required to adopt technology
- researchers have access to farmers' knowledge.

11.4.2 Organisational issues

To link research to transfer of technology we need to develop an organisational structure. An organisational structure can be achieved through:

1. Grouping research and technology transfer tasks

- The most important interactions should reflect the grouping. Units should be set up according to the degree of interaction needed to meet a specific objective.
- Grouping people whose work might overlap.
- The difficulty with this approach is that no group takes responsibility for translating research results into specifications for a new technology, packaging that technology and providing the materials necessary for its use.

2. Merging research and technology transfer units

In this approach two or more units in the same institution have a common supervisor who is responsible for integrating their functions and work. Merging is assumed to increase efficiency, facilitate communication and collaboration and promote a shared goal between researchers and technology transfer agents. This approach has its problems and is not as easy to implement as it may sound. It requires the following conditions to succeed:

- Researchers and transfer of technology agents share a common goal and area of concern, e.g. to improve productivity of livestock.
- Financial and human resources are available for linkage activities.
- The size of the new institution is manageable.
- The management of the new institution must aim at making the groups work together.

3. Co-ordination units or positions

This approach can use subject-matter specialists, research–extension liaison officers or pre-extension services. Unlike direct supervision, these positions have no authority over the units they will co-ordinate. Co-ordination units or positions can handle technical matters better than direct supervision as they have the time and resources to use for integration, to develop expertise and to recognise and fill gaps. However, this approach has many disadvantages:

- institution managers may overlook their responsibilities in the belief that the task is already under control
- the co-ordinated groups or units may ignore liaison staff because the co-ordination positions have neither formal authority nor support from management
- liaison staff may resent the job of only linking others who are doing the interesting work.

This approach may therefore lead to additional barriers (new procedures, objectives, language) rather than removing existing ones.

4. Permanent committees

These committees help promote horizontal and vertical integration. The members may be drawn from various units or institutions. For such a committee to succeed:

- all parties consider it necessary
- members of the research–transfer of technology groups have a stake in its work and implement its decisions or recommendations
- it is action oriented and not only a forum for discussion
- its mandate is specific
- senior management in all involved institutions support it
- meetings are well planned and chaired and follow agreed-upon procedures.

11.4.3 Types of linkage processes

In the previous section we dealt with the structural issues of linkage. This section will deal with the process which will apply links between on-station and on-farm research as well as between research and transfer of technology.

Planning and review processes

Planning and review meetings have been widely used to forge linkages between research and technology transfer operations. To be successful tools, they require resources (staff time and operating funds). These processes function through:

1. Joint problem diagnosis

Joint problem diagnosis is best done in the field. Informal diagnostic field survey proved effective in bringing together on-station researchers, on-farm researchers, technology transfer agents and farmers. The survey helps on-station researchers learn about farmers' problems and appreciate the potential benefits of the technology.

2. Joint priority setting

This exercise is very useful but is difficult to implement. It can be a potential source of conflict as its expected outcome is the work agenda. One group may perceive another as trying to dictate the agenda. The problems can be overcome by including senior managers in the exercise.

3. Joint programming and review meetings

These meetings should be kept small and should concentrate on a particular commodity (e.g. livestock) and region. A meeting is successful when it is attended by people who can make decisions and implement actions.

Collaborative activities

1. Collaboration in trials, surveys and dissemination

This is a very effective mechanism for linkage. Formal arrangements are needed to facilitate collaboration between on-farm researchers and transfer of technology agents at the field level. Such agents should be trained in skills needed for trials or surveys. Researchers need to be trained in dissemination skills.

2. Joint decision making on recommendations

This can be a problem for linkages if not treated properly by senior management. Management needs to develop a system that agencies can use to reach consensus on flexible mechanisms for assigning the relevant agencies in joint decisions and recommendations. Management should also assign agencies to implement these decisions and recommendations.

3. Field visits

Joint field visits are very effective in strengthening linkages. For this activity to be sustained managers should allocate adequate operational funds.

4. Informal consultations and sharing of tasks

This system is a low-cost way of collaborating. It is very effective for links between on-station and on-farm research and should supplement, but not replace, formal mechanisms. The system is successful when staff are willing to share additional responsibilities and when institutions are flexible. It depends on individual relationships.

Resource allocation

The resources allocated to research–transfer of technology reflect its importance to managers. The major resources are staff time and operational funds.

1. Guidelines for allocating time

Research staff rarely allocate time to transfer of technology activities; they prefer to use their time solely for research. Managers need to provide researchers with clear guidelines on the time to be spent on activities for technology transfer: joint meetings, field visits etc. Managers should, however, be careful not to affect the core professional activities of the researcher.

2. Allocation of funds

Senior management should provide operational funds to meet transport, fuel etc. Lack of funds will slow or stop collaboration. Collaborative activities should be line items in the programme budget and the funds should be the responsibility of those who will use them. Collaborating institutions should share in providing the funds.

3. Staffing

The rotation or secondment of staff is an effective way of getting the necessary human resources for linkage activities. It is essential to set a clear time frame for rotation or secondment.

Communication

Communication for research–transfer of technology links must be planned at the onset of activities and funds must be provided. Commitment, skills and talents are usually needed.

1. Reports, audio-visual material and publications

Extension workers are interested in short, easy-to-read and understand (preferably in local languages and without scientific jargon) publications, e.g. brochures, bulletins, leaflets. Research results should be made available to all involved in the research–technology transfer continuum. Researchers should not wait until the results are published as it takes a long time for papers to appear in journals. In addition, extension workers may not have access to the journals. Institutions should invest in audio-visual resources, human resources and infrastructure. Visuals and radio messages are often more effective than printed material.

2. Seminars and training courses

Seminars and training courses are effective means to foster links. These activities are specially effective among groups that are new to each other or do not understand each other's work.

11.4.4 Management of linkages

Senior management of the institutions or units involved in research–transfer of technology links need to:

- participate in research–transfer of technology activities to demonstrate their importance
- build linkage responsibilities into the job description of all involved staff
- provide guidelines to staff on how time and funds are allocated to linkage activities
- provide funds for linkage activities which are shown as budget line items
- reward participation and minimise hardships.

11.5 Extension for integrated crop–livestock systems

The population pressure in sub-Saharan Africa is driving the cropping and livestock systems towards integration. Farmers and governments are therefore seeking to integrate the currently separate extension services for crops and livestock. This should lead to efficient delivery of viable technologies and efficient use of financial, physical and human resources. The integrated service should aim at improving farmer–researcher–extension linkages. Unfortunately, many livestock departments in Africa are resisting the process for fear of being submerged into crop departments. Nigeria took this bold step in 1991 and their experience shows that the integration process will not be easy.

The majority of extension agents in sub-Saharan Africa have crop production backgrounds and their educational level is low. They are therefore unable to provide advice on animal production to farmers. The agents should be able to provide effective advice on common livestock needs such as feeding regimes, calf feeding, clean milk production, fodder production, vaccination, deworming, dehorning, castration, breeding management systems, marketing, resource allocation etc.

Animal production specialists working with or in the extension service are essential to provide more advanced advice. They need to work with farmers' training centres. As farmers become sophisticated, the need for more specialised information becomes acute. Training can best be done by the farmers' organisations and newly sprouting businesses. Government services should co-ordinate and encourage these efforts. An example of services that can be provided by private organisations is dipping. There is a need to find new and innovative ways to provide information to farmers. Sub-Saharan Africa can benefit from the example of information dissemination in Asia where progressive farmers have been the most important source of information for other farmers.

11.6 Extension for pastoralist systems

Pastoralists differ from sedentary farmers in many respects and therefore need different transfer of technology approaches. The management requirements for livestock differ between pastoralists and sedentary farmers. The acceptance of new technologies also differs between the two groups. There is no specific technique for transferring technologies to pastoralists.

Experts on rangelands should work closely with pastoral groups to improve the systems. The experts should have the knowledge and skills to do the job; they should also have high quality interpersonal communication skills. In addition, they need to be familiar with the communities they serve. Knowledge of the local language is a great advantage.

Pastoralists may need information on the following aspects of livestock improvement:

- animal health
- better feeding technologies
- improved breeding programmes
- seeds for food crops and animal traction technology
- processing of animal products (milk, dried meat, hides and skins)
- improving water supplies.

The type of extension work and who should do it will vary depending on the needs and movement of the pastoralist. Usually government services to pastoralists are limited to health services. To remedy this situation governments should provide well trained multi-purpose subject matter specialists. To solve the problem of movement, these specialists can meet with the pastoralists at watering points or certain camping sites. The pastoralists should be encouraged to select certain extension agents to perform health services and other simple extension requirements. This will relieve the burden of the subject-matter specialists who will limit their intervention to scheduled visits.

11.7 Case studies

In this section of the module we will use case studies to illustrate the concepts of transfer of technology and research–transfer of technology links. As the stories occurred in diverse conditions, they might not cover all the aspects of transfer of technology or the linkage mechanisms. Still we consider them useful and hope you use them as guidelines while pursuing your own activities.

11.7.1 Case study 1: Fodder banks in Nigeria

Background

Nigeria has 56 million small ruminants. The majority of livestock owners are semi-settlers and live in the harsh environment found in the north of Nigeria. During the last two decades pastoralists have settled in the subhumid zone.

The problem

- Natural pastures in the subhumid zone of Nigeria are the main source of feed for ruminants. However, the pastures do not meet the nutrient requirements of the animals throughout the year.
- Crude protein is sufficient for only three months.
- By the end of the dry season, it is common for animals to have lost 10–20% of their body weight. Losses associated with nutritional stress are reproductive wastage, deaths and prolonged calving intervals.

- Even though feed supplementation can be used to alleviate nutritional stress, supplementation with agro-industrial by-products is beyond the reach of smallholder farmers because of their high cost and shortage.
- Attempts to increase productivity of the rangeland using conventional methods (bush control, selective burning and rotational grazing) fail because the rangelands are grazed communally and are burned accidentally.

Research

To deal with the problem of poor nutrition, researchers introduced the fodder bank concept (de Leeuw et al 1994; Saleem and von Kaufmann 1995). The researchers observed that farmers only grew forages when there was no competition with crops for labour and when the forages were protected, even though the forages were needed as animal feed. The researchers also observed that animals were allowed to graze on regerminated legumes. It was therefore hypothesised that a technology that could provide fodder and impose no competition for labour with crops could be appealing to farmers. This was an example of researcher–farmer interaction that led to refinement of the farming system. In 1980 ILRI started experiments on farmers' fields undersowing the sorghum crops with stylos (*Stylosanthes guinensis* cv Schofield and Cook and *S. hamata* cv Verano). The results of this on-farm research showed that:

- land preparation for sowing stylos was minimal
- intercropping with forage conflicted with weeding of the crop
- itinerant herds attacked the legume pastures and it was necessary to protect the legumes with fencing.

ILRI concluded that the techniques available to integrate forage production with food crops were inadequate, agropastoralists were ready to grow forage crops provided there was adequate protection and there was a need to increase feed resources in arable farming systems and fallow lands.

ILRI conducted different levels of researcher-managed/executed and farmer-managed/executed trials. Various techniques for incorporating forage legumes (mainly Verano and Cook stylo) into compatible cereal–forage crop mixtures were assessed. The sowing date of forage legumes in cereal crops was found to differ for each cultivar. The best crop geometry that produced the highest yield of grain and fodder per land unit was found to be inter-row sowing of stylo with two rows of sorghum and one row of soybean on alternate ridges.

ILRI conducted a series of trials to refine the technology:

- Fodder improvement in the fallow lands
- Nutrient and water-management trials
- Screening of legumes
- Nodulation trials
- Wet-season grazing trials.

The technology

Out of ILRI's research the fodder bank technology emerged. A fodder bank is an 'enclosed area of concentrated forage legumes reserved for dry or wet season supplementary grazing'. A fodder bank can be established by farmers as follows:

1. Fencing fodder banks

- A good site is selected (stony or waterlogged areas avoided).
- A small unit of land is fenced and sown with stylo. The size of the fodder bank (1–4 ha) depends on the number of animals in the herd.
- Materials for fencing include wooden posts and barbed wire, metal fences and live fences using suitable trees or shrubs.
- Fire breaks are established to prevent accidental fires during the dry season.

2. Preparing land for fodder banks

Land is best prepared using tractors but this is expensive and so the technology uses alternative methods:

- kraal animals on the fenced site and burn before sowing
- undersow legumes in crops at the appropriate time, in the last year of the cropping cycle.

3. Sowing seed to establish a stylo fodder bank

- Use a seeding rate of 15–20 kg per hectare.
- Sowing is done after it has rained sufficiently. This ensures that seed-harvesting ants will not gather seeds during dry spells. The ants can also be prevented by sowing a slurry of mixed stylo seed with wood ash or manure.
- Stylo seeds have hard seed coats and therefore exhibit hardseededness which can be reduced by scarification and hot water treatment to encourage better germination. This is, however, a disadvantage if all the sown seeds germinate at the same time followed by a dry spell. It is better to sow a mixture of softened and hard seeds.
- Mixing stylo seeds with 150 kg superphosphate per hectare before broadcasting generally gives satisfactory establishment of a good fodder bank.

4. Weed control

Animals can graze fodder banks early in the season to selectively control the fast-growing grasses which otherwise smother the slow-growing legumes.

5. Dry season management of the fodder bank

- Grazing begins as required during the dry season.
- The animals can graze the fodder bank either early in the morning or in the evening after returning from free grazing.

Linkage mechanisms

On-station research by ILRI was followed by on-farm research (results highlighted above) which led to the fodder bank technology. The technology was packaged by the researchers and National Livestock Projects Division (NLPD) for transfer to livestock owners. Features of the linkage mechanism used to transfer the fodder bank technology in the subhumid zone of Nigeria:

- extension staff worked closely with researchers
- collaboration was strengthened during a survey and frequent visits to the research sites and farmers' fields
- research staff trained extension staff.

Transfer of technology

- NLPD extension staff in collaboration with researchers from the National Livestock Project and ILRI conducted a rapid appraisal for several states. Results showed that few farmers were aware of the fodder bank technology. To correct for this, NLPD publicised the technology through many radio programmes.
- The World Bank provided credit to farmers between 1987 and 1991 to establish fodder banks.

Impact and lessons

The following are highlights of adoption rates and benefits of the technology. Detailed studies and follow-up are needed to document the large-scale impact across Nigeria if any.

- By 1986 about 25 fodder banks were established.
- By 1991 farmers had established 637 fodder banks under the supervised loan scheme of the World Bank Second Livestock Development Project.
- Adoption rates were increased when credit was provided to establish the fodder banks and when pastoralists were allocated land.
- Adoption rates were high among pastoralists who owned land or settled inside grazing reserves.

The benefits of using fodder banks are:

- they provide supplement feed during the dry season
- animals grazing fodder banks have increased growth rates, milk production and calf survival
- pastoralists are forced to sell fewer underfed stock
- fencing increases security by preventing trespassing
- confining animals inside the fenced fodder bank saves labour costs
- crops following legumes benefit from nitrogen build-up.
- the fenced fodder bank can be used for rotational cropping.

The extension package now includes rotational cropping showing beneficial interaction between cropping and the fodder bank technology. The problems facing adoption are:

- The high inflation rate that followed the devaluation of the Nigerian currency increased the cost of establishing fodder banks. However, many farmers still believe the benefits of fodder banks outweigh the cost.
- Attempts to introduce fodder banks in the semi-arid zones of Nigeria were less successful than in the subhumid zone because of lower rainfall and a shorter growing season.

11.7.2 Case study 2: Alley farming in West Africa

Background

The humid zone of Africa receives over 1500 mm of rainfall annually and extends over the coastal area of West Africa, eastern Madagascar and part of Mozambique. In this case study we will focus on the humid zone of Nigeria which contains 9 million small ruminants. Farmers keep small ruminants to generate cash for special needs. Animals are kept in varying systems ranging from free range to confinement. Among the important breeds of small ruminants in West Africa are the West African Dwarf goats and sheep which possess a degree of tolerance of trypanosomosis.

The problem

Due to population pressure and the need for land for crops, farmers increasingly confine goats and sheep all year round and cut-and-carry pasture to feed the animals. As tropical grasses mature, they are less palatable as lignin content is high and crude protein is low. The productivity of goats and sheep is therefore low due to poor nutrition. Small ruminants are infected with many diseases in the humid zone. Thus better nutrition is hypothesised to increase tolerance of the effects of trypanosomiasis and other diseases and thus enhances productivity.

Research

To solve the above problem, ILRI started its Humid Zone Programme (HZP) in 1978 in Ibadan, Nigeria. This programme collaborated with the International Institute of Tropical Agriculture (IITA) which developed the alley cropping technology. In alley cropping, the prunings from leguminous trees are applied as mulch during the cropping season. To increase the productivity of small ruminants, ILRI considered the possibility of using the prunings during the non-crop dry season as protein-rich supplement to traditional feeds. ILRI called the new technology (a modification of alley cropping) alley farming

(Jabbar et al 1996). A research programme was pursued on-station and on-farm with the following main components:

1. Agronomic studies to modify alley cropping for using tree leaves as mulch and fodder

- Suitable tree–grass combinations and their methods of establishment and management were developed.

2. Animal nutrition studies to determine animal response to browse supplementation and develop feeding strategies for utilising limited feed supply

- *Leucaena leucocephala* and *Gliricidia sepium* were found to be the most promising trees for alley farming. *L. Leucocephala* contains mimosine which is toxic to animals if fed in high amounts. A technique was developed for growing *Leucaena* sp and *Gliricidia* sp in alternate rows and offering them to the animals in a 1:1 ratio to avoid possible toxicity.

- The optimum level of supplementation was established for young and mature animals. Supplementation generally increased the survival of lambs and kids. Digestibility and nitrogen balance studies showed that utilisation of fresh or dry *Leucaena* was similar. Any surplus fresh material from wet seasons can be dried and stored for use in dry seasons. Intake of *G. sepium* was higher in the dry form than in the fresh form.

3. On-farm studies were conducted

- On-station results on biological performance were validated.

4. Socio-economic studies to assess the benefits of feed supplementation and identify factors related to adoption potential

- Including livestock in the farming systems increased return by 13 to 16%.

- Including small ruminants in the alley farming system increased its sustainability.

The technology

1. Technology 1: Fodder trees in alley farming systems

- Grow *L. leucocephala* and G. *sepium* in alternate rows. Both trees can be established by direct seeding in association with crops. Establishment can be improved by applying phosphorous and nitrogen and inoculating with effective strains of *Rhizobium*.
- Grow crops in the alleys formed by the two leguminous trees. If the farmer is growing maize, four rows of the crop are recommended.
- During the cropping season, the trees are pruned and the prunings are applied as mulch to improve fertility and control erosion. Mulching done during the later part of the cropping season is not beneficial to the crop.

Pruning is done during the later part of the cropping season and during the remaining part of the dry season to provide the animals with a protein rich feed supplement to the traditional diet. Supplementation is given at about 600 g dry matter per day for young animals and 800–900 g dry matter per day for adults.

2. Technology 2: Intensive feed gardens

An alternative technology to resolve the competition between trees and crops is planting small feed gardens with trees-only or tree–grass combinations.

The trees are sown at 50 cm spacing in trees-only small feed gardens. The trees are pruned at 12-week intervals.

The trees are established 2.5 m apart with 2 rows of grasses. Recommended grasses are *Brachiaria mutica* and *Panicum maximum.*

Linkage mechanisms

In this case study the research–transfer of technology involved researchers from ILRI, IITA (through AFNETA) and a number of education and research institutes in Nigeria. Extension and development organisations were partners in on-farm research. Farmers participated in on-farm research and other activities needed to transfer technology. An extension worker from the Ministry of Agriculture was trained by ILRI and was placed with ILRI technical staff in the villages where the research and transfer of technology were done. Other extension staff participated on an irregular basis.

Extension agents and researchers collaborated in the selection of sites for on-farm experiments.

The combination of transfer of technology (semi-extension developmental approach) and research (on-farm experimental approach) resulted in two advantages:

- Farmers learned the technology package through hands-on experience and so they owned it.
- Time from on-station experiments to adoption was reduced.

Transfer of technology

Many farmers neighbouring the on-farm experiments decided to adopt the technology and planted alley farms. Attracted by the interest of farmers in and around the research villages, the National Livestock Projects Division (NLPD), a World Bank-funded federal government agency in Nigeria, showed interest in the alley farming technology package.

In 1989 NLPD established pilot projects in several states in southern Nigeria. The projects included establishing plant nurseries in selected villages and distributing tree seedlings to farmers. NLPD provided additional services: a package of animal health care, credit and advice. Staff from NLPD received training from ILRI scientists on how to establish and maintain the alley farms. The NLPD staff then passed this information on to the farmers.

In 1991 FAO launched a two-year pilot project in Ghana, Togo and Nigeria to disseminate alley farming through national extension and development agencies. The mechanism:

- FAO assessed the alley farming situation in those countries in consultation with extension services, development agencies and universities.
- Training was provided for both extension agents and farmers.

Impact

1. The benefits of alley farming were demonstrated.

2. Initial adoption by farmers was low and remained around the on-farm research areas. This was because:

- Alley farming is a complex technology. Farmers need to invest time to learn the technology, especially establishment and pruning.
- Even though the technology was profitable, it needed labour input for pruning at a time when it competed with weeding the crop. Even though the total labour requirement was the same between alley farming and non-alley farming systems, this labour competition partly contributed to the slow rate of adoption.

3. The transfer of technology mechanism of NLPD and the FAO project did not function well in spite of special effort. However, their input is yet to be evaluated.

11.7.3 Case study 3: Crossbred goats for milk production in Burundi

Background

The Burundi highland plateau is part of the Great Lakes highlands. The high population pressure has resulted in shorter fallow periods and cropping on steep land and in the swamps. This evolution pushed cattle out of the system and farmers replaced them with goats.

The problem

There is a need to improve animal productivity to provide for household nutrition and cash. Farmers needed dual-purpose goats to produce milk and meat.

Research and technology development

A national network on small ruminants was created in 1987 to link research and development projects in Burundi. The national university, Facagro, co-ordinated the network. At the university research was conducted on:

- crossbred goats
- characterisation of goats
- utilisation of *Leucaena, Panicum maximum* and *Pennisetum purpureum* and rice straw by goats.

A package of improved does, improved feed resources and disease control was tested on 21 farms in Mutaho, Burundi. The goat development project in Ngozi started in 1980 with funding from German Agency for Technical Co-operation (GTZ). The project targeted 3500 smallholders. The project staff crossbred the local goats with Alpine bucks. Research found that this crossbred increased milk and body size. The project established buck centres where farmers can bring their does for mating. During 1988, 1989 and 1990, more than 8000 matings were performed. ILRI scientists in Burundi joined the research–transfer of technology effort to determine how the livestock system fitted in the farming system and to identify opportunities for increasing the productivity of livestock in the system (Rey 1993). A total of 240 farmers were selected, 120 of whom brought their does for mating. The researcher observed that:

- farmers who adopted crossbred dairy goats had farms
- farmers established fodder crops before adopting crossbred goats
- there was a decrease in off-farm employment
- many farmers back-crossed the Alpine–Small East African does with Small East African bucks to limit the negative effect of a high level of Alpine genes.

Linkage mechanisms

Collaborative research was developed between the Ngozi goat project and ILRI. The thrust of the research was technology transfer. The Ngozi goat project staff collected day-to-day data while ILRI staff visited the project to follow-up on data collection. The university facilitated the participation of graduate students.

Transfer of technology

The project established an extension unit to encourage farmers to participate. In addition to cross-breeding, the unit provided farmers with information on improved housing, management, fodder crops and disease control. To commercialise milk production, the project built a factory to process cheese and organised marketing of the milk.

Impact

The Ngozi project operated only for a limited period. When the project terminated, the breeding of crossbred goats stopped in 1991. Therefore it was not possible to assess adoption rates or impact. This is an example of a project which is not sustainable as it depends exclusively on external funding. When the donor stopped funding, the projected activities ceased.

11.7.4 Case study 4: Dual-purpose goats in Kenya

Background

Due to the rapid increase in human population in Kenya, the demand for livestock products is increasing. The Kenyan government set a goal for improving the diet and standard of living of rural people through enhancing the productivity of goats. The Kenya Agricultural Research Institute (KARI) established the Small Ruminant Collaborative Research Support Programme (SR-CRSP) in 1979. The programme is part of a collaborative effort involving research institutions in Bolivia, Brazil, Indonesia, Kenya, Morocco, Peru and the United States of America. It is focused on production of milk, meat and manure from goats on small farms.

The problem

The population pressure in western Kenya has increased rapidly causing a decrease in farm size. The prevailing agricultural system could no longer support the needs of smallholder farms for food and cash. SR-CRSP diagnosed the farming situation in western Kenya and formulated the following hypotheses:

- Dual-purpose goats can convert unused crop residues and browse to milk and meat.
- Keeping three to five does instead of a cow can add a small but year-round supplement of milk protein to family diets.
- A typical doe can produce three kids in two years, thus increasing marketing prospects and meat for family consumption.
- The technology to promote dual-purpose goats must be low-cost, low-risk and complementary to cropping activities.

Research

The Small Ruminant Collaborative Research Support Programme (SR-CRSP) was implemented in three phases:

- Phase 1 1980–82: The programme characterised social, economic and biological activities of production systems.
- Phase 2 1983–85: The programme conducted on-station research on goat breeding, health, nutrition and agronomy. It also conducted on-farm research on agronomy, goat nutrition and health management, and research on preliminary cost–benefit and social feasibility studies.
- Phase 3 1986–91: The programme performed large-scale economic and social evaluation of dual-purpose goats' performance in production systems.

SR-CRSP emphasised the farming systems approach to ensure that the research was relevant to farmers' needs.

The technology

Technology packages were ready for expanded testing during 1988 (Semenye and Hutchcroft 1992). The technology package was:

- Two-way and four-way cross goats composed of equal parts of two exotic breeds, Toggenburg and Anglo-Nubian, and two indigenous breeds, East African and Galla.
- The goats were dual-purpose to produce milk and meat.
- The goats were fed crop residues and agricultural by-products. This base ration was supplemented with foliage from trees (*Leucaena* or *Sesbania*), Napier grass or sweet potatoes vines.
- The goats were confined and the forages were cut and carried to the unit.

Linkage mechanisms and transfer of technology

The principal institutions involved were SR-CRSP of KARI and various units in the Ministry of Agriculture. SR-CRSP also worked with scientists from Egerton University and the University of Eastern Africa at Baraton.

- Linkage with the universities was done through graduate studies. Thirty-seven students earned their masters or PhD degrees. They conducted research relevant to the programme.
- Extension field assistants were trained by SR-CRSP staff on the new technology packages.
- On-farm demonstrations and group meetings were held. They led to interactions among extension field assistants, farmers and scientists.
- SR-CRSP used a memorandum of understanding between the programme and collaborating farmers. This detailed the rights and duties of the farmers; it placed ownership of the goat with the farmer.
- SR-CRSP exhibited its technology packages in local agricultural shows. These provided feedback on how the public perceived the technology packages.
- SR-CRSP conducted on-farm research in Emuhaya, Hamisi and Vihiga in Kakamega District, Maseno in Kisumu District and Boro in Siaya District.
- During on-farm testing participating farmers were given one doe to start a dual-purpose goat flock. During the large-scale testing, new farmers were given two does in 1988.

Impact

Socio-economic monitoring showed that the technology packages were adopted enthusiastically by farmers in the relatively higher elevation, higher rainfall and more densely populated villages. Farmers in less densely populated villages at low elevation and with less rainfall were not highly receptive of the technology. This was due to the bias in research to high elevation areas and the fact that farmers in low elevations had larger farms and could afford cows.

11.8 Exercises

1. Transfer of technology can link with research through formal or informal mechanisms. List mechanisms linking research to transfer of technology in your region. Are the linkages effective? If not, explain why.
2. Agricultural technology system (ATS) consists of all the individuals, groups, organisations and institutions engaged in developing and delivering new or existing technology. The involvement of the various parties listed in this definition requires various types of skills. List these skills and the basic activities you think the groups should be engaged in.

11.9 References and reading materials

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