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IDENTIFYING INVESTMENT OPPORTUNITIES FOR RUMINANT LIVESTOCK FEEDING IN DEVELOPING COUNTRIES

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Acknowledgements

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Executive summary

Driven by population growth, increasing demand, stricter quality and safety standards for animal source food and increasing competition for land and water resources, the livestock sector is changing rapidly. Within this changing landscape, smallholders with crops and livestock will remain the mainstay of the sector in developing countries for some decades to come. For example, the projections in this report foresee an increase in cattle, sheep and goat populations in the mixed crop-livestock systems in the developing world from 467 million to 648 million adult cattle equivalents. However, also here, the abovementioned mega-trends and the resulting competition for feed resources imply that these systems will have to intensify to ensure an acceptable livelihood for its producers. Enhancing the quality and quantity of feed, as one of the most important factors of animal production will play a critical role in this process of intensification. However, feed improvement should not be seen in isolation, but rather be assessed as part of the greater value chain, including all stakeholders. For example, investing in feed improvement without markets to sell the increased production from this investment or without an adequate feed quality control regulatory framework, would yield negative returns. This report follows a step-by-step analytical framework that will provide the priority investments and actions in technologies, policies, and institutions.

As the first step in this framework, the most promising value chains, where feed-related strategies and investments are most likely to have significant impacts, have to be identified. On the basis of the key characteristics of (a) growth and market opportunities, (b) number of poor and pro-poor potential and (c) the supply constraints, in particular disease risk and feed resources availability, this report identifies first Sub-Saharan Africa and South Asia as priority areas, and then, within these areas, it identifies three commodity value chains in five regions of particularly great potential to benefit poor producers and consumers. They are:

- Dairy in East Africa and South Asia, because of the expected growth in demand (including export potential), the number of poor involved (135 million), and the moderately adequate situation resource situation;
- Beef in West Africa, because of its potential for import substitution and potential for improvement, in spite of the resource constraints.
- Small ruminant meat in West Africa and Southern Africa because of the number of poor involved (110 million) and new domestic market opportunities.

The framework was then used to analyze the diversity of feed types, the availability of feed sources both from within and from outside of local systems, based on informant interviews and quantitative modeling of the current situation and with projections to 2030. Detailed data for each feed type and source are available in the main text, but the general trends show (a) a reduction in the use of crop residue such as straws and stovers, although at a projected between 20 and 50 percent these remain a substantial part of the daily ration of the livestock of those systems; (b) an increase in the use of crop-by-products (such as oil cakes and by-products of the milling industry) and concentrates, although staying in 2030 mostly below ten percent, with the exception of the South Asian dairy systems, where they would amount to 25 percent of the total diet. With such a low share of the diet, and with most products not edible for humans, these systems would not endanger global food

security; (c) an increase in the area planted for forages, in particular in dairy systems; and (d) a sharp increase in feed procurement from the market instead of supply from the own farm.

Based on these projections to 2030, opportunities for feed-related investments with major positive impacts on the poor are then identified. A number of strategies, policies, technologies, and services come to light as especially promising areas for such investment in a variety of scenarios. Applying the assessment framework to each of the three value chains yielded similar results for all chains. First of all, they stress that addressing feed related issues in the context of evolving value chains requires combinations of public and private investments: policies, strategies that facilitate adoption and market engagement with reduced transactions costs such as improved access to knowledge and services for smallholder producers and other market agents together with adoption of improved feed technologies. The more specific areas of improvement that warrant priority in targeting investments are:

- Technological feed improving solutions include in all value chains studied (a) more attention to research and development for feed/food crops, i.e., crops that provide both food (mostly grain) for humans and feed (mostly straws) for livestock; (b) better ration formulation, through the introduction of feed processing and storage technologies (including micro-sizing, ensiling, etc.) and (c) forage seed production. These interventions can often be implemented as private investments (farm/household) but are in themselves inadequate and need to be bundled with other investments. Innovation systems approaches are important in this context.
- Institutional issues include access to land and water for all smallholders, as a primary concern and as the main incentive to improve crop-residues. Effective governance on feed quality is also a common institutional issue raised. Similarly, reduction on transaction costs (both to access the feeds and to participate in product markets) is another key area for institutional investment support. In all value chains, the report strongly advocates support to Business Development Services – interpreted in the broadest sense as a key to facilitating access to feeds, markets and for reducing transaction costs. Effective development of such mechanisms demands the introduction of enabling policies concerning the investment climate, and institutional capacity building (for a variety of development, extension, small-scale private sector and individual actors). The potential of such services to impact on access to information, inputs, services, credit and social capital is considered high.
- The policy concerns are more value chain specific, and include the protection against dumping of meat and milk from the OECD countries, reduction of regional tariff barriers (in particular in Sub-Saharan Africa) and lack of investment in infrastructure.
- While for many households increasing animal numbers is perceived as attractive, there are severe environmental limitations of the extent this is possible. Policies and investment that increase per animal productivity, such as adequate ration formulation and emphasis on mineral supplementation in the feed and nutrition domain, as well as genetic and health improvement related investment will be important. However, in some areas, increased

efficiency (producing the same with fewer animals, or more with the same number of animals) can also be achieved through incentive systems such as payment for environmental services.

Ranking those investments regarding their economic return constitutes the final step in the analytical framework, underpinning this study. The analysis shows that for an individual household, the increase in animal numbers is the most attractive option, as has also been proven in the past. Indeed, according to FAOSTAT (2010) data, most (57 percent over the period 1990-2010) of the increased production in Sub-Saharan Africa comes from an increase in animals, and not from increased productivity per animals. This is obviously not sustainable. The key challenge therefore is to increase the profitability of raising productivity per animal. As better feed utilization will be a critical factor in enhancing the profitability and hence in ensuring the long term sustainability of these system, it is therefore encouraging that in most evaluations feed improvements (and in particular the use of crop-residues) rank from the third to the fifth place. The analytical framework also provides a ranking of the importance of timing over the 2010-2030 period in which investments are made. The results show that in general a fast trajectory (i.e. transformation early in the 20-year interval) is associated with relatively higher returns accruing to investments in selected feed types, compared to a "slow" trajectory. Fast action is therefore recommended.

The results of this study demonstrate that the assessment framework developed could be applied readily in other systems, and at the same time provides a basis that can be further built upon.

1. The context

The livestock sector contributes about 40 percent of agricultural GDP and provides, at least in part, a livelihood for about one billion people. Over the last decades, it has developed in a highly dynamic context, characterized by the following mega trends. Many of these trends are expected to continue over the next decades.

- Increasing demand: From the beginning of the 1970s population growth, urbanisation and higher incomes in developing countries have resulted in the increased consumption of the livestock products, meat, milk and eggs. The rate of this increase is some three times higher than in developed countries (Delgado, 2005; Delgado et al, 1999). This so-called "Livestock Revolution" is projected to continue for decades to come in the developing world, particularly in Asia (FAO, 2009; Pica-Ciamarra and Otte, 2009).
- Wealthier and more discerning consumers leading to more exacting food quality and safety standards. There are considerable economies of scale in the compliance of the stricter standards, established both by public as well as private sector bodies, which puts smallholders into a potential comparative disadvantaged position to compete in the more lucrative markets of these wealthier consumers. The pressure of stricter standards will lead therefore to increasing farm size.
- However, in the poorer countries, the growth in demand is for the coming decades mostly for "wet," products, i.e. relatively unprocessed animal source foods such as meat from freshly slaughtered animals. This will probably also meant that in the majority of developing countries, most animal commodities will likely continue to be produced within easy reach of a domestic market.
- Faster growth in the pig and poultry sector (non-ruminant) sector, with the cattle, sheep and goat (ruminant) sectors somewhat lagging behind. As in the case of food standards, pig and poultry are more susceptible to economies of scale, and have technologies which can be easily transferred from developed to developing countries. Ruminant production is much more dependent on local conditions and location specific technologies, and can therefore less easily be transferred from the North to the South, and is less susceptible to economies of scale;
- Greater competition for feed resources. This is a major issue in the grain sector, where alternative uses (bio-fuel) and increasing grain shortages for human consumption causes major price volatility (Steinfeld et al., 2010; Herrero et al., 2009b; Dixon et al., 2010). This affects in particular the non-ruminant sector, which relies for a much greater part of their nutrition on grains. It might, over time, cause a reverse of the current increased demand of feed grains by non-ruminant pigs and poultry with a shift in favour of production systems which rely on grass, rangeland and crop residues (and hence ruminant cattle, sheep and goat production);
- Increasing shortage of land and water resources, in particular in South and East Asia. This implies that the future increased demand for animal source foods will have to be met by increase in productivity, intensification of production and more efficient resource use;

- Structural changes in the sector. As the manufacturing and service industry expands, and employment opportunities outside the sector increases, it can be expected that the number of smallholders will gradually decline, as happened (and is still happening) in OECD and middle income countries. On the other hand, new entrepreneurs are entering the sector. Some of them engage directly in raising livestock, including new breeds, and some providing feeds, forages, or veterinary services;
- Increasing concerns regarding the environmental and ethical aspects of livestock production, in particular of the so-called "bio-industry".

In summary, in the future scenario for livestock development, there is a continuing role for smallholder producers, particular for dairy and small ruminants, relying heavily on grass and crop-residues, however in a growth mode, intensifying production, and enhancing the efficiency of resource use (less land, labour and feed resources per unit product). In particular improving the efficiency of converting feed into milk and meat will be critical in increase their income. Ensuring that to happen will require technical solutions, in ensuring that feed rations are adequately balanced with the appropriate feedstuffs of adequate quality, and institutional solutions on how to provide smallholders access to high quality information and reliable supplies of sufficient quality feeds. Investment strategies will need to be purposefully tailored to fit these specific contexts.

This study assesses where the demand for feed is likely to change the most, and where investments in feed are most likely to increase animal productivity and improve the livelihoods of those who raise livestock. It covers policy, institutions, knowledge and innovation as well as technical issues – all in the context of rapidly changing demand for livestock products in developing countries. At the producer level, solutions may include aspects of choosing and accessing the best feeds from those locally available and, as market access increases, from new sources (Herrero et al., 2010a; McDermott et al., 2010; Tarawali et al., 2011). New institutional arrangements may be needed to ensure reliable access to feeds, as well as appropriate regulatory policies that ensure feed is of reliable quality. In many instances these policies will be essential in reducing and managing smallholder risk. Effective knowledge systems are required to ensure that timely and accurate information on the availability and quality of seeds is accessible. The public sector will have important roles to play in these regards, and in promoting the uptake of feed-related technologies and services.

The study focuses on smallholder ruminant-based livestock systems because they have potentially major transformative effects on the livelihoods of producers and others engaged in the related value chains. While pig and poultry enterprises typically play an important role in livelihoods at very low input levels, such as backyard scavenging poultry, they tend to be replaced very quickly by larger scale commercial units (Costales et al., 2006). In India for instance, broiler production moved from a few hundred birds per unit to units with a weekly turnover of ten to twenty thousand between 2001 and 2006. The contribution of backyard poultry to national egg production dropped from 33 percent to 23 percent during this period (Kornel, 2008). This is not to underestimate the importance of small scale mono gastric production for the poor; or the potential for engagement in various contract farming arrangements for animals or inputs into larger scale production units; these issues could be explored in other studies.

The present assessment of feeds in relation to transitioning smallholder ruminant based systems demands a stepwise, systematic approach to focus the evaluation of this potentially vast agenda. The analysis begins by considering how livestock systems in developing countries are changing, mainly in relation to anticipated increases in demand for livestock commodities. The characteristics of those systems in which feed-related strategies and investments are most likely to have significant impacts are discussed in chapter 2. Chapter 3 employs a series of empirical analyses to identify priority regions and commodity value chains with the greatest potential pro poor impact. Chapter 4 develops the analytical framework that captures the diversity of feed types, feed sources and opportunities for feed improvement, and then classifies them according the availability of feeds from within the immediate system and the potential to improve feed use using feeds sourced from outside the local system. This framework is then used in chapters 5 through 7 to identify feed resource constraints and the opportunities for feed-related investments in each of the three priority livestock commodity value chains to 2030. The assessment of the categories of feed related options suggests a number of strategies in each, including policies, services, and technologies that are likely to affect the impacts of the investment. In order to further strengthen and prioritize this qualitative assessment, the results were then subjected to an econometric evaluation of scenarios to further disaggregate potential investment opportunities in chapter 8. Given the importance of strengthening institutions for delivering sustainable solutions and enhancing the capacity of the poor engaged in various livestock commodity value chains (whether as producers or other market actors) to respond to dynamic situations, some consideration is given in Chapter 9 to innovation approaches. The report concludes in chapter 10 with a summary of priority feed-related investment opportunities. A step by step approach is provided below.

A step-by-step approach for defining and assessing investment priorities in feed

First step: Identify systems, where feed-related strategies and investments are most likely to have significant impacts

Second Step: identify priority regions and commodity value chains with the greatest potential pro poor impact. Regions and systems are filtered by the following factors

Growth and Market Opportunities	**Pro-poor potential**
Domestic market: Growth rate? Import substitution: Share of national production imported	Number of poor (total and keeping livestock) Value of production
Supply Constraints	**Potential Interventions**
Genetics: Animal health: Nutrition:	Potential productivity gains: Technical interventions.
Market/Institutional constraints:	Reduce transaction costs
Relative Potential Gains from Interventions Production on high technical level farm	
Existing technology:	

Third step: Apply in these priority regions/chains the analytical framework to classify feed types, feed sources and opportunities for feed improvement, distinguishing

- The **types** of feed (e.g. natural pasture; planted forages; the residues and by-products from crops; feed grains and roots, mineral supplements, etc.);

Natural grazing ***Planted pastures*** ***Other planted forages (including trees and shrubs)***	***Crop residues (**including crop thinning **and weeds)*** ***Crop by-products*** ***Other by-products (**e.g. from brewing, oil milling**)***	***Grains*** ***Roots and tubers*** ***Others***

- The **sources** of feeds (own-farm; common-property resources; the market); and
- The **opportunities** for increasing feed (quantity and quality) availability.

Feed sources	Produce more	Import from outside	Utilize better
Grazing, etc..			
- On farm			
- Community			
- Market			
- Supporting Policies & Institutions.			

As a fourth step assess the expected future trends. This assessment can be based on projection of existing models, such as IFPRI's IMPACT, and ILRI's Sustainable Livestock Futures Team's baseline of animal numbers and production, and informed expert opinions. This will provide a number of strategies in each, including policies, services, and technologies that are likely to affect the impacts of the investment.

Fifth step: Apply an econometric evaluation of scenarios to further disaggregate potential investment opportunities by:

- Quantifying returns to investment across a range of forms and combinations of interventions; and
- Interpreting those results in terms of the opportunities and constraints faced in each livestock system.

Sixth step: Select mechanisms to disseminate those priorities potential investments.

2. Drivers of change in livestock-based systems and their projected impacts

As described in chapter 1, the global livestock sector is affected by several of mega-trends. These trends will affect how the main characteristics of the livestock systems in terms of mix and level of intensity of use of the factors of production (land, labour and capital), species composition, herd and farm size, etc. These characteristics, in turn, define feed quality and quantity needs. They are detailed below.

Population pressure

An overview of rising population and its relation to different livestock systems (described below) is presented in **Table 2.1**. Sub-Saharan Africa's total population is expected to nearly double and, while proportionally more people will practise intensive crop-livestock farming, the livelihoods of most people in the region will remain dependent upon pastoral, agro-pastoral, and extensive crop-livestock systems. This will place additional stress on these marginal environments. In South Asia by contrast, intensive crop-livestock system sustain nearly two-thirds of the population, thanks in large measure to investments in irrigation. The population of the region is expected to reach 1.2 billion people by 2030. Currently prevailing resource constraints, particularly for water and soil organic matter, will be severely aggravated unless they are systematically addressed. (Herrero et al., 2009b; 2010a). Both regions require combinations of technical solutions in areas such as genetics, health, and nutrition, together with policy interventions to ensure that resources are used more efficiently.

Farming system	**Global**		**SSA***		**South Asia**	
	2000	**2030**	**2000**	**2030**	**2000**	**2030**
Pastoral/Agro-past.	837	1302	245	459	89	134
Mixed extensive	1298	1956	151	275	228	335
Mixed intensive	2499	3366	87	175	824	1221
Other	1039	1394	135	233	168	244
Total	5673	8018	618	1142	1309	1934

*SSA: sub-Saharan Africa

Table 2.1: Human population (millions) in 2000 and projected to 2030 globally and in SSA and S Asia by four farming systems (Herrero et al., 2009b).

These fundamental influences of population are further nuanced by national economies, which can be classified broadly as 'traditional/agriculture-based', 'modernizing/transforming,' or 'globalizing/ urbanized' (Pingali, 2006; World Bank, 2007). The national economy and its policy and institutional environment will influence the costs of land and labor and the access to, and utilization of, input and output markets by crop and livestock producers. This operational environment will support or inhibit the responses of resource-poor households to the growing demand for livestock products, particularly in agriculture-based countries (**Figure 2.1**), and it will affect the supply of the feed required by poor livestock-keepers to produce marketable surpluses of livestock products.

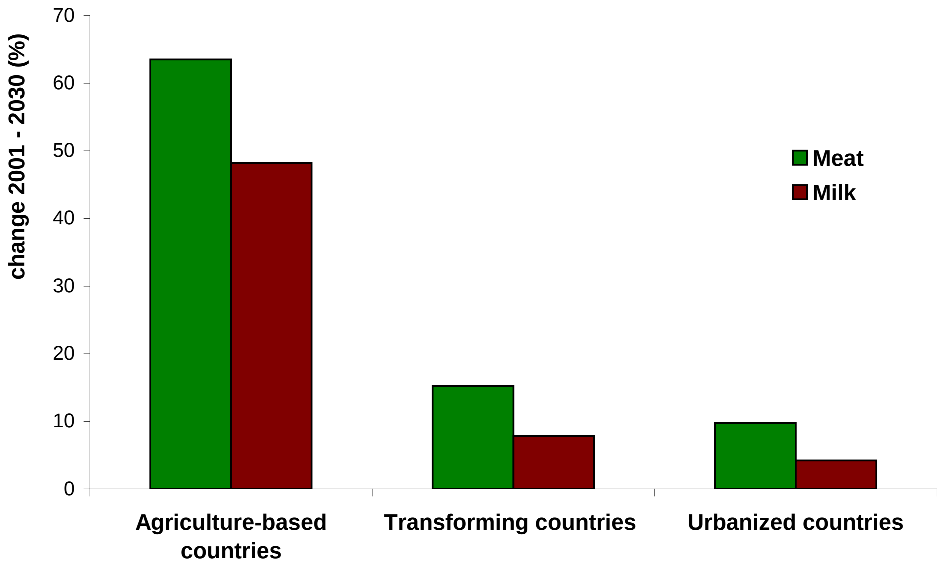


Figure 2.1: Projected changes in demand for livestock products, 2001 – 2030, adapted from IAASTD, 2009 (McDermott et al., 2010)

Impacts on production systems

Such drivers of change, including market demand, need to be considered in the context of land use by resource-poor households, their production of crops and livestock and the intensification of production. To address these issues, Herrero et al. (2009b, 2010a) present a typology of agricultural systems that integrates natural resource potential, human population density and market access. The major systems with livestock - and their descriptors (McDermott et al., 2010) - are:

- *Pastoral and agro-pastoral systems*, which are characterized by low population densities, low agro-ecological potential and weak linkages to markets. Crop production in these areas is marginal and ruminant livestock – mainly cattle, sheep and goats - are the major source of livelihood.
- *Extensive mixed crop–livestock systems*, which are characterized by rain-fed agriculture, medium human population densities, moderate agro-ecological potential and weak linkages to market. Households produce crops and (mainly) ruminant livestock with limited use of purchased inputs. Often livelihoods depend more on livestock than crops.
- *Intensive mixed crop–livestock systems*: these have high population densities, irrigation or high agro-ecological potential and good linkages to markets. Households produce crops and livestock (ruminants and non-ruminants, the balance depending on the region), but with intensive use of purchased inputs. Generally livelihoods depend more on crops than livestock but some households (particularly with small landholdings) may intensify their livestock sub-system and thereby increase its importance for their livelihood.
- *Industrial livestock systems,* which are characterized by large vertically integrated production units (mainly for non-ruminants, i.e. chickens and pigs, but some dairy) in which feed, genetics and health inputs are combined in controlled environments. These systems account for the largest share of the volume of tradable livestock products (McDermott et al., 2010). The industrial

units and their sources of feed (mainly grains) are generally separated spatially, with the feed originating from specialized feed-producing farms.

In Sub-Saharan Africa most cattle are in the extensive systems (with no or limited cropping), where natural grazing is the main feed resource. This contrasts with S, SE and E Asia, where intensive crop-livestock systems have the largest cattle (and buffalo) populations and crop residues are major feed sources, a reflection of the higher human population densities in these regions. Small ruminants (sheep and goats) follow the same pattern except in E and SE Asia where most are in the pastoral and agro-pastoral systems. Projections to 2030 of ruminant livestock populations in these systems show significant increases with marked changes in E & SE Asia (**Table 2.2**; Herrero et al, 2009b). It is expected that growth in numbers rather than improved productivity will explain most of the ruminant production increases, however, increasing numbers has major environmental implications (Blümmel et al., 2009a; Tarawali et al., 2011) and there are considerable benefits from increasing productivity rather than animal numbers per se. Ruminant and monogastric systems differ in this respect, because it is anticipated that productivity increases will account for most of the growth in pig production (Thornton, 2010), mainly in the industrial systems (using cereal-based diets) and concentrated in E and SE Asia. Growth of industrial chicken production (for meat and eggs) is expected to occur in all developing regions.

Farming system	**Developing World**		**SSA***		**S Asia**		**E & SE Asia**	
	2000	**2030**	**2000**	**2030**	**2000**	**2030**	**2000**	**2030**
Cattle								
Pastoral/Agro-past.	130	178	40	49	14	16	16	30
Mixed extensive	104	138	27	31	31	32	10	20
Mixed intensive	154	195	5	7	77	84	24	42
Other (landless/industrial)	78	107	6	8	19	20	15	28
Total	**467**	**617**	**78**	**95**	**141**	**152**	**65**	**120**
Small ruminants								
Pastoral/Agro-past.	239	372	53	79	20	30	64	121
Mixed extensive	98	150	40	55	23	32	15	34
Mixed intensive	111	165	9	13	52	75	28	47
Other	49	76	8	12	12	17	13	23
Total	**498**	**763**	**110**	**158**	**106**	**154**	**120**	**225**

*****Sub-Saharan Africa

Table 2.2: Livestock populations (millions of LU) **in 2000 and projected to 2030 by four farming systems for the developing world, SSA and S Asia** (Herrero et al, 2009b)

How to reconcile these numbers of animals and the predicted demand for animal source foods is an important question. In the developing countries of sub-Saharan Africa and Asia, will most of the increase of food and feed production come from intensive systems, or are there options through intensifying areas that are currently more extensive (McDermott et al., 2010; Tarawali et al., 2011)? To address such questions Herrero et al (2009b) applied IMPACT, the agricultural sector model developed at IFPRI (Rosegrant et al, 2005), to project changes in animal numbers and product demand from 2000 to 2030. The model, which represents a partial equilibrium in food, is specified as a set of country-level demand and supply equations and spatially disaggregated in food production units by region. Country-level models link to the rest of the world through trade. The model also links agricultural production to water availability and use, and to food security through estimates of the number of malnourished children. For the analyses reported by Herrero et al (2009b), input variables were: population growth, income growth, agricultural trade, yields of crops and livestock, shifts in diets of humans, while output variables included: crop area, crop and livestock production, commodity prices, food demand, feed demand, other demand, net trade and food nutritional security.

Underpinning the analyses was a conceptual framework which considered the development context, the indirect and direct drivers and their impacts on agro-ecosystems services, including the production of livestock feed, and their interactions with human well-being. Within this framework the IMPACT analyses compared responses in the four agricultural systems in developing countries described above: pastoral/agro-pastoral; mixed extensive; mixed intensive; and, others (which included industrialized livestock systems), and in developed countries (Herrero et al, 2009b). Developing country responses were estimated for six regions: Central and South America (CSA); East (EA), South (SA) and Southeast Asia (SEA); sub-Saharan Africa (SSA); and, West Asia and North Africa (WANA). For these systems and regions, the scenario analyses (2000 to 2030) included: (i) "business-as-usual" (growth at current rates in population, agriculture and incomes, i.e. a continuing "Livestock Revolution"); (ii) an expansion of irrigated lands; (iii) a growing demand for bio-fuels; and, (iv) a reducing demand for meat.

A major conclusion from the analyses of Herrero et al (2009b; 2010a) was that smallholder crop-livestock systems are the key to meeting the anticipated demands for food (and feed) in the developing countries: currently these systems produce 50% of the world's cereals and most of the staple foods consumed by the world's poor: 40% of maize, nearly 90% of rice, two-thirds of sorghum and three quarters of millet production. They also produce 75% of the milk and 60% of the meat in developing countries.

The data presented by Herrero et al (2009b) show that by 2030 the production of cereals and of some livestock products from these developing country crop-livestock systems will surpass their production in developed countries. Even so the projected increases will be insufficient to keep up with population growth and, consequently, the livelihoods of rural households in developing countries will be threatened. If food security is to be achieved and the demand for livestock feed met, agricultural research and development must focus on integrated, sustainable and efficient

approaches to producing and marketing more food (staple crops and livestock products) and feed (digestible biomass) from these crop-livestock systems. This challenge must furthermore be addressed in the context of other competing demands for biomass (especially crop residues) such as biofuel (Dixon et al., 2010) and soil fertility (Giller et al., 2009) and the land and water resources need to produce it. Whether these smallholder-dominated systems can be transformed to address future food and feed demands, without moving towards the industrial type systems of many developed countries remains a subject of debate. Several authors have recently argued that for some systems, livestock commodities and economies there is a real potential for positive change based on smallholder crop livestock systems (McDermott et al., 2010; Tarawali et al., 2011). Addressing this potential implies new approaches to research and development that integrate institutional, policy and process issues with technical dimensions. In all cases, feed is a central part of the equation because of the role played in both influencing productivity - which is a fundamental dimension of smallholder market participation as well as the intersection with environmental dimensions. For the purposes of the present study, which focuses on feed, the broader setting, the intensification processes and drivers are considered here to place the topic in context and to focus the subsequent assessment.

Intensification

Implicit in the dynamics of land-use and livestock production is change over time on a gradient of intensification - from extensive to intensive - of crop-livestock systems, the main elements of which are presented in **Table 2.3.** Derived from recent field studies in the Indo-Gangetic Plains, the table builds upon the analyses and conclusions of McIntyre et al (1992) and subsequent work on crop livestock systems (Parthasarathy Rao and Birthal, 2008). From a feed resources perspective the major changes during intensification are the shifts in the biomass used by livestock from rangeland (natural pasture) grazing to crop-based feeds and from subsistence to a market orientation, with each affected positively or negatively by the area's agro-ecology. Agro-ecology determines the technical limits of crop, and therefore feed, production such that where cropping is not possible or is very risky, livestock-keeping in pastoral and agro-pastoral systems is the core land-based livelihood activity (Jones and Thornton, 2009).

	Intensification gradient		
	Extensive	**Intermediate**	**Intensive**
Crop nutrients	Fallow	Manure	Chemical fertilizer
Livestock feed	Rangeland	Crop residues	Feed crops, concentrates
Power	Manual	Animal traction	Motorized
Finance	Natural assets/stocks	Informal credit/loan	Formal credit/loan
Market orientation	Subsistence, barter exchange	Semi-commercial	Commercial, monetized market
Crop + livestock system evolution	Parallelization	Integration	Specialization

Nominal cost gradients:			
- Capital	High	◄────	Low
- Labour	Low	────►	High
- Land	Low	────►	High
Induced innovation	Capital saving	◄───►	Land and/or labour saving

Table 2.3: Conceptualization of crop-livestock systems along an intensification gradient (Source: Erenstein and Thorpe, 2010)

At the other extreme, when both agro-ecology and markets are favorable for cropping and the opportunity costs of land and labour are high, specialized crop and livestock systems develop (**Table 2.3**). In the final "stage" livestock production, especially for non-ruminants (chickens and pigs), becomes industrialized to achieve efficient returns to land, labour and feed through economies of scale using highly-selected breeding stock and their progeny which are fed nutritious, concentrate diets and managed to high health standards. Such systems are typical of many developed countries, and often referred to as "industrial" livestock production systems. These have high levels of efficiency but may present environmental, health (human and animal) and environmental challenges. At the intermediate stages of intensification the production of crops and livestock are spatially integrated, while at the extremes they are invariably spatially separated (**Table 2.3**).

As indicated above, biomass availability and use is likely to be a key parameter influencing the transition of today's crop livestock systems, in particular the potentially competing uses for this resource between feed, fuel and soil fertility (www.vslp.org). Future scenarios of bio-energy use vary widely (Van Vuuren et al. 2009) and, as Thornton (2010) points out, there are large evidence gaps concerning the likely trade-offs between food, feed and fuel in developed and developing countries. One factor affecting the price relationships will be the expected emergence of second-generation bio-fuels, which will potentially include the breakdown of the food-feed crop residues that currently form a major part of feed resources in crop-livestock and agro-pastoral systems (Dixon et al, 2010). The emergence of second-generation bio-fuel technologies will, therefore, have implications for the feed supplies on which the majority of poor livestock keepers in developing countries depend. However, even if all (global) crop residues are used for bio-fuel production, it was estimated that they would provide only approximately 4% of the fuel required by the global transport sector. Second-generation bio-fuel technologies would, therefore, impact little on ethanol supply. On the other hand diverting biomass (including crop residues) into biofuel production, or allocating major tracts of land for this would have very large negative trade-offs on ruminant livestock production, and therefore on livelihoods, particularly in the developing countries of SSA and S Asia. It should also be noted that there are potentially positive spin offs from the research on second generation biofuel processes, because these involve developing technologies to break down cellulose – which would have the potential to impact on increasing the utilization of poor quality roughages by

ruminants. A final trend, which will also affect feed availability, is the shift away by urban consumers from the traditional carbohydrate food stuffs such as sorghum, millet and roots and tubers towards the "modern" cereals wheat or rice.

Environmental issues

The present study does not consider in depth the environmental dimensions of intensifying crop livestock systems, however, it is pertinent to highlight the importance of such issues, which intersect strongly animal feeding and potential trajectories of livestock systems transition in the coming decades. Such a transition also presents an opportunity to ensure that future livestock systems do not compromise environmental integrity (FAO, 2009; Steinfeld et al., 2010; Tarawali et al., 2011). The recent work of Baker et al., 2011 on livestock investment opportunities finds that, according to most stakeholders in a selection of case study livestock projects improved livestock production and marketing (including intensification) led to greater use of water, degradation of soil, and a decline in numbers of animals of indigenous breeds. Here, we briefly consider water and land use for livestock production and broader environmental issues especially in relation to feed issues.

By 2025, 64% of the world's population will live in water-stressed basins, compared with 38% today (Rosegrant et al. 2002; Molden, 2007). Increasing livestock numbers will add to the demand for water, particularly in the production of livestock feed: one cubic metre of water can produce anything from about 0.5 kg of dry animal feed in North American grasslands to about 5 kg of feed in some tropical systems (Peden et al. 2007). Integration of crop and livestock production gives better water productivity than either enterprise alone (Descheemaeker et al., 2009; Haileselassie et al., 2009; Harrington et al., 2009). Nevertheless, water used for feed production constitutes some 90% of water used for livestock and there are significant opportunities to improve efficiency through feed management strategies, water management and animal management (Peden et al., 2007; Descheemaeker et al., 2010) and will be essential if water scarcity issues are to be addressed as part of the solution to sustainable intensification. Mekonnen and Hoekstra (2010) have recently highlighted the water footprint of animal production on a global scale. Thornton (2010) stresses that improving the water productivity of livestock in mixed (crop-livestock) systems will require more and better utilization of crop residues and by-products, while more efficient management of the spatial and temporal distribution of feed resources can better match availability with demand and conserve water resources. To achieve that will require research on livestock–water interactions to develop integrated site-specific interventions that contribute to sustainable, productive use of water resources for crop and livestock production (Peden et al. 2007).

At the same time, global pressures on land suitable for cropping – and therefore the related feed by products - have been exacerbated by the traumatic rises in food prices of 2008 and the distrust of world food markets that they provoked, prompting "land grabbing" (mostly by state companies or governments) through contracts to buy or lease some 20m hectares of the best farmland in poor countries by rich food-importing countries like Saudi Arabia, Kuwait, China and South Korea (The Economist, Nov 19th 2009; Cotula and Vermuelen, 2009; Daniel and Mittal, 2009).

Allied to these pressures on natural resources is the need to reduce greenhouse gas emissions (GHG) from livestock (Steinfeld et al., 2006). Positive genotype x nutrition x health interactions can deliver large productivity gains (more milk and meat produced from fewer animals and less feed) that reduce GHG and the amount of land and water required to feed the animals. For dairy production in the USA Capper et al. (2009) estimated that in 2007 only 21% of the animals, 23% of the feedstuffs, 35% of the water and only 10% of the land were being used to produce one billion kg of milk compared to 1944. While the environmental carbon footprint per animal was twice as high in 2007 compared to 1944, the four-fold increase in milk production per animal resulted in a carbon foot print per billion kg milk reduced to 37% of the 1944 level. Blümmel (2010a) has estimated that annual methane emissions from India's dairy animals would be halved (from 2.3 to 1.1 million tons) if the average daily milk yield is increased four-fold, i.e. from the current 3.6 to 15 litres per animal. Feed sourcing and strategies have a major role to play in impacting such efficiency issues, the greenhouse gas emissions – both directly through impacts of better feed on ruminant metabolism as well as through overall productivity increases which could reduce the environmental impact by requiring less animals to produce the same amount of product (see for example Blümmel et al., 2009a; Tarawali et al., 2011).

Responding to change

Against this background of pressure on natural resources, constraints on crop production and rising demand for livestock products, ruminant numbers are expected to increase and outpace the rate of growth in the availability of feed per animal, but with significant variation by region and crop (Herrero et al, 2009b). Additional pressures, such as climate change, may exacerbate the reductions in rangelands and the availability per animal and composition of crop residues in certain regions (Thornton and Herrero, 2010) and could drive feed prices higher than expected. System- and location-specific[1] interventions are, therefore, going to be key to successfully managing the transition of resource-poor household livelihoods from less to more intensive systems and from production favouring subsistence to more market orientation, changes in which the productivity of livestock and, implicitly therefore, their feed supplies will be central.

By anticipating these population and climatic pressures and strategically targeting technical, institutional and policy interventions, it should be possible to alleviate input constraints to food and feed production in ways that provide nutritional security for vulnerable households while supporting the efforts of resource-poor households that have livestock to exploit market opportunities for livestock products. Given that agro-pastoral and mixed systems maintain the large majority of the poor (**Table 2.2**), the improvement of food-feed crop production (particularly for the staple food crops) and the more efficient utilization of residues and by-products for ruminant livestock production, is likely to be critical for the successful alleviation of poverty, while mitigating any negative impacts on the environment, including water resources.

[1] Location-specific refers to an area having the same (or very similar) agro-ecological and socio-economic characteristics, e.g. the central highlands of Kenya

Implicit in this transition is that increased production must come primarily from efficiency gains (i.e. using the current farmed land and water resources and more product per unit if feed) rather than from, as in the past, extending the area of land that is cropped or grazed and increasing the number of livestock (IAASTD, 2009). The challenges are great because the finite resources of land and water in developing countries are under increasing pressure from more people, their livestock and the competition for fuel energy. Moreover, these pressures have already reached critical levels in, for example, the irrigated intensively-managed Indo-Gangetic Plains of S Asia, in the densely populated rain-fed East African highlands and in some of the rain-fed marginal areas of West Africa (Herrero et al, 2010a; Thornton and Herrero, 2010).This again highlights the opportunity for a positive transition, in particular of the extensive mixed crop livestock systems of the developing world.

The way forward

Given this global context, the major challenges for effective pro-poor investments that address poverty and the opportunities presented by the increasing demand for animal-source foods, centre on how to intensify crop-livestock systems in which cropping provides biomass as grain (e.g. maize), roots and tubers for human food and their by-products (e.g. bran) and residues (e.g. stover) for livestock feed. This has to be achieved in ways that overcome the feed shortages for ruminants and, to a lesser extent, non-ruminants without using more grain or degrading the environment. The key trade-offs will be the competing uses of biomass for food, feed, fuel and conservation agriculture. As McDermott et al (2010) stressed, major constraints faced by smallholders in meeting these challenges are not just producing more plant biomass but also paying the higher relative costs of improved livestock genetics and health care and ensuring access to the knowledge required to produce crops and livestock more efficiently and with less risk. To achieve that, public investment and its interactions with private investment have a critical role through the provision and targeting of knowledge and technologies that deliver not only more and better feed (often through crops) but also improved animal health, breeding, technical advice and other services. Therefore, essential complements to successful private investments and technical innovations – generally combinations of feed, health and breeding interventions – that offer significant benefits to resource-poor households will be public investments that deliver supportive policies, enabling institutions and pro-poor market development. These dimensions are, to an extent, going to be location-specific, at least at the level of sub-region and livestock commodity value chain. The implication is that it is important to prioritize the regions and value chains where opportunities for smallholders and livestock feed interventions are greatest. The regional livestock commodity value-chains that are considered most likely to delivery pro-poor benefits from these targeted investments are identified in the next chapter.

3. Identifying priority regional livestock commodity value-chains for investments targeting feed resources

Given the scenario of continuing increased demand for animal-source foods and the intensification of crop-livestock systems, this section considers how to further disaggregate and target regions and livestock commodities where investments in feed resources are likely to have the most impact. This chapter draws on the recent report, of Staal et al (2009) that seeks to prioritize developing country livestock production systems according to their development potential. Their study applied a systematic approach to identify the regional livestock commodity value-chains through which to target priority pro-poor investments in support of market-oriented livestock production. The approach used a set of analytical filters that combined market potential, likelihood of impact on the poor, and supply constraints.

The first filter, **Number of Poor** defines the target region (s). With the fast majority of the poor livestock producers in SSA and South Asia, (see table 2.2) these two are selected as the target regions.

The second filter**, Growth and Market Opportunities**, differentiates value chains by their potential for demand-driven growth over the medium term through assessing trends in domestic consumption (which is generally the largest source of demand), the potential for import substitution and for regional and international exports.

The third filter**, Pro-Poor Potential,** assesses which livestock value chains are likely to have the most direct impact on poor livestock-keepers and the ability of the poor to participate sustainably in market growth. Factors like economies of scale, local factor values and resources and the species/breed mix, determine whether small-scale producers (with land and the landless) will be competitive or whether livestock production will evolve towards industrial, large-scale and capital-intensive producers (Staal et al, 2009).

Location	Intervention area	Opportunity	Comments
West Africa	Dairy	Import substitution	High ratio imports to domestic prod. along coast. However, severe animal disease constraints may limit increase in production for foreseeable future.
West Africa	Beef	Domestic growth	Positive growth rate in production and consumption but per capita consumption still low; rising incomes, urbanization = latent demand.
West Africa	Small	Domestic	Positive growth rate in production and

	ruminant meat	growth	consumption but per capita consumption still low; rising incomes, urbanization = latent demand.
Central Africa	Chicken meat	Import substitution	High ratio imports to domestic prod., high consumption (DR of Congo, Eq. Guinea, Gabon). Difficult to overcome environmental, animal health and feed resource constraints.
East Africa	Dairy	Export potential	Positive production growth rates, already high consumption levels.
East Africa	Beef	Export potential	Production growth higher than consumption/population growth; also, income growth indicates domestic market potential.
East Africa	Small ruminant meat	Domestic growth	Growing per capita consumption and production; export potential also.
Southern Africa	Small ruminant meat	Domestic growth	Growing per capita consumption and production; some export.
Southern Africa	Beef	Export potential	Consumption high; potential to reverse falling production trends and increase exports.
South Asia: India	Chicken meat and eggs	Domestic growth	High growth rate in production & consumption but per capita consumption still low; rising incomes, urbanization = latent demand.
South Asia: India	Dairy	Domestic growth	Very high production growth rate.

Table 3.1: Opportunities for targeting value-chain interventions in sub-Saharan Africa and South Asia (Staal et al, 2009)

The fourth and final filter**, Supply Constraints,** differentiates the value-chains in which there are attractive options for small-scale producers to improve productivity (and therefore to produce a marketable surplus) from the value-chains with insurmountable challenges to increased production. These barriers may be policy and institutional factors and/or technical constraints that cannot be resolved at least in the medium term, with available or emerging technologies. Applying this Supply-Constraints filter excluded regions where production risks from livestock disease are high and for which solutions are not expected in the foreseeable future (the next 10-15 years) and/or where lack of available feed resources are likely to significantly constrain expansion or intensification. These

limiting factors inhibit the adoption by small-scale producers of more productive livestock genotypes and, at the same time, may stimulate the development of capital-intensive, industrialized systems dependent on imported inputs (FAO, 2009). As Staal et al (2009) point out, in many cases, particularly where consumption of livestock products depends upon high levels of imports, there are strong technical reasons –disease risk and/or feed scarcity- that both limit domestic livestock production and preclude profitable investments in feed, breed or genetics.

Selecting value-chains for priority investment: Drawing on available quantitative data and expert knowledge, Staal et al (2009) compiled a long-list of value-chains for a range of livestock commodities in SSA and S Asia[2] (Table 3.1). Each commodity (milk, beef, chicken meat, small ruminant meat) represents a potential intervention opportunity because of growth in domestic demand, substitution of imports and/or the potential for exports. In turn some of these opportunities may be unattainable because of local constraints, e.g. the disease risks to dairy production in W. Africa and the lack of locally-produced grain for broiler (chicken meat) production in Central Africa (Table 3.1).

Region	Dairy	Beef	Small ruminant meat
East Africa	Rain-fed: grazing, cultivated fodders, crop residues & by-products	-	-
South Asia	(i) Irrigated: crop residues & by-products (ii) Rain-fed: grazing, crop residues & by-products	-	-
West Africa	-	Rain-fed: grazing, crop residues & by-products	Rain-fed: grazing, crop residues & by-products
Southern Africa	-	-	Rain-fed: grazing, crop residues & by-products

Table 3.2: Priority regional commodity value-chains and their principal feed resources

Based on the combined criteria of, the size of the target population, good market growth opportunities, potential for poor people to participate in that growth and resolvable technical constraints to small-scale production, Staal et al (2009) selected as priorities for development investment the value-chains for dairy production in S Asia and E Africa, beef production in W Africa, small ruminant meat production in W Africa and Southern Africa.

[2] In the analyses by Staal et al (2009) S Asia uses only data for India and Bangladesh.

Table 3.2 lists these five selected regional commodity value-chains and their principal feed resources. Given the impact of irrigation on biomass production, the "S Asia dairy" value-chain will be considered in this report within two production systems, the rain-fed and the irrigated crop-dairy systems. Other (sub-) divisions of these major systems are considered in the following chapters (essentially based on the degree of intensification) to further aid targeting the assessment.

In **Chapters 5** to **7** these priority regional commodity value-chains are described and their key feed investment opportunities are identified through applying an analytical framework, the development of which is described in the following chapter. The framework provides the systematic steps for the review of available and potential feed resources in a regional commodity value chain and the identification of the technologies, knowledge and service provision and policies through which feed resources and their utilization can be improved.

4. More and better feed: identifying the opportunities for investment

Having identified priority regional commodity value-chains in (Table 3.2), each of which have: (i) a good coverage of the number of potential beneficiaries; (ii) good market growth for livestock products; (iii) the potential for poor people to participate in that growth; and (iv) resolvable constraints to increased small-scale livestock production, as the next step a framework was devised to compare various dimensions of feed in a commodity value chain context and to assess likely dynamics and implications. In order to address the complexity of the target regional commodity value chains and their dynamics, the analytical approach bridges disciplinary and professional barriers and encourages thinking about the scenarios that will determine the investment recommendations.

The framework that emerged after a series of consultations was subsequently used in each of the regional priority value chains for an expert consultation to determine present and future (to 2030) feed based opportunities. Whilst relatively simple, it allows for the key feed dimensions to be assessed and projected into the future. A further strength is that the articulation of feed issues in this straightforward way facilitated the quantitative assessment of intervention opportunities that forms part of this study.

Identifying opportunities for improving feed resources The framework for analyzing feed resources has at its centre poor livestock-keeping households and the crop-livestock system on which the majority depend. Its components apply equally well to pastoral and agro-pastoral systems and it allows for a simple assessment of the potential results of increasing animal product demand on the key dimensions of feed availability. The framework addresses the contributions of and the interactions amongst:

- the **types** of feed (e.g. natural pasture; planted forages; the residues and by-products from crops; feed grains and roots);
- the **sources** of feeds (own-farm; common-property resources; the market); and
- the **opportunities** for increasing feed (quantity and quality) availability.

Feed types are captured using the feed resource groups[3]: the ten groups of feed resources that are currently, or potentially can be, utilized by poor livestock-keeping households in smallholder systems (Renard, 1997; Devendra and Sevilla, 2002).

1. *Natural grazing*
2. *Planted pastures*

[3] See **Appendix 1 and 2** for some definitions of these feed types

3. ***Other planted forages*** *(including trees and shrubs)*

4. ***Crop residues*** *(including crop thinnings and weeds)*

5. ***Crop by-products***

6. ***Other by-products*** *(e.g. from brewing)*

7. ***Grains***

8. ***Roots and tubers***

9. ***Micro-nutrient supplements***

10. ***Balanced concentrates***

As agro-ecological potential increases and where crop-livestock systems are intensifying (Chapter 2), the balance of available feed resources will generally shift from the grazing of natural pastures (**group 1**) to crop residues and by-products (**groups 4 and 5**) and/or planted pastures and forages (**groups 2 and 3**), the shifts influenced by human population pressure and market opportunities. Cereal straws and stovers (from the staple food crop/s) are quantitatively by far the most important crop residues, while the much smaller quantities of by-products are important because they are less fibrous, have relatively more digestible nutrients, and are often high in protein (Devendra and Sevilla, 2002). However, for the future, the productivity of straws and stovers will remain low, and their quality is generally not adequate for the foreseen intensification. The intensification will require an increasing reliance on crop by-products and other high-energy products.

Other feed sources rich in digestible nutrients are grains, roots and tubers (**groups 7 and 8**), crop products which in smallholder crop-livestock farms are generally grown first to meet household needs for (human) food, i.e. for subsistence, but which may have seasonal roles as livestock feed, particularly for non-ruminants (pigs and chickens) and dairy production. With the intensification of non-ruminant production, the cropping of feed grains, roots and tubers (e.g. maize, cassava and sweet potato) for sale to the commercial market may attract smallholder farmers: maize grown for the chicken feed industry in Bangladesh is a recent example (CIMMYT, 2009). Where available feeds and their combinations lack essential micro-nutrients, then feeding for optimal livestock production will require micro-nutrient supplements (**group 9**), while to achieve high levels of live-weight gain or milk production may require smallholders to supplement locally-available feeds of low nutrient density with balanced concentrates (**group 10**), assuming that the benefit-cost ratios are favourable.

Given the importance in smallholder crop-livestock systems of crop residues for livestock feeding, Egan (1989) suggests subdividing crop residues (**group 4**) into three classes: the first class contains residues that are low in cell wall contents, high in crude fibre and lignin, with low *in vitro* digestibility (30–40%) and intake; the second have relatively low cell wall contents of medium digestibility (40–50%); and the third class relatively high in cell wall contents, not as highly lignified, and having high digestibility (50–60%) and intake. As Devendra and Sevilla (2002) point out, most cereal straws and stovers have lower nutritive values than the haulm from grain legumes or vines from root crops

such as sweet potato. Therefore, when defining priorities for the development and use of feed resources in crop-livestock and related systems, it is important to take into account the differences both amongst and within feed resource groups, especially for crop residues. One strategy to address this is to identify the most appropriate combinations of such resources, such as supplementing low quality basal diet of cereal stover with small, strategic amounts of legume hay (Ayantunde et al., 2008).

When deciding from where to **source** its livestock feed (feeding strategies), each of the livestock-keeping households (some of which may be land-less livestock keepers) in a community is influenced by and interacts with:

- the other households in the community (*Community)*;
- the prevailing markets for crop and livestock outputs (products) and inputs (e.g. seeds and feeds) (***Market****)*; and,
- the policy and institutional environment (***Policy* –** which could be envisaged as an fourth, outer circle in Figure 4.1b) that affects the production and marketing of crops, livestock and feeds and access to common property resources (CPR).

A household's feeding practices (i.e. the way it feeds its livestock) which will be conditioned by the availability and quality of feeds which are the outcomes of the "on-farm", "community", "market " and "policy" factors and their interactions, and how these influence decisions about land-use for cropping and for grazing (individual and common properties) and other feeding options. These land-use decisions will reflect the household's objectives and the trade-offs between cash generation (from, e.g. high-value vegetables or milk) and (subsistence) food and feed production which, in turn, are dependent on the enabling environment for the different sub-sectors (livestock vs staple crops vs high-value crops: ***Market*** and ***Policy***).

For example, if the market price of a particular crop, e.g. maize, increases markedly (perhaps as a result of a revised policy), then it is likely that more arable land will be planted to that crop replacing another crop, e.g. cotton, resulting in changes in the quantity, quality and seasonality of available feeds: in this example, more residues and by-products of maize and less from cotton. The result is a change in the quantity and quality of the feed sourced from the **Crop Residues** and **By-products** types.

If on the other hand crop prices drop below the local profit threshold while the price of livestock products, e.g. milk, remains strong, and in particular when the return to labor invested in pasture production is higher than the return to labor for crop-production, more arable land may be fallowed and used as individual or communal grazing during the cropping season or even to grow fodder crops. The result would be to increase the feed from **Pastures and Forages** while reducing the

availability of crop residues and by-products, thereby decreasing **Crop Residues** and **By-product**s. The seasonality of the quantity and quality of feed would also be affected.

In the same way, the entry into the community of a reliable retail outlet to supply crop by-products (e.g. wheat bran) or compounded feed[4] may offset sufficiently the transport costs from more distant markets to reduce within the local **Market** the farm-gate price of these feeds that it stimulates their profitable use by small-scale livestock-keepers. Depending on the household's production objectives, this purchased feed may replace other locally-produced feeds or it may increase the quantity and/or the quality of the feed given to the household's livestock and whether it is used in specific seasons (i.e. a household's feeding strategy may change). However, using the purchased feed profitably may require technical advice, the access to which may be difficult in an area with weak agricultural R&D services (***Policy*** *and institutional)*.

Strategic ways to improve the availability and utilization of feed Within this framework, there are three ways through which feed-related development, research and related investments can effectively support more livestock production and the increase the market orientation of livestock-keeping households. The three strategic areas for improving the availability and/or the utilization of feed by resource-poor households are:

1. ***Produce more*** feed from the household's own resources;
2. ***Import feed*** from common-property resources or, more likely, through feed purchases from the market; and,
3. ***Utilize better*** the feed available to the household.

In the context of the hundreds of millions of resource-poor livestock keepers in crop-livestock systems, a household might be supported to ***produce more (quantity and quality)*** feed from its own land by, for example, replacing their traditional staple crop varieties (grain, roots or tubers) with varieties that yield more total biomass with better feed quality (human food and livestock feed; Blümmel, 2010b). Or there may be the opportunity for the household to replace some of its natural pasture with a higher-yielding grass (although fertilizer application may be required) (Reynolds et al, 2005), or mix with other herbaceous or woody forage species.

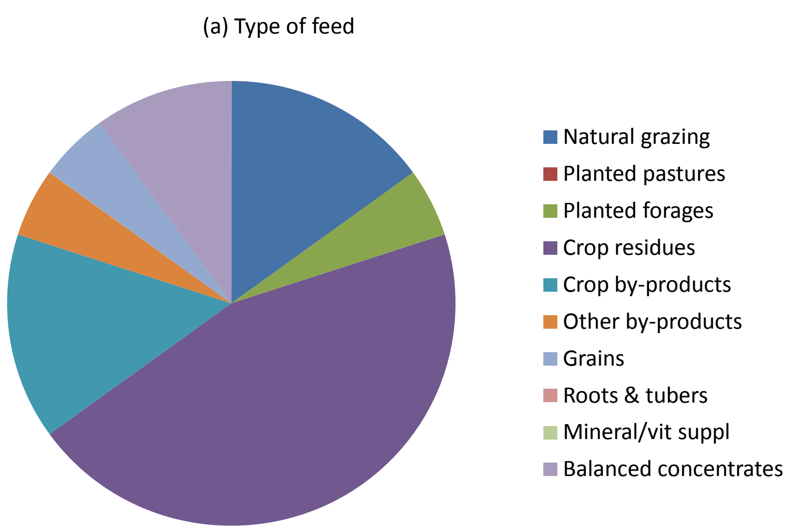
From where can the household ***import feed***? If the common property resources to which the household has access are degraded, then community action to improve their management could be explored as a way to increase feed availability (Tiedeman et al., 2005). Buying agro-industrial by-products ("concentrates/supplements") from the local mills may be one of the other ways of importing more feed, although one that would require the household having cash -or access to credit- and prioritizing the use of the cash for purchasing feed. Farmer cooperatives or associations may also facilitate such access. Feed transport is becoming increasingly important in intensifying

[4] See **Appendix 2** for definitions

crop livestock systems, and strategies that enable feed densification may be important in this respect (Anandan et al., 2010).

And how can the household ***utilize better*** the feed from these various sources? One way may be to manipulate the physical structure of feeds (to increase intake), for example, by making feed blocks or by chopping poor-quality crop residues to increase their intake (Blümmel et al, 2009a). Another might be combining the feeds produced by the household or acquired from neighbours, from common property resources or from formal market channels so that the mixture of available feeds better matches the animal's nutrient requirements, thereby increasing the efficiency of conversion of the feeds to live-weight gain or milk, whether on an annual basis or seasonally.

Figure 4.1 captures schematically the type of feed (upper figure, shown as slices of pie) combined with sources of feed (the concentric circles) of feed which, together, affect the availability (quantity) and quality of livestock feeds for individual households and for the community. At the centre of the framework is a livestock-keeping household with its own farmland (***On-Farm***). The household and its land are set within the (village) community of other households, their land and the community's common property resources (***Community***). In the hypothetical example shown in **Figure 4.1** nearly half the feed biomass used by the household's livestock comes from crop residues, about a quarter comes from pasture and forages, less than a quarter from crop and other by-products, and the balance from concentrates and other supplements.



(b) Type and source of feed

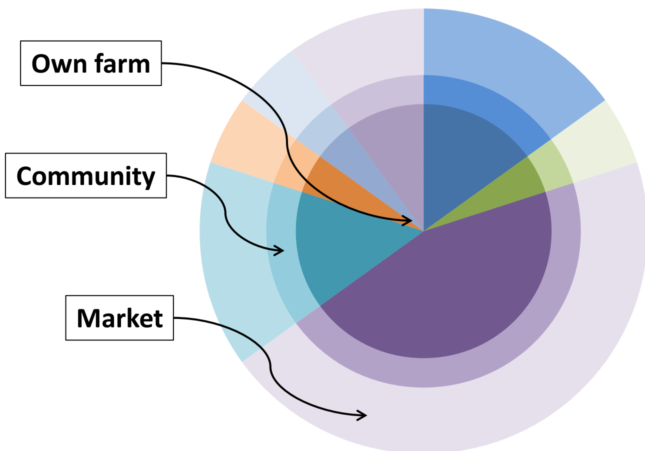


Figure 4.1: **Schematic presentation of the interacting factors that affect the feed resources of a livestock-keeping household in a crop-livestock system** (Source: modified from Randolph, 2009). The upper figure (a) represents different feed types as slices of pie; in the lower figure, these are combined with the feed sources which are represented by concentric circles, with the size of the circle illustrating the portion of feed from each source.

Applying the framework Tabulating the framework using these three dimensions provided a simple structure in which to present and synthesize the information for each of the regional livestock commodity value-chains in which the lack of quantity and/or quality of feed is considered a priority constraint to improved livestock production by resource-poor households. **Table 4.1** presents the format within which the information was gathered on the sources and types of feeds (the first column) and the three strategic areas for improving their availability and utilization: ***produce more*** (second column); ***import*** (third column) and ***utilize better*** (fourth column). The information was gathered from groups of key informants who were expert in a region's farming systems and its feed resources, and supplemented from the formal and grey literature.

Feed sources	Produce more	Import	Utilize better
1. Natural grazing			
- On farm			
- Community			
- Market			
- Supporting Policies & Institutions.			

2. Planted pastures			
- On farm			
- Community			
- Market			
- Supporting Policies & Institutions.			
Etc...........			

Table 4.1: Analytical framework for assessing current and potential feed resources and feed-related interventions in intensifying smallholder crop-livestock systems

The objective of the systematic steps was to capture, first, the key opportunities to improve the availability and utilization of feed resources for current systems and markets within each of the target recommendation domains - the priority regional commodity value-chains (Table 3.2) and, second, to anticipate the needs and opportunities to 2030. The latter were based to some extent on assessment on the on going changes, including the "exceptional" – those emerging changes in smallholder feed practices that indicate the potential pathways for the future (Perrin, 2002). The groups of experts were asked to analyse the current (2010) feed resource scenario and to give projections to 2030.

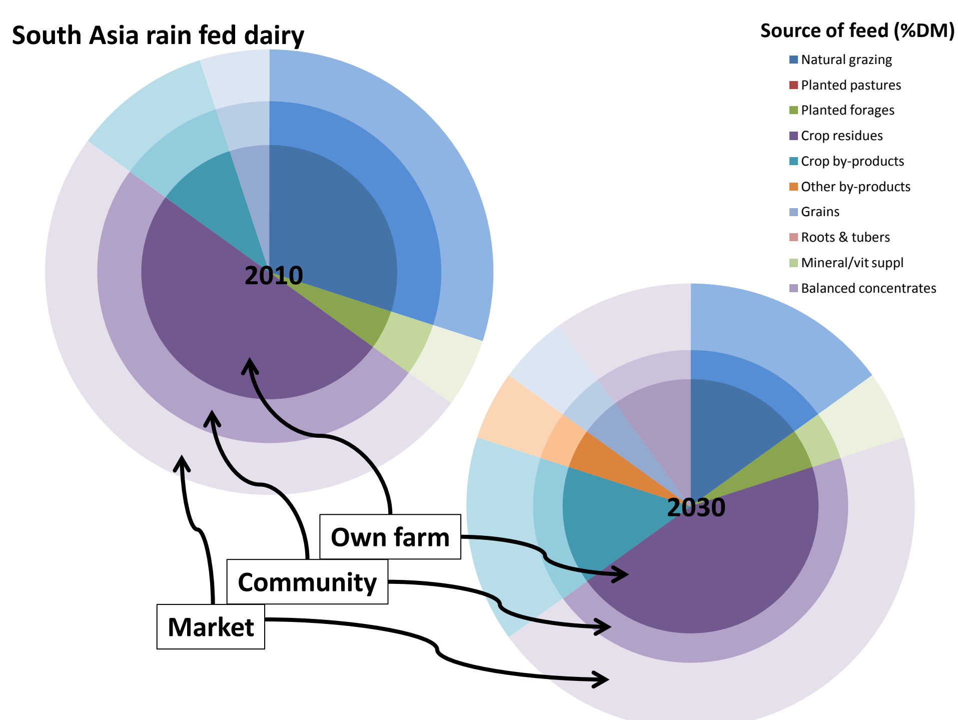


Figure 4.2 Illustration of the application of the framework to assess changes in feed type and source based on South Asia rain-fed dairy systems (Table 6.2). The inclusion of more by products and concentrates, and greater market sourcing of feeds is apparent.

Concurrently the analysis addressed the need for feed investments that are environmentally friendly. Key is increasing animal productivity, i.e. ensuring that livestock systems utilize feed resources more efficiently, i.e. reducing the nutritional requirements of maintenance relative to production, to deliver increased marketable surpluses of livestock products, reductions in greenhouse gas emissions and improved water productivity (Blümmel et al, 2009a, 2009b; Blümmel, 2010). The assessment by the expert groups related to all dimensions of the life cycle of livestock and the related crop production and grazing – with feed biomass and its sources the central element.

Summarizing the results A schematic representation of the analytical process is presented in **Figure 4.2** (using the example of South Asia rain fed dairy from chapter 5). This gives a general overview of the anticipated changes in feed types and source as the sector responds to increased animal product demand. In general, there is an anticipated shift towards more off-farm sourcing, a transition with initially more diversity of feed types as concentrates are introduced moving towards a less diversified but more nutrient-dense set of feeds. Specific examples and opportunities for improving feed resources and their utilization in a regional commodity value-chain are identified from the analytical framework (**Table 4.1**). For each regional commodity value chain, a number of key opportunities arose through this assessment, which were then assembled and used to articulate the policy, technical and knowledge/innovation systems dimensions relevant to the particular system. Options were assessed in relation to the prevailing policy, institutional and technical conditions and the potential for change, drawing on the principles and good practices from other regional value-chains, while noting trends and exceptions and lessons from specific examples.

Opportunities may include interventions that are technically-based (e.g. balancing rations) or that relate to market issues (e.g. trading of crop residues and establishing business development services) or that require policy and governance changes (e.g. business environment and feed quality regulation). Implementing the analysis enables the key issues for each regional value chain to be highlighted.

In summary, therefore, within the five priority regional commodity value-chains (Table 3.2) this is the framework used by the expert groups for assessing, first, current feed resources and, second, how these feed resources are expected to change through to 2030 as the systems intensify in response to human population pressure, market demand and other factors. These assessments and the key issues that arose as a result, were the basis for identifying investment opportunities in livestock feeds that are consistent with the principles and good practices that have underpinned past successes, that can account for past failures and which will address the future needs of poor livestock keepers and the market agents on which they will increasingly depend.

In each of the following three chapters (5 through 7), the selected regional commodity value chains are described in general terms and the results of applying the framework and the feed investment opportunities are presented. Chapter 8 then uses these assessments to describe scenario models to further disaggregate and prioritise the investment options proposed.

5. Feed-related investments for dairy production in East Africa and South Asia

Dairy production dominates the livestock sectors of the East African Highlands and South Asia. It is an integral part of the crop-livestock systems of hundreds of millions of the rural poor. Increasing population pressure on land and a growing demand for dairy products are driving these systems. A key challenge for these small-scale dairy producers is how to utilize better their limited land and family labour to engage and compete in the growing market for milk and processed dairy products. Central to that challenge is the production and utilization of the feeds required for their dairy animals. Currently fodder in East Africa and crop residues from major cereal food staples, e.g. rice straw, dominate feeding systems (over 50% of feed for dairy systems in India is from crop residues; Blümmel et al., 2010b). Increasing the yield and quality (nutrient density) of these feeds is the main avenue for enhancing productivity and ultimately the livelihoods of these rural poor.

Description of production systems

East Africa: Dairy production sub-systems in East Africa vary considerably within the crop-cattle systems that dominate the region (Staal et al, 2009). Much of the variation is explained by a combination of agro-ecology (potential for crop production) and access to markets. In the semi-arid areas, which are often distant from major urban markets, indigenous (zebu) cattle graze mainly communal natural pastures and, after the harvest of the staple food grain (which, increasingly, is maize), private crop residues. The cattle receive few feed supplements or other purchased inputs and, therefore, in these extensive low-input systems, marketable milk surpluses are small. By contrast in the densely-populated highland areas, where crop yields are relatively high and market access for liquid milk is generally good (other than in Ethiopia), high-grade crossbred and exotic dairy cattle are stall-fed a basal diet of planted forage (especially Napier grass) and crop residues (mostly grown on-farm, but some purchased) along with gathered grasses, supplemented by purchased concentrates. In these more intensive crop-cattle systems marketable milk surpluses represent an important part of the household's cash income. Between these extremes are the semi-intensive systems in which animals are grazed only part of the day or the year, depending on feed availability. Average herd sizes vary from one to five cows in the most intensive systems and up to 10 in the extensive systems. Labour is mainly provided by family members, although intensive dairy is labour-intensive and may require hiring external labourers, therefore creating employment opportunities (Staal et al (2009). In the extensive systems, milk is mainly consumed by the household, due to low production levels coupled with limited market opportunities. On the other hand, a high percentage of the milk production in intensified systems is sold -the large majority through traditional market chains- and manure is highly valued and used as fertilizer on crops.

South Asia : Dairy production in South Asia dairy depends largely on smallholder dairy producers (up to 70 percent), using crop residues as the main feed resource (Staal et al, 2009, Blümmel, 2010b), and this is expected to remain so for the medium future (Parthasarathy Rao and Birthal, 2008, Chacko et al., 2010). Rice, wheat, sorghum and maize are the major staple food crops. Buffalo dominate the crop-dairy systems in the west of the region while cattle characterize the east and

south. The majority of farming households keep dairy animals, generally in small herds with 2-5 adult females (Staal et al, 2009). Some poor landless households also keep one or more dairy animals. The proportion of the cattle population that is crossbred is increasing. For the landed majority, feeding is based mainly on crop residues from private farmland and common resource grazing. However, in many areas the availability of open-access land has declined considerably, particularly in irrigated areas. In the latter, where cropping intensity may exceed 200% and the storage of crop residues is common, there may be some planted forage, e.g. berseem (Egyptian clover) (Erenstein et al, 2007). Along with the basal diet of crop residues or grazing, small quantities of crop by-products may be fed to lactating animals. Balanced dairy-meals are generally restricted to use by the relatively small number of larger scale farmers. Fresh milk is the main output of the small-scale dairy units and its marketing is widespread, both through formal and, mainly, informal (traditional) channels. The quality of available marketing options often determines production intensity with higher levels of production in areas with good market access (Staal et al, 2009). In India slaughter of cattle is banned in nearly all states but meat from buffaloes is marketed to some extent, a factor contributing to the increasing popularity of buffalo. To varying degrees, dung is used as a fertilizer and as a fuel marketed by poor households and the landless (Erenstein et al, 2007). The family is the main source of labour with women often being responsible for managing the animals. Draught power is still widely used in the less mechanized eastern regions of India while tractors and power-tillers are replacing bullocks in other areas.

East Africa	**South Asia**
Dairy Growth and Market Opportunities	
Domestic market: 2.8 % annual consumption growth rate. Significant regional differences Import substitution: 1.7 % imports of domestic prod. But little competition for local production, because of consumer preference.	Domestic market: Annual consumption growth rate: Bangladesh: -0.6%; India: 2.4% Import substitution: Imports as share of domestic prod. Bangladesh: 40.4%; India: 0.1%
Socio-economic characteristics	
Pro-Poor Potential 1.1 Million poor keeping dairy cattle, 24 million poor farmers keeping local or beef cattle 68 Million poor in the region (under $1US per day) Value of dairy production: 4,290 million US$/year	Millions of poor keeping dairy cattle or buffalos: India: 124.3 m; Bangladesh: 10.1 m Bangladesh: 37 million; India: 446 million poor under $1US/day: Value of dairy production: Bangladesh: $US 200 m; India: US $7,088 million

Supply Constraints	
Genetics: Lack of cost-effective way of adopting crossbred cows, because of unreliable, costly and poorly performing AI services Animal health: East Coast fever and FMD are major threats to improved dairy animals. leading to mortalities in calves of 20%, and 10% in adults Nutrition: Poor quality basal diet and low level supplementation in particular in the dry season	Genetics: Lack of improved indigenous sires; poor AI for upgrading, technical constraints in buffalo AI Animal health: Not a major constraint relative to genetics and nutrition and compared to SSA Nutrition: Poor quality basal diet and low level concentrate supplementation because of costs
Market/Institutional constraints: Limited access to formal output market and poor input services	Market/Institutional constraints: Poor access to formal output market and inadequate input services. Cooperative development has only partially met the challenge
Potential Interventions	
Potential productivity gains (dairy cattle): For cross-bred cattle, lactation milk yield can be multiplied by 3, from low of 644 kg to 2657kg (mixed farms in temperate/highlands). Potential interventions: Improvement of quality and quantity of planted fodder in the high potential areas and natural grazing In the low potential areas, and increased use of low-cost and high quality feed combined with continued improvement of genetic and health services	Potential productivity gains (dairy cattle): For cross-bred cattle, 67% gain in lactation yield - from low of 1200 kg to 2000 kg- are observed in mixed farms. However, some indigenous breeds can reach 3000kg. Potential interventions: Focus on buffalo, because of better adaptation to low quality feed and beef export and feed efficiency, in view of rising grain prices. Besides cooperative model, other models closer linked to private sector can be considered
Relative Potential Gains from Interventions Existing technology: Improved genetics: 20%; health: 25%; nutrition: 30% Formal market access: 30% Improved delivery of inputs: 40% New technology: Sexed embryos: 30%	Relative potential gains from interventions Existing technology: Improved genetics: 15%; health: 5%; nutrition: 40%; Formal market access: 25% Good delivery of inputs: 30% New technology: sexed embryos: 50 percent

Table 5.1: Dairy value-chain in East Africa and East Asia: Growth and market opportunities; pro-poor potential; supply constraints and potential interventions

Current and projected feeding systems: Drawing on the results of field surveys carried out in the two regions by recent research and development projects and our experience in those regions, we estimated the distribution of current (2010) feeding systems and projected the distribution to 2030

for East Africa and South Asia dairy systems. They are presented in Tables 5.2-5.4. For South Asia, the results are differentiated for the "rain-fed" and "irrigated" systems. The key trends in both regions are very similar and are expected to be:

- A decreasing importance of communal grazing. In East Africa, it is expected that grazing will decline from 64 percent now to 35 percent in 2030. For the rain-fed systems of South Asia, it will decline from a third of the annual feed DM for the dairy animals to about one sixth in 2030. For the irrigated system it remains small.
- An increasing reliance on cultivated fodders, in particular in East Africa, changing from 36 percent to 65 percent of the households expected to have staff feeding mostly with planted forages (table 5.2), mostly consisting of Napier grass and in the South Asian irrigated system; and
- An increasing reliance on concentrate supplementation, changing in South Asia from practically nil to 10 percent and more of the total feed intake.

East Africa small-scale dairy		**% households**	
Feeding system		**2010***	**2030****
Grazing	Low supplementation	64	35
Stall-feeding	Low supplementation	35	25
Stall-feeding	High supplementation	1	40

Table 5.2: Estimates of small-scale dairy households in East Africa practising razing or stall-feeding with low or high supplementation for 2010 and a projection for 2030

East Africa small-scale dairy	**Source of feed** (% of DM)			**Est. share (%) of herd feed***
Type of feed	**Own farm**	**Community**	**Market**	**Total**
Natural grazing	0	1	0	**1**
Planted pastures	0	0	0	**0**
Planted forages**	40	0	10	**50**
Crop residues	25		5	**30**
Crop by-products	1		4	**5**
Other by-products			4	**4**
Grains			5	**5**
Mineral/vit. suppls.				**0**
Balanced concs.			5	**5**
TOTAL	**66**	**1**	**33**	**100**

Table 5.3 Approximate distribution of different feed resources in East African small scale dairy

S.ASIA DAIRY Rain-fed	**Source of feed** (% of DM*)						**Est. share (%) of herd feed***	
Type of feed	**Own farm**		**Community**		**Market**		**Total**	
	2010	2030	2010	2030	2010	2030	2010	2030
Natural grazing			**30**	**15**			**30**	**15**
Planted pastures								
Planted forages	**5**	**5**					**5**	**5**
Crop residues	**40**	**35**			**10**	**10**	**50**	**45**
Crop by-products					**10**	**15**	**10**	**15**
Other by-products						**5**		**5**
Grains	**3**	**3**			**2**	**2**	**5**	**5**
Roots and tubers								
Mineral/vit suppls								
Balanced concs						10		10
TOTAL	**48**	**43**	**30**	**15**	**22**	**42**	**100**	**100**
S.ASIA DAIRY Irrigated	**Source of feed** (% of DM*)						**Est. share (%) of herd feed***	
Type of feed	**Own farm**		**Community**		**Market**		**Total**	
	2010	2030	2010	2030	2010	2030	2010	2030
Natural grazing			**5**	**2**			**5**	**2**
Planted pastures								
Planted forages	**10**	**15**					**10**	**15**
Crop residues	**60**	**40**			**5**	**10**	**65**	**50**
Crop by-products					**10**	**15**	**10**	**15**
Other by-products								
Grains	**4**	**4**			**1**	**1**	**5**	**5**
Roots and tubers								
Mineral/vit suppls								
Balanced conc.					5	13		
TOTAL	**74**	**59**	**5**	**2**	**21**	**39**	**100**	**100**

*DM dry matter , *DM ** cut-and-carry

Table 5.4 Estimates of annual share of types and sources of feeds (on a dry matter basis) used currently (2010) and projected to 2030 for dairy production in rain-fed and irrigated crop-livestock systems in South Asia

- In both South Asian systems own farm-produced crop residues (mainly from the principal staple food crops, e.g. sorghum and rice, depending on the region) are, and are expected to remain, the largest single feed source. Along with purchased crop residues, own farm-produced crop residues contribute currently an estimated 50% of annual feed DM in the rain-fed systems and 65% in the irrigated systems; by 2030 these proportions are expected to reduce to 45% and 50% respectively (**Table 5.4**).
- By 2030 the proportion of the feed expected to be met from the market will have doubled from approximately 20% of annual DM to approximately 40%. The increase is expected to come mainly from purchases of crop and agro-industrial by-products and balanced concentrates, which will improve the overall nutrient balance of rations. In the irrigated systems there is also expected to be an increased contribution from own-farm forage production (**Table 5.4**), again improving ration quality. Short-duration, multi-crop forages, e.g. sorghum and maize, are likely to be popular, replacing current staple food crops (see text **Box 5.2**).

Opportunities for improvements

From this 2010 baseline and the 2030 projections, the kind of support through better feeding increased and more efficient dairy production by poor households is determined by applying the analytical framework and its tabular format (**Table 4.1)**, a group having in-depth knowledge of the crop-dairy systems in the region identified interventions with good potential to increase the availability of feed on-farm (**Produce more**) or through the market (**Import**) and to improve the utilization of the feed (**Utilize better**) (**Appendix 5**).

Success will require an improved knowledge base (education and access to services) such that feeds are utilized more efficiently through the better balancing of diets in relation to a specific animal's requirements (e.g. cost-effective matching of the requirements of an early lactation cross bred dairy cow in whatever the season). A pre-requisite, therefore, will be good governance of feed quality and water issues, while a basic requirement will be the strengthening of breeding and veterinary care services. Therefore, within the context of current and projected crop-dairy systems in East Africa and South Asia, the key feed investment opportunities and their strategic entry points are:

Produce more (on own farm)

- Institutionalise multi-dimensional improvement of food-feed crops;
- Improve access to high-yielding planted forages: knowledge system and planting material/seed;
- Evaluate and address any price-policy disincentives to growing more productive food-feed and forage crops (South Asia in particular); and

- Improve water efficiency through harvesting and better utilization.

Import (on to farm)

- Improve marketing of feeds (including micro-sizing of supplements);
- Put in place effective incentives for and regulation of small scale entrepreneurs, in particular to ensure feed quality regulations; and
- Provide effective health, advisory and credit services.

Utilize better

- Improve the processing of planted forages and crop residues to reduce seasonal feed scarcities;
- Put in place an effective knowledge system to improve:
    - Balancing and targeting of rations;
    - Processing of crop residues and planted forages to reduce seasonal feed scarcities.

Box 5.1. Summary of key informant interviews with feed sector actors in East Africa

Physical infrastructure:

- Telecommunication is not a constraint to most respondents. However, it is a constraint to distributors.
- Transport is a major constraint to all types of businesses and it influences pricing. Poor state of roads and high fuel prices affect transportation of both raw materials and distribution of the finished product. Traffic jams were cited as a major constraint by respondents in Nairobi area.
- Water supply does not adversely affect most respondents except for milk processors who have to incur costs to ensure availability of enough water.
- Energy is a major constraint to feed manufacturers, with very high and fluctuating tariffs resulting in high production costs.

Feeds and feed ingredients

- Policies on importation of feed and feed ingredients affect small, medium and large scale millers and feed compounders.
- There is inadequate supply (quality and quantity) and high cost of raw materials, for example, although such costs are perceived to be lower in neighbouring countries.
- Restrictions on importation of grains was highlighted as a constraint, alongside the need to set and enforce standards of raw materials. In some cases manufacturers indicated that national standards were too rigid thereby preventing new innovations, such as feed additives.
- Among the limitations faced by small-scale feed manufacturers, costs associated with formal certification were highlighted as being prohibitive. .

Feed and food quality

- Despite good awareness of national feed standards, in many cases these are not enforced, not least due to limitations of capacity at national level. In some cases this results in a focus on a few large and medium scale manufacturers.
- Food safety regulations for concentrate feeds; are not applied to forages and crop residues. There were also some concerns that aflatoxin contaminated grain still enters the livestock feed industry.
- Greater collaboration between national standards agencies and feed manufacturer association was highlighted as a key way forward, especially regarding feed industry standards.

Technical innovations and knowledge services

- Access to reliable advisory services such as government extension service, National Research Institutions and other feed manufacturers was generally good
- There seemed to be a disconnect between advice to farmers and demand for livestock feeds
- Access to analytical services is often limited – either because of capacity or cost (or both).

Other important issues

- Fuel and energy costs
- Standards need to be comprehensive, including forages, minerals, premix. They should also capture all scales of feed manufacturers to ensure equitable market dynamics.

Challenges

- Rapid increases in small-scale feed manufacturers need to be included in training and certification to ensure uniform and reliable feed quality from all scales. .
- The impact of fluctuating milk prices as it impacts on sustained investment in feeds is a limitation.
- As a result of competition between humans and livestock for grains, good quality grains go to food manufacture while rejected grains end up in the livestock industry.

- Put in place effective governance of feed quality and water issues
- Ensure access to services delivering improved dairy genetics and livestock health;These opportunities represent clear priorities for interventions through investments in policies, knowledge and service provision and technologies. In turn, for the interventions to be effective in support of small-scale dairy in East Africa and South Asia poverty alleviation,

they will require a production environment having an adequate infrastructure and supportive policies and institutions,

- aspects emphasized in the responses from a recent survey of feed sector market agents in the East Africa region (summarized in **Box 5.1**).

Policies	Knowledge and service provision	Technologies
• Insuring adequate major and rural-access roads and water and electricity and telecommunication networks • Supporting business development services (BDS) which may involve policy related dimensions of an enabling environment • Supporting effective governance of natural resources: o Land tenure (customary and national)* o Grazing* and water management • Eliminating tariff barriers to competitive regional and international feed imports (East Africa) • Facilitating public-private consortia for breeding and access to food-feed and forage crops • Ensuring effective and appropriate governance: - Water supply and quality - Feed quality • Supporting livelihood options for agro-pastoral communities including through ecosystem service payments*	Developing Business Development Services to improve access to: 1. Knowledge services - Market information feeds - Food-feed crop varieties - Forages - Seed/planting materials - Processing fodders - Feed storage - Balanced rations - Veterinary services - Breeding advice 2. Physical inputs - Planting materials - Concentrates/suppl ements - AI, vaccines and vet drugs 3. Credit	• Farm management tools • Improved crop husbandry • Food-feed crop improvement • High yielding forages** • Water harvesting to produce and utilize feed* • Processing crop residues and forages • Better feed storage • Balancing rations to improve dairy productivity

*Rain-fed in East Africa and South Asia ** East Africa and South Asia irrigated

Table 5.5 Priority feed-related investments to support pro-poor dairy development in East Africa and South Asia.

Table 5.5 presents the key inter-related elements in a summary of the priority feed-related opportunities for the public investments required to support pro-poor dairy development in East Africa**.**

As many failed development investments have shown, addressing single components of this complex is unlikely to be successful. On the other hand, an integrated approach to resolve these policy, knowledge and technology constraints through well-targeted and coordinated public

Box 5.2: Planted forages
Issue: Producing more feed biomass for dairy production on smallholder farms by planting forages

The context: In the intensifying crop-dairy systems of East Africa and South Asia where farm sizes are small (often 1 ha or less), marketable surpluses of milk are limited by feed scarcities. Staple food crops occupy most of the household's land. Their crop residues (e.g. maize stover or rice and wheat straws), which have low nutrient density, are the main feeds for dairy production. Planted forages can boost feed availability but they compete with the staple food and cash crops for the household's scarce land and labour (Waithaka et al., 2006).

Why would planting forage make a difference? In the rain-fed crop-dairy systems of the East African highlands the planted forage, Napier grass, a perennial, produces more biomass than the staple maize, a short-duration crop, thereby improving year-round availability of feed (Lukuyu et al, 2007). In the irrigated cropping systems of semi-arid north-western India, berseem (Egyptian clover) is the preferred planted forage for winter cropping and forage sorghum or maize in the monsoon (summer cropping) (Roy et al, 2009; Erenstein et al, 2007). They complement the basal feeds, rice and wheat straws, the low nitrogen content of which results in poor digestion in the rumen and low milk production. In each case the planted forage is an integral part of the land use system, improving the quantity and quality of feed available to produce marketable surpluses of milk. If the planting of forages is well targeted these examples of success can be repeated to increase the productivity of other intensifying crop-livestock systems.

What do we know? The success of Napier grass, Egyptian clover and forage sorghum can be explained by how well they "fit" the faming system: their planting materials are readily available; they allow multi-cuts and have low labour requirements; their husbandry is hassle-free; their forage complements the seasonality of the other feed resources; and the milk the forages produce is an important cash source for the resource-poor crop-dairy households contributing to their food and nutrition security. Ensuring this "fit" to the system is important: in Africa decades of research and development investment in planted forage legumes resulted in little or no adoption by smallholders or agro-pastoralists. The legumes were promoted because of their biological characteristics without taking account of the bio-physical and socio-economic factors that limited their adoption (Sumberg, 2002). Recent methods for analyzing smallholder systems and applying the innovation systems approach largely overcome these deficiencies and planted forage technologies can be targeted more effectively (Staal et al., 2002; Ouma et al., 2007; Tesfaye Lemma Tefera et al., 2010). See also for example fodder innovation research – Chapter 11.

Policies and investments: Planted forage technologies can serve as key components of an enabling environment for smallholder dairy development. An enabling environment requires a market system in which prices and infrastructure favour milk production over other farm products and that delivers effective dairy breeding and health services as well as planting materials for improved feed resources. The enabling environment will have knowledge services to facilitate increased dairy productivity for improved farm profitability and reduced risk. In many circumstances investments will be required to improve physical infrastructure, e.g. rural access roads as well as power and water supplies. Investment to strengthen research and development capacity will be essential to understand and apply innovation systems approaches (see **chapter 10**) for analysing and addressing systems constraints and opportunities. A central component will be identifying location-specific and system-adapted feed interventions. For crop-dairy systems these options will include using improved food-feed crops, planting forages and practices to store and process feeds and to balance rations for increased land, labour and dairy productivity. Investing successfully in planted forage technologies, therefore, requires holistic approaches that produce and utilize efficiently feed biomass from smallholders' scarce private land, from common-property resources and from purchased feed (Lukuyu et al., 2007; Tesfaye Lemma Tefera et al., 2010).

investment with feed resources as its focus, and partnering the private, development and voluntary sectors, would be expected to deliver pro-poor dairy development in both regions. Therefore, priority in the short and medium terms for public investment should be given to ensuring adequate infrastructure (roads, water and electricity) and to working with the private sector to support business development related to knowledge services for improved feeds,

Institutional challenges and investments

Given the limited success of the co-operative model in many parts of the region (Staal et al., 2008) and the increasing commercialization of the dairy sub-sector, the BDS (business development service) "hub" model with private sector participation and public-private partnerships currently being tested to support smallholder dairy in East Africa (**Appendix 4**), is an option that should be explored. In S Asia strategic lessons can be learnt from the increasing numbers of local companies targeting the dairy input and output markets, from the evolving programmes of the region's national dairy boards and from the marketing initiatives in India's NW of the multinationals, Nestle and Cargill, and by Reliance elsewhere in India. Functional BDS models will vary, influenced by current institutions, the level of market orientation, land-use systems and local culture. They will evolve and develop through active, on-going interaction between suppliers and customers. Experience in various settings has shown that it is vital to give time and space for learning (Caniels et al., 2006), such that medium- (6-10 years) rather than merely short-term (5 years) support to Small and Medium Enterprises (such as those developing decentralised feed processing options; Anandan et al., 2010; Blümmel et al., 2009a)serving small-scale dairy producers may well be required.

Developing BDS with a focus on feed resources will contribute to increasing and conserving biomass yields and improving the efficiency of feed utilization year-round. Developing cost-effective balanced rations and overcoming seasonal feed shortages using local and "imported" technologies and resources will require participatory approaches and institutional capacity building to understand systems interactions and to address the key constraints to feed availability and their use at each stage of the life-cycle of dairy production and of the cropping systems on which it depends. At the same time, large private feed companies are exploring opportunities in both Africa and Asia and there will be a need for some new models of engagement, especially if this is to result in transitions that are environmentally sustainable and equitable for small and female farmers.

6. Feed-related investments for beef production in West Africa

Cattle are integral components of the livelihood strategies of rural households in West Africa and beef is a popular product sold through local, national and regional value-chains (Okike et al., 2004a,b; Kamuanga et al, 2008; Williams et al, 2006; Ly et al., 2010). The region has four principal agro-ecological zones: arid, semi-arid, sub-humid and humid, which, through their rainfall patterns, soils and natural vegetation, characterize the livestock (pastoral) and crop–livestock systems from which beef is a product (Fernandez et al, 2004). The large majority of producers in the crop-livestock systems are poor and their land and animal holdings are small. These and the pastoral and agro-pastoral systems respond to the risks associated with the uncertainty of rainfall (there is little irrigated crop production) and to the demand for live animals from the urban consumption centres. Markets for beef are particularly strong in the highly populated areas of the coastal belt, with considerable live animal trade from the drier, more northerly regions to these southern coastal areas. In West Africa inter- and intra-year (seasonal) variation in feed supply and demand are important factors affecting how cattle (and small ruminants) are fed. At present there is little, if any stratification of cattle (beef) production systems in West Africa and whilst this was dismissed as unfeasible several decades ago, with the increasing demand, improved communication and infrastructure, and more sophisticated urban consumers, it may be a dimension to be re visited.

In the recent systematic analysis by Staal et al (2009), the methods for which were outlined in **Chapter 3**, the growth and market opportunities for beef in West Africa and its pro-poor potential were quantified (**Table 6.1**). In this regional market, which is worth well in excess of a billion US$, the strong growth of beef consumption represents good opportunities for increased beef production by its 70 million poor cattle-keepers, provided that supply constraints, amongst which cattle nutrition and its interactions with disease are particularly important, can be resolved (Staal et al, 2009) **Table 6.1** summarizes for the beef value-chain the constraints to improve production and marketing and the potential interventions.

Growth and Market Opportunities Beef in West Africa	**Pro-poor potential**
Domestic market: 2.3 % annual consumption growth rate with strong regional growth Import substitution: 7.7 % imports of domestic prod, with opportunities for import substitution, provided quality and protection to dumping is addressed.	70 Millions of poor keeping beef cattle, with opportunities for stratification with beef feedlots in urban areas using young males not needed for traction 130 Millions of poor under $1US per day 1.2 US$ billion value of beef production:
Supply Constraints	**Potential Interventions**
Genetics: Lack of improved indigenous sires (and proven cross-breeding systems for emerging stratified systems), but lack of	Potential productivity gains: As observed on farms, gains of 50% with carcass weights exceeding 130 kg or more and

infrastructure and institutions makes rapid progress unlikely. Animal health: Nutrition x disease complexities are constraints in particular in young stock. Nutrition: Under-nutrition of breeding females	potential incremental value of US $ 183 per animal are potentially achievable. With: • Reducing trade transaction cost through investments in bulking assembly and information systems; • Animal health interventions, focusing on CPBB, possibly FMD and with nutrition on calf-mortality, although limited scope for the latter; • Promotion of feedlots using local feed stuffs if a) premium for the meat and b) cost ratio for meat/feed are favorable.
Market/Institutional constraints: Very limited input services and inefficiencies in output marketing, because of sparsely populated area with poor infrastructure and poor marketing infrastructure with high transaction costs	
Relative Potential Gains from Interventions	
Existing technology: Improved genetics: 20%; health: 15%; nutrition: 30%, Improved market access: 20% Good delivery of inputs: 15%	

Table 6.1: Beef value-chain in West Africa: growth and market opportunities; pro-poor potential; supply constraints and potential interventions (Staal et al, 2009)

Description of production systems: The region's agro-ecological zones which range from the humid coastal zone to the dry Sahelian zone, roughly define an increasing gradient of dependence on ruminant livestock for livelihoods (Staal et al, 2009). From the drier northern region, in the Sahel rangelands of Niger, Burkina Faso, Mali, Chad, Mauritania, Gambia and Senegal, the keeping of ruminant livestock in extensive pastoral systems (about five cattle per sq. km) provides the livelihood for millions of people. They depend on cattle for meat, milk, transport, manure, as a store of wealth and source of societal prestige. For the latter reasons, and in the absence of alternative saving institutions, households in the pastoral system use all available household labour to continue to build their herd sizes irrespective of the condition of the animals (50 cattle per household of six people is common, and about the minimum needed for survival) (Staal et al, 2009). Pastoral transhumance remains important (Kamuanga et al, 2008). In climatically favourable years, pastoralists produce and market some excess young bulls, although with very low incremental costs to keep additional animals, it can be quite rational to take the animals to a maximum weight at 5-6 years. During a drought, poorly performing cattle of all sexes and ages are sold to buy food grains, with the male animals the first to be sold. However, during normal years, some of these young bulls do not head directly to terminal markets and instead provide replacement stock for traction and fattening operations in the adjoining crop-livestock systems of the Savanna zones. In the latter, households of, on average, 11 persons own 2-4 bulls and plant up to 5 ha of farmland to cereal and legumes using both household and hired labour (Staal et al, 2009). The cropping systems (with ruminant livestock) include: pearl millet–cowpea; sorghum–maize–cowpea; maize–sorghum; cotton–maize–sorghum; groundnut–rice; yam–cassava–maize; cassava–yam; rice–cassava–maize; pearl millet–groundnut (Fernandez et al, 2004, p 98). The availability of crop residues in these crop-cattle

systems enables farmers to maintain the bulls in very good to excellent body condition through supplementary stall-feeding within homesteads. Though this practice is primarily aimed at keeping the bulls fit to provide traction, it not only yields heavier animals for the beef market (when the bulls are retired from traction) but also pools manure for return to farmlands at the beginning of each planting season. Commercial ranching with stall-fed beef production is an emerging, but at present somewhat limited, trend in the drier agro ecologies in Nigeria. Increased intensification of crop production will provide new fodder supply (Staal et al, 2009). Livestock marketing opportunities are excellent responding to demand for meat in the urban areas, particularly coastal cities, for which there is a well-developed, although cost-constrained, cross-border trade in live animals (Williams et al, 2006; Kamuanga et al, 2008).

Current and projected feeding systems, feed types and their sources: Based on extensive experience in the region and drawing on the results of field surveys from recent projects, we estimate that in the current (2010) feeding systems of the **intensive crop-cattle systems** (described above), natural grazing and crop residues dominate with, on average, 55% of the total DM (dry matter) fed annually by households to their herds coming from communal natural grazing (**Table 6.2**). However, by 2030, in response to the stimulus of market demand for beef (and, to a lesser extent, for milk) and the pressure on land from human (and cattle) population growth, it is expected that these crop-cattle systems will intensify their cropping and, where possible, expand its area. This will reduce the availability of natural grazing and increase the proportion of feed sourced from crop residues and by-products to meet the needs of what will be a larger cattle population. As **Table 6.2** shows, by 2030 these changes in demand and supply are expected to result in more feed DM being sourced from the market (13% in 2030 compared to 2.5% currently) and less feed DM coming from common property grazing. Therefore, during the next 20 years cattle production in the intensifying crop-livestock systems will increasingly shift from a grazing base towards being more crop-based. This could also lead to a reduction in animal numbers, especially if per animal productivity can be increased and associated risks of keeping fewer animals mitigated – a scenario which would have positive environmental benefits.

Type of feed	**Own farm**		**Community**		**Market**		**Total**	
	2010	2030	2010	2030	2010	2030	2010	2030
Natural grazing			**55**	**44**			**55**	**44**
Planted pastures								
Planted forages								
Crop residues	**15**	**15**	**25**	**25**		**5**	**40**	**45**
Crop by-products	**2.5**	**3**			**1.5**	**1.5**	**4**	**4.5**
Other by-products					**1**	**5**	**1**	**5**
Grains						**1**		
Mineral/vit suppls						Trace		
Balanced concs						0.5		0.5

TOTAL	17.5	18	80	44	2.5	13	100	100

*high rainfall semi-arid and sub-humid, including fattening phase; **DM - dry matter

Table 6.2: Estimates of the proportion of feed by source and type used by small-scale intensive crop-cattle households in West Africa currently (2010) and projected to 2030

This same shift, towards a more crop-based beef production, will also occur in the region's **extensive crop-livestock** and **agro-pastoral systems.** The changes will be driven by the same factors, human (and cattle) population growth and the market demand for beef and for finishing, draught and breeding animals (Herrero et al, 2010b; Kamuanga et al, 2008; Fernandez et al, 2004). **Table 6.3** presents our estimates of the proportion of feed by source and type used currently (2010) by these systems and the projections to 2030. As with the more intensive crop-cattle systems, communal natural grazing and crop residues dominate the feeding resources from which beef is currently produced. And, in common with the intensive systems, by 2030 it is expected that proportionally less feed DM will come from these common property resources and more, although still only 10% of the total, will come from the market. Because planted pastures and forages, roots and tubers, mineral/vitamin supplements and balanced concentrates are not current or projected types of feeds in these systems, they were not included in the presentation of **Table 6.3**. A possible exception to this projection may occur if analytical and advisory services become sufficiently developed (by 2030) to identify and respond in cost-effective ways to any specific micro-nutrient deficiencies that significantly limit key stages of the production life-cycle, e.g. cow fertility or pre-weaning calf survival. There may also be opportunities for sourcing feed (including crop by products) from the more highly crop focused areas of the south. Anecdotal evidence has indicated that for example, cassava peels produced in southern Nigeria are being transported to the north of the country for cattle feed (E.Grings, personal communication, 2010).

W. Africa beef-agro-pastoral and extensive crop-livestock systems	**Source of feed** (% of DM*)						**Est. share (%) of herd feed***	
Type of feed	**Own farm**		**Community**		**Market**		**Total**	
	2010	2030	2010	2030	2010	2030	2010	2030
Natural grazing			**72**	**62**	**5**	**5**	**77**	**67**
Crop residues	**5**	**6.5**	**16**	**19**		**3**	**21**	**28.5**
Crop by-products	**2**	**2**				**1**	**2**	**3**
Other by-products						**1**		**1**
Grains						**0.5**		**0.5**
TOTAL	**7**	**8.5**	**88**	**81**	**5**	**10.5**	**100**	**100**

*DM dry matter

Table 6.3: Estimates of the proportion of feed by source and type used by agro-pastoral and extensive crop-cattle households in West Africa currently (2010) and projected to 2030.

For the region's **pastoral systems**, it was estimated that, apart from 10% of annual DM from communal crop residues and 0.5% DM from purchased crop by-products, all the remaining feed is communal natural grazing (**Appendix 7.1**). And it is projected that, even in 2030, these common property rangelands will continue to provide the large bulk of feed (88%) because purchased by-products are only expected to increase to approximately 2% of annual DM and, in these arid and drier semi-arid areas and through transhumance, the quantity of crop residues accessed communally are unlikely to change. The region's pastoral systems are uniquely adapted to manage risk, especially through mobility for access to feed and water, related to their often precarious existence in very variable environments. There may be opportunities for more sustainable production and market engagement from these systems, but it will be important to target such efforts in relation to the natural resource base, so as not to put either the environment or the pastoralists' livelihoods at risk.

Opportunities for improving the availability and impact feed resources: To assess the feasibility of increasing the availability and improve the utilization of feed resources for producing beef from the cattle herds of poor households in West Africa, within these scenarios of changing land use practices, the analytical framework and its tabular format (**Table 4.1,** presented in C**hapter 4)** were applied. The results were summarized for each group of systems: intensive crop-cattle systems; extensive crop-livestock and agro-pastoral systems; and, pastoral systems in which the results are summarized in relation to **Produce more, Import** and **Utilize better** livestock feed (**Appendix 7).**

Feed resources interventions and investment opportunities: Based upon the results of these expert consultations, improving the feed resources to increase beef production in the region will require community-based strategies for improving the management of natural resources (water, land and vegetation) and, closely related to that, the harmonization of customary and national laws of land tenure and measures to resolve and limit conflicts over grazing and watering rights (**Table 6.4**). And, given the increasing importance of crop residues and by-products for cattle production, a priority intervention will be improving the principal food-feed crops of the region through institutionalizing multi-dimensional breeding approaches and ensuring ready access to these higher feed yielding varieties and other inputs. These interventions will support crop-livestock farmers to intensify their cropping and the associated beef production by **producing more** feed within their own cropped land and increasing the availability of the crop residues that will continue to be grazed communally (**Import)**. With the purchasing of feed being more widely practised, improving access to market information and how feeds are marketed will support cattle-keepers who are seeking to sell one or more animals or to improve the market value of these animals (**Table 6.4**). And, to that same end, key interventions for improving the utilization of feeds will be reducing seasonal scarcities

by improving the storage and processing and improving the balancing and targeting of rations (**Utilize better**). Access to information about combining feed resources to make the most of what is available will be important.

These and the other key issues summarized in **Table 6.4** reflect the inter-related nature of the proposed interventions which require addressing policies, institutions, technologies and knowledge systems. They, therefore, re-emphasize the critical importance of taking an integrated approach to investments in the continued development of these complex systems on which many millions of poor West Africans depend for their livelihoods.

The feed-related interventions listed in **Table 6.4** for beef production in West Africa address how to improve the biomass yields of the region's staple food crops in ways that will not degrade the natural resource base of the cropped lands and the associated areas of natural grazing, but that will also address effectively the increasing scarcity of water. Good descriptions of these land-use and cropping systems are given by Fernandez et al (2004). Required will be policy and institutional interventions to overcome barriers to the delivery of multi-dimensional crop improvement and to secure effective community-based strategies for managing land and water resources.

	Intensive C-L*	Agro-past. & Ext. C-L*	Pastoral
PRODUCE MORE (on own farm for C-L*)			
• Improve the management of natural resources (water, land and vegetation) through community-based strategies	√	√	
• Reconcile customary and national laws of land tenure systems	√	√	√
• Institutionalise multi-dimensional approaches to improving food-feed crops	√	√	For host cultivators
• Improve access to high-yielding crops, planted forages: input markets (planting material/seed, fertilizer, etc)	√	√	For host cultivators
IMPORT (on to farm for C-L*) (to herd for pastoralists)			
• Improve the management of natural resources (water, land and vegetation) through community-based strategies	√	√ Incl. fadamas	√
• Reconcile customary and national laws of land tenure systems	√	√	√
• Improve access to market information and marketing of feeds (including micro-sizing of supplements)	√	√	
• Agree contracts for accessing crop residues			With host cultivators
UTILIZE BETTER			
• Improve the management of natural resources (water, land and vegetation) through community-based strategies	√	√**	√**
• Reduce seasonal feed scarcities by improving storage and processing	√	√	For host cultivators
• Improve the balancing and targeting rations	√	√	√
• Put in place effective governance of water issues and feed quality	√	√	√ Focus on water
• Explore payments for ecosystem services as llivelihood options			√

*****C-L: crop-livestock (cattle) systems; ** paying particular attention to livestock mobility, land-use plans and pricing policies for water

Table 6.4: Opportunities for development interventions related to feed resource constraints to beef value-chains in West Africa

To support increased and profitable beef production, efforts to improve the efficiency of utilization of the available feeds will be important but challenging. Required will an improved knowledge base (education and access to services) built through institutional capacity building and the BDS (business development service) model with private sector participation and public-private partnerships. This "hub" model is currently being tested in East Africa (**Appendix 4**). A key outcome should be delivering to resource-poor cattle-keepers services that ensure that the extensive knowledge of ruminant nutrition science brings significant benefits in practice. However, it is important to note that hub models are presently focused on dairy systems, with the natural focus of milk chilling and/or collection – there are likely to be a different set of focal issues for beef production systems. Important elements will be delivering balanced rations and overcoming seasonal feed scarcities at critical stages of the production life-cycle (**Table 6.4**). Decision-support tools have the potential to play an important role: FEAST (Feed Assessment Tool https://sites.google.com/a/cgxchange.org/feast) is a recent example which presents an evolving methodology for conducting rapid appraisals of livestock feed issues in smallholder livestock systems. FEAST uses a systematic method for assessing local feed resource availability and use with a view to designing intervention strategies aimed at optimizing feed utilization and animal production.

Given the inevitable increased pressure on natural grazing lands, community-based strategies and land tenure systems to improve the management of natural resources will be critical to improving livelihoods in the pastoral and agro-pastoral areas and, therefore, are a priority for feed-related development investments (**Table 6.5)**. The recent guidelines by Flintan and Cullis (2010) and their framework for developing participatory rangeland management, together with the manual for community-based participatory approach in agro-pastoral areas by Nefzaoui et al (2007), provide a sound basis for developing these initiatives. In addition to these interventions directly related to feeds, support for livestock insurance schemes would help mitigate risk, while developing schemes paying for environmental services (PES) would create alternative income sources with benefits to land management (World Bank, 2009).

The other priorities for feed-related development investments presented in **Table 6.5** reflect the same core issues affecting feed resources for dairy production by resource-poor households in S Asia and East Africa (**chapter 5**), regions in which human and large ruminant population densities are already higher than in much of West Africa. Without the supportive policies and institutions and adequate infrastructure described in **Table 6.5**, the environment for beef production in, e.g. Mali or Nigeria, will inhibit resource-poor households and their communities in their efforts to improve their livelihoods. Addressing

feed issues in isolation will not be effective: required is an integrated approach to public investment to resolve the policy, knowledge and technology constraints and to deliver the inter-related components presented in **Table 6.5.** With feed development central to a comprehensive programme, the well-coordinated **t**argeting of these key constraints would be expected to promote pro-poor beef production in West Africa.

Policies	Knowledge and service provision	Technologies
• Ensuring adequate major and rural-access roads and water, electricity and telecommunications • Supporting effective community-based governance of natural resources: o Land tenure (customary and national) o Grazing and water management • Supporting business development services (BDS) • Facilitating public-private consortia for breeding food-feed and forage crops • Ensuring effective governance of: - Water quality - Feed quality • Supporting livelihood options for pastoral and agro-pastoral communities including ecosystem service payments	Developing BDS to deliver: 1. Knowledge services - Market information: feeds - Food-feed crop varieties - Forages - Seed/planting materials - Processing fodders - Feed storage - Balancing rations - Vet. advice - Breeding advice 2. Physical inputs - Planting materials - Concentrates/suppleme nts - Vaccines and vet drugs - Proven breeding stock 3. Credit 4. Institutions for payment for environmental service	• Improved crop husbandry • Food-feed crop improvement • High yielding forages • Water harvesting to produce and utilize feed • Processing crop residues and forages • Better feed storage • Balancing rations to improve beef productivity

Table 6.5: Priority feed-related investments to support pro-poor development of beef production in West Africa

In summary, therefore, the investment opportunities to support poverty alleviation through more productive and profitable beef production in the complex of systems in West Africa should focus on:

1. Developing community-based strategies and land tenure systems to improve the management of natural resources (water, land and vegetation) for intensifying crop and cattle production;
2. Institutionalizing multi-dimensional approaches to improving food-feed crops and improving their input markets;
3. Improving the knowledge base through institutional capacity building and developing business development services.

7. Feed-related investments for small ruminant meat production in West and Southern Africa

Along with cattle, small ruminants (sheep and goats) are integral components of the pastoral, agro-pastoral and crop-livestock systems that sustain the livelihoods of rural households in West and Southern Africa (Fernandez et al., 2004, (Staal et al, 2009; **Table 7.1)**. They have savings and insurance functions, produce manure for fertilising crops and meat (and sometimes milk) for home consumption, and they can be sold for cash for incidental expenses such as school and medical bills. In both regions, agriculture is rain-fed with a marked mono-modal rainfall distribution and an extended dry season. In the majority they belong to smallholder systems, small ruminants (SR) are particularly important for women.

Description of the production system

West Africa Approximately 70% of West Africa's SR population are found in the arid and semi-arid zones with, in the latter, a concentration of some 24 million in the pearl millet-cowpea-livestock system (Fernandez et al, 2004). In the drier part of the sub-humid zone, the sorghum-maize-cowpea-livestock system and the maize-sorghum-livestock system each have approximately ten million SR, as does the "irrigated" rice-livestock system and, in the wetter part of the sub-humid zone, the cassava-yam-livestock system. The other crop-livestock systems support smaller, yet significant, SR populations (Fernandez et al, 2004). In the cereal/legume cropping systems SR typically graze non-cropped land and are fed on crop residues – cereal stovers supplemented with legume (cowpea or groundnut) hay and various combination of bran generated by household processing of grain (Staal et al, 2009). Most households collect manure and return it to crop fields at the start of the planting season. A household may keep up to 10 SR, with as few as 2-3 also being very common. In the southern (wetter humid and subhumid) parts of the region, West African Dwarf goats (and to a lesser extent sheep) are kept by many households mainly as an "insurance" or "emergency cash" resource; they are often owned and managed by women and there is very little husbandry – animals are left to scavenge, fed on household waste, etc (Staal et al, 2009). In the drier (semi-arid) areas SR play a similar role in most cases, but there is an increasing market orientation, especially for sheep which often are raised especially for Muslim festival times when prices are at a premium. In some parts sheep are the purview of men only (e.g. northern Nigeria), whereas in other regions (e.g. Niger) women may purchase sheep to fatten specifically for the Eid al-Adha (*Tabaski*) festival (Staal et al, 2009). Goats are frequently owned and managed by women and serve as an important "cash reserve" for meeting household emergencies. In urban and peri-urban areas stall-feeding of SR is common, again associated with fattening for Tasbaski and other celebrations. The stall-feeding results in significant nutrient transfers from rural to urban and peri-urban areas.

The marked variation in annual and seasonal rainfall that characterizes the region impacts through voluntary and forced sales on the off-take from the ruminant population (**Figure**

7.1). Inter-annually, these sales can be associated with the failure of subsistence (staple) food crops, rising food prices and the drought that reduces the availability of the main feed resources - grazing and crop residues - that sustain ruminant livestock. Generally after a drought the small ruminant population recovers more quickly than the cattle population. During a year, feed supplies vary with the access to harvested residues and the availability of forage for grazing. Feed availability is therefore often limited in the late dry season after crop residue supplies are exhausted and the beginning of forage growth in the rainy season. Opportunities exist to fill these feed-scarcity gaps through improved planning and management and the development of feed markets to increase and stabilise supply.

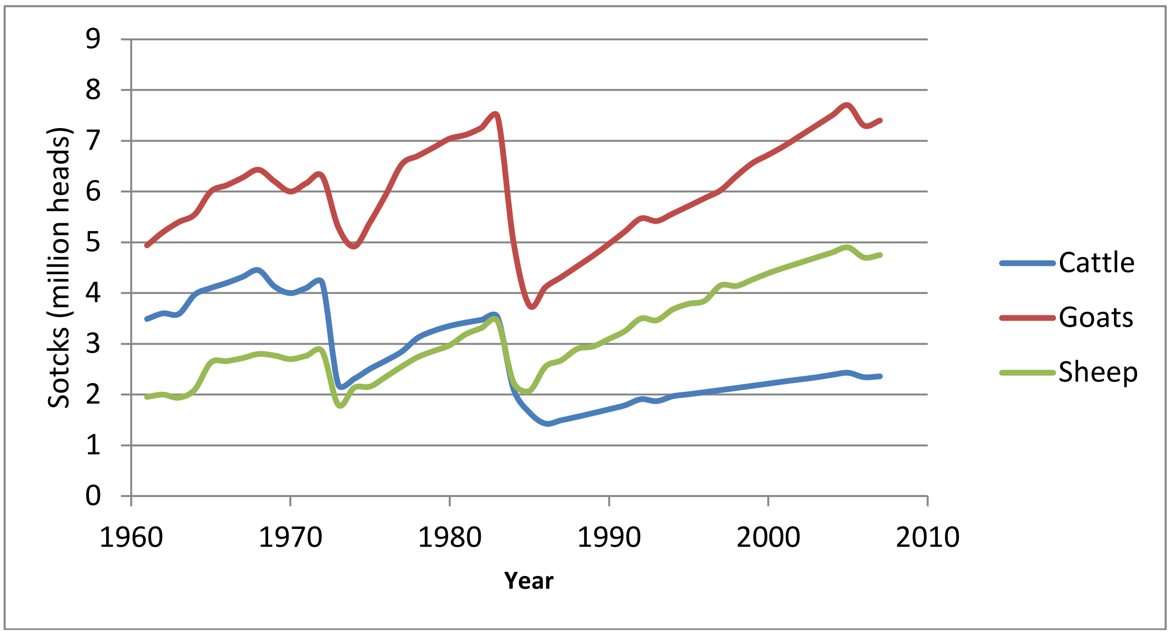


Figure 7.1: Livestock demographic trends in Niger (source : FAO stats)

Southern Africa In southern Africa maize is the main staple food crop, often grown with a legume, generally groundnuts. The dominant livestock are cattle, which are commonly used for traction, and small ruminants. Goats are particularly important for the more resource-poor smallholders, some 21 million of whom are estimated to keep them in the region (Staal et al, 2009; **Table 8.1)**. Sheep are more often kept by ranchers than by resource-poor farmers. This distinction (between small scale goat raising and sheep ranching) typifies southern Africa's agricultural economy which is characterized by two production systems: large-scale commercial and small-scale semi-subsistence farming. The former is well developed in Namibia, South Africa and Zimbabwe, whereas the latter – sometimes termed the communal sector – equates to the smallholder crop-livestock systems of West and Eastern Africa.

The productivity and offtake (for meat) of smallholder systems of SR production remain low in most of the region, though there is large variability. Namibia and South Africa have well-

developed goat markets and export within the Southern African Development Community (SADC) region, whereas markets in Mozambique or Zimbabwe are largely undeveloped (van Rooyen, 2007). Although smallholders dominate the production of goats, there is some stratification, where smallholders produce young animals that are sold to close-to-market feedlots in, e.g., the E Cape and Natal regions of South Africa and in Namibia and Botswana. However, generally poor nutrition and poor husbandry methods result in low reproduction rates, high mortality rates (particularly pre-weaning) and low off-take (Staal et al, 2009; **Table 8.1**). The large majority of goats are indigenous. For example, in the eastern and central areas of Zimbabwe the population is mainly the smaller East African type while in the south and west of the country the larger Matabele type dominates (van Rooyen and Homann, 2008).

Goats are particularly suited to the semi-arid areas due to their ability to adapt to harsh climatic conditions including drought (van Rooyen and Holmann, 2008). Within these areas of natural vegetation grazing, flock sizes vary, management is minimal and degradation of the fragile natural resource base occurs. In the areas with higher agro-ecological potential and, therefore, more reliable cropping, flock size tends to be smaller (fewer than 12 goats) and they are managed to reduce damage to crops. They receive few inputs beyond family labour, which generally has low opportunity cost. In both the agro-pastoralist/extensive crop-livestock systems and in the more intensive crop-livestock systems, the main factors limiting goat production are linked to the interaction of seasonal under-nutrition, poor heath and un-selective breeding, yet there is good potential for significant gains in production and in productivity (Staal et al, 2009; **Table 7.1**).

West Africa	**Southern Africa**
Growth and Market Opportunities	
Domestic market: 1.1 % annual consumption growth rate, with possible increase with future rising incomes. Import substitution: 2.1 % imports of domestic production.	Domestic market: - minus (-) 3.1 % annual consumption growth rate (FAO), probably due to negative economic growth in Zimbabwe and rising prices Import substitution: 16.1 % imports of domestic production, offering some scope for import substitution
Socio-economic characteristics	
Pro-Poor Potential Poor keeping small ruminants: 81.6 million with local goats, 110000 with dairy goats, 21.3 million with sheep. Annual value of meat and dairy production: US $ 970 million from all small ruminants (goat & sheep, meat & milk) Number poor under $1US per day: 130 million Opportunities and challenges	Pro-Poor Potential Poor keeping small ruminants: estimates 21.2 million with goats and 7.1 million with sheep Annual value of small ruminant production: $ 132 million from goats, and $ 262 million from sheep. Number poor under $1 per day. 40 million Opportunities and challenges

• Increasing stratification through close-to-market feedlots, • Key opportunity for women – particularly in situations where men migrate for labour. Working models of this may be hard to find • The potential may be mostly local market, so marketing issues may be easier. However, growth may be mostly in urban areas.	• Goats are particularly important for the poor, some 21 million of whom are estimated to keep them in the region. • Smallholders dominate the production of goats, with in some cases increasing stratification, with smallholders producing young animals that are sold to close-to-market feedlot, e.g. E Cape and Natal, Namibia and perhaps Botswana. • Key opportunity for women as male family members who migrate for wage labour opportunities. • Low cost local crop by-products and natural forage, and family labour, as well as public land.
Supply Constraints	
Genetics: Lack of improved indigenous sires Animal health: PPR a threat and high pre-weaning mortality due to disease-nutrition interactions Nutrition: Under-nutrition of breeding females.	Genetics: Lack of improved indigenous sires, and systems to supply them. Animal health: PPR, and pre-weaning mortality, due to nutrition interaction and PPR threat. Nutrition: Under-nutrition of breeding females.
Market/Institutional constraints: Inefficient output marketing and absence of input services	Market/Institutional constraints: Inefficient output markets, with high dependency on itinerant trades and poor access to services.
Potential Interventions	
Potential productivity gains: US$ 15/ anim. With highest yields from indigenous goats are seen on institutional farms in the semi-arid regions (>20 kg). Interventions • Production interventions: - organize marketing to meet seasonal demand (control breeding to meet seasonal demand) - focus on prevention of PPR - strategic feeding - reduce mortality • Targeting finishing/fattening at peak periods, Eids etc,	Potential productivity gains: Evidence from observed weaning weights in mixed systems suggests productivity gaps of 250 to 300%. Interventions • Reducing mortalities of young animals and increasing weight gain, through strategic feeding combined with targeted animal health interventions to overcome seasonality constraints. • Organizing marketing through farmer-managed associations or farmer clusters to overcome the transactions costs associated with spot markets, and to provide a vehicle for health/feed improvements; • Exploring new market opportunities for fiber (mohair and wool), linked to industries in South Africa, including market information systems
Relative Potential Gains from Interventions Existing technology: improved genetics: 20%; health: 25%; nutrition: 30% , Improved market access: 20%	Relative potential gains from interventions Existing technology: Improved genetics: 30% (although longer term); health: 20%; nutrition: 25%

Good delivery of inputs: 15%	Improved markets/institutions: 20% Good delivery of inputs: 15%

Table 7.1: Small ruminant meat value-chain in West and Southern Africa: growth and market opportunities; pro-poor potential; supply constraints and potential interventions (Staal et al, 2009)

Current and projected feeding systems, feed types and their sources

West Africa Field surveys from recent projects and the authors extensive experience in the region provide the estimates of the proportion of feed by source and type used currently (2010) and projected to 2030 for households in the various systems: pastoral; agro-pastoral/extensive crop-small ruminants; intensive crop-small ruminants; and, urban/peri-urban.

For the **pastoral systems** it is estimated that natural grazing (with browse being especially important for small ruminants) contributes currently about 80% of feed DM and that crop residues and small quantities of crop by-products constitute the balance (**Appendix 8.1**). It is projected that by 2030 there will be no major changes in feeding practices but that crop by-products and other by-products will increase in importance (from 1% to 6%) and that the proportion from natural grazing will reduce. Communal grazing and the interaction of the pastoral flocks with areas having agro-pastoral and crop-livestock systems will remain the norm. However, if market demand for small ruminant meat increases as expected, then the population that depends on these feed resources could well change from a mixed age/sex flock to one in which breeding and young females and lambs/kids under two-years-of-age dominate, i.e. young males and cull/surplus females would be sold for growing, finishing and slaughter to areas with a less seasonal feed base. This change would have significant implications for the management of feed resources.

A similar pattern is projected for the **agro-pastoral and extensive crop-small ruminant systems** in which it is estimated that currently three-quarters of the DM comes from communal grazing and communally-grazed and own-land crop residues and another 10% purchased from the market (**Appendix 8.2**). By 2030 it is expected that the market share will increase to nearly a quarter of all DM and the more nutrient-rich feeds will contribute more to the annual feed consumption. These trends in changing feed sources and types are similar in the **intensive crop-livestock systems (Table 7.2)**: communal natural grazing is estimated to provide currently 45% of annual DM and it is expected to drop to only 30% by 2030 as competition from cropping increases, other feed sources become available and the structure of the SR flock in the system shifts towards growing and finishing. Pressure on own crop residues will reduce their proportional contribution and more will be purchased along with nutrient-rich feeds such as by-products and even some balanced/compound concentrates (**Table 7.2**). By 2030, therefore, in these intensive crop-livestock systems it is anticipated that nearly a quarter of the DM fed to small ruminants will come from the market. In contrast to the current mixed age/sex SR flocks in the pastoral and agro-

pastoral/extensive crop-livestock systems, the **peri-urban and urban flocks** comprise mainly growing and finishing animals. Their current feed sources comprise, mainly feeds purchased from the market (including crop residues) and limited communal grazing (an estimated 10% of DM), complemented by small quantities of by-products from the producer household (**Table 7.2**). By 2030 it is expected that the feed from communal sources will decrease and that feeds purchased from the market will increase in nutrient density with more crop and other by-products, limited quantities of roots, tubers and grains but more balanced/compound concentrates (**Table 7.2**).

Therefore, during the next 20 years, it is expected that households producing meat from small ruminants in West Africa will respond to human and livestock population pressure on grazing and cropping land and to growing market demand by increasingly stratifying production of the breeding, growing and finishing phases of the production cycle. This will increase profitability and productivity by better matching the seasonal quantity and quality of feed to the requirements of the region's flock. It will also dictate that more feed is sourced from the market and less from communal areas and the producer's own land.

Opportunities for improving feed resources: To explore the possibilities for improving feed resources and their utilization for small ruminant meat production in the W Africa value chain in the context of the scenarios described above, the analytical framework and its tabular format presented in C**hapter 4 (Table 4.1)** were applied to generate four tables produced, one for each system (intensifying, crop livestock, pastoral and per- urban: **Appendix 8.3 to 8.6**).

Feed investment opportunities: Based upon the results of this assessment, improving feed resources for SR meat production had much in common with the challenges facing the beef value chain in the West African region (**Chapter 6**). This was an unsurprising conclusion given the shared feed resource base and the similar feeding practices which they utilize, mainly, communal grazing, crop residues and crop by-products, except for the SR peri-urban/urban systems with their greater dependence on more nutrient-dense feeds. This is also likely to imply greater reliance on the private feed sector, which is presently nascent in the region. An informal, key informant survey of feed sector players (**Box 7.1**) highlighted some of the present and emerging challenges in this respect. A priority intervention for SR meat production will be improving the principal food-feed crops of the region and making readily available the higher-yielding varieties and other inputs. Improving crop varieties and husbandry practices will **produce more** feed on households' own cropped land and increase the availability of crop residues for grazing by the household's own flock or communally (**Import)**. The breeding and dissemination of improved dual-purpose cowpea varieties in W Africa and their benefits to SR production is a promising example of a successful intervention applying these principles (Tarawali et al., 2005), although its long term sustainability and the potential for up-scaling still has to be demonstrated. To build upon this

success, policy and institutional interventions will be required to overcome barriers to the delivery of multi-dimensional improvement of the major staple grains and legumes and to secure effective community-based strategies for managing land and water resources, to reduce conflicts over grazing and cropping rights and to have in place secure contracts for grazing.

Southern Africa_ The framework has been applied also to estimate proportion of feed by source and type used currently (2010) and projected to 2030 for households in the agro-pastoral/extensive crop-small ruminant and the intensive crop-small ruminant systems of southern Africa. The results are presented in **Tables 7.2**.

For the **agro-pastoral/extensive crop-small ruminant systems** it was estimated that 80% of current feed for SRs is communal natural grazing (including browse, especially for goats). Own-farm natural grazing provided another 5 percent units and own-farm crop residues 14%. The balance, 1%, was own-farm produced (mainly spoilt) grain (**Table 7.2**). By 2030, given the expected increase in human population density and the likelihood of less reliable cropping because of the effects of climate change (Jones and Thornton, 2009), it is expected that crop residues will provide 20% of annual DM and planted forages, e.g. shrub/tree forage, 5%. With these extensive areas better linked to markets by 2030, it is projected that purchased concentrates and a little more grain will, together, form nearly 10% of the annual feed DM. Notwithstanding these changes communal natural grazing is still expected to provide approximately two-thirds of all feed DM. Therefore, the management of these communal grazing resources will be critical to the improvement of the feeding of SR and efforts to increase animal production and productivity.

In the areas with relatively intensive crop-livestock systems, rainfall and its distribution, and, therefore, yields of grain and of residues from crops are more reliable and human population densities are higher. Therefore, relative to the extensive systems, natural grazing is much more limited and, consequently, feeds sourced from own-farm crops currently provide most, over 70%, of the annual feed DM for SRs (**Table 7.2**). It was estimated that the balance is sourced mainly from communal, and the remainder from own-farm natural grazing. Some crop residues and by-products are bought from the market.

West Africa SR meat intensive[1] crop–livestock system[2]								
Type of feed	**Est. share (%) of annual flock feed***							
	Own farm		**Community**		**Market**		**Total**	
	2010	2030	2010	**2030**	2010	2030	2010	**2030**
Natural grazing	0	0	45	30	0	0	**45**	**30**
Planted forages	0	0	0	0	0	1	**0**	**1**
Crop residues	25	22	25	22	0	12	**50**	**56**
Crop by-products	2.5	3	0	0	1.5	3	**4**	**6**

Other by-products	0	0	0	0	1	6.5	**1**	**6.5**
Grains								
Roots & tubers								
Mineral/vit suppls	0	0	0	0	0(trace)	0(trace)	**0(trace)**	**0(trace)**
Balanced concs	0	0	0	0	0	0.5	**0**	**0.5**
TOTAL	**27.5**	**25**	**70**	**52**	**2.5**	**23**	**100**	**100**
West Africa SR meat – Peri-urban/urban								
Type of feed	**Own farm**		**Community**		**Market**		**Total**	
	2010	2030	2010	**2030**	2010	2030	2010	**2030**
Natural grazing	0	0	10	5	10	5	**20**	**10**
Planted forages	0	0	0	0	4	4	**4**	**4**
Crop residues	0	0	0	0	39	30	**39**	**30**
Crop by-products	5	5	0	0	15	20	**20**	**25**
Other by-products	0	0	0	0	10	17	**10**	**17**
Grains	0	0	0	0	1	2	**1**	**2**
Roots & tubers	0.5	0	0	0	0.5	2	**1**	**2**
Mineral/vit suppls	0	0	0	0	0	0	**0**	**0**
Balanced concs	0	0	0	0	5	10	**5**	**10**
TOTAL	**5.5**	**52**	**10**	**5**	**84.5**	**90**	**100**	**100**
Southern Africa Agro-pastoralist/ extensive crop–SR meat system								
Type of feed	**Own farm**		**Community**		**Market**		**Total**	
	2010	2030	2010	**2030**	2010	2030	2010	**2030**
Natural grazing	5	3	80	64	-	-	**80**	**67**
Planted forages	-	5	-	-	-	-		**5**
Crop residues	14	20	-	-	-	-	**20**	**20**
Crop by-products	-	-	-	-	-	-		**-**
Other by-products	-	-	-	-	-	-		**-**
Grains	1	3	-	-	-	-		**3**
Roots and Tubers	-		-					
Mineral/vit suppls								
Balanced concs	-		-	-	-	5		**5**
TOTAL	**20**	31	**80**	**64**	**0**	**5**	**100**	**100**
	Southern Africa intensive crop–SR meat system							
	2010	**2030**	**2010**	**2030**	**2010**	**2030**	**2010**	**2030**

Natural grazing	7	10	21	10	10	-	**28**	**20**
Planted forages	1	3	-	-	3	2	**1**	**5**
Crop residues	50	40	-	-	40	12	**60**	**52**
Crop by-products	8	8	-	-	8	4	**8**	**12**
Other by-products	-	-	-	-	-	5	**2**	**5**
Grains	1	2	-	-	2	-	**1**	**2**
Roots and Tubers	-	2	-	-	2	1	**-**	**3**
Mineral/vit suppls	-	-		-	-	-	**-**	**-**
Balanced concs	**-**	-	-	-	-	1	**-**	**1**
TOTAL	**67**	**65**	**21**	**10**	**65**	**25**	**100**	**100**

Table 7.2: Estimates of the proportion of feed by source and type used currently (2010) and projected to 2030 by intensive crop, peri-urban and urban households keeping small ruminants in West Africa and by agro-pastoralist/extensive crop-small ruminant and intensive crop small ruminants households in southern Africa.

Box 7.1. Summary of informal key informant interviews with feed sector players in West Africa

Physical Infrastructure
Poor power supply and bad roads were negatively affecting the majority of the businesses. most respondents listed energy supply as a major concern with the high price of diesel to run generators during power outage driving up production and supply costs. Two of the respondents not listing power as a negative issue were fodder dealers who sold in open markets. Bad roads, telecommunications, and water supply were other issues.

Policies affecting Feeds and Feed Ingredients
Only a minority (25%) of respondents felt that there were government policies on feed and feed ingredients that were adversely affecting their business. This minority did not fall into any one category of business type. Within this group the majority of concerns cited were related to rules on importation of ingredients. Concerns expressed included high import duties and taxation and cumbersome and time-consuming processes for importation. A few respondents expressed the need for improved clarity of role and enforcement by regulatory agencies.

Policies on Food and Feed Quality
Many respondents were unaware whether feed regulations existed. For those that were, comments indicated that feed standards were being applied only to large scale compounders and suggestions were made that smaller feed industry businesses should also be inspected. Inadequate enforcement of standards was also highlighted, with issues of capacity, analysis facilities and connections between various agencies identified as potential issues to address.

Technical Innovations and Knowledge Services
Advisory services were generally limited, with few making use of these. In general those that do exist are focused on the poultry sector. The need for appropriate analytical support was again emphasized.

Other Important Issues Related to Livestock Feeding
Fluctuating prices and unpredictable supply of grains, storage facilities and irregular policies were cited as opportunities to improve the sector, along with the infrastructure and regulatory issues highlighted above.

Opportunities for improving feed resources and priorities for public investments

Southern Africa By 2030 it is projected that increasing human population density and crop expansion will further restrict communal grazing, halving its proportional contribution to annual DM. Consequently more feed – planted forage, crop residues and by-products and other more nutrient-dense feeds – will be bought from the market, such that a quarter of annual DM will be purchased (**Table 7.2**). These projections of intensification of land use and feeding practices assume sustained increases in demand for SR meat, better access to and utilization of markets (for both inputs and outputs) and some incentives to improve carcass quality.

Based upon the results of these expert consultations (see two tables in **Appendix 9**), improving feed resources for SR meat production in southern Africa has much in common with the challenges facing the equivalent SR value chains in West Africa. The two regions share similar feed resource bases (not least because of similar agroecologies) and feeding practices which utilize, mainly, communal grazing, crop residues and crop by-products, with the balance between these components within annual feed DM determined by agro-ecological potential and human population pressure. These set the extent of cropping relative to the area of communal grazing. One apparent difference between the two regions is that, at least in the short- and medium-term, intensification of these crop-ruminant livestock systems in southern Africa will be more severely affected by the impacts of climate change and the labour constraints resulting from AIDS-related deaths and rural-urban migration. Uncertainty of crop yields and labour scarcity are likely to favour perennial forage sources, such as MPTs (multi-purpose trees and shrubs) over annual crops. Nevertheless the improvement of food-feed crops should remain a priority focus for increasing food and feed security allied with programmes to enhance the harvesting of rain water and to improve the efficiency of its utilization.

To improve SR productivity, basic animal health, nutrition and housing initiatives are needed to reduce mortality rates, particularly pre-weaning (Sikosana, 2008). Husbandry improvements will help build flocks and generate surplus stock for sale, provided effective markets encourage farmers to invest in improved management. In northern Mozambique and Malawi improved feeding practices based on legume hay supplements are overcoming poor nutrition (Siboniso Moyo, personal communication, 2010), initiatives that require extending throughout the year because of the intensity of cropping in the wet season and the poor quality of feed resources in the dry season. Sikosana (2008) stresses that linking extension and input delivery more directly with marketing strategies will improve production and create better prices for farmers. Few countries in the region have a grading system for slaughter goats which may serve as an incentive for farmers and feedlot developers to invest in finishing. These inter-related elements of input and output marketing resonate with the

calls for investments in business development services to support the dairy chains for smallholder dairy producers in East Africa and S. Asia (**Appendix 4**; **chapter 5**). Given the importance of women in SR, and particularly goat, production, the services need to give special attention to ensuring appropriate gender balanced strategies.

Table 7.3 captures the various inter-related policy, knowledge and service provision and technology interventions that are required to develop and sustain the momentum for market-oriented improvements in the SR value chain.

Policies	Knowledge and service provision	Technologies
• Ensuring adequate major and rural-access roads and water and telecommunications networks • Supporting effective community-based governance of natural resources: o Land tenure (customary and national) o Grazing and water management • Supporting business development services (BDS) • Facilitating public-private consortia for breeding food-feed and forage crops • Ensuring effective governance of water and feed qualities • Supporting livelihood options for pastoral and agro-pastoral communities including through ecosystem service payments • Supporting agricultural lending policies by private banking institutions	Developing BDS to deliver: 1. Knowledge services - Market information: feeds - Food-feed crop varieties - Forages - Seed/planting materials - Processing fodders - Feed storage - Balancing rations - Vet. advice - Breeding advice - Flock management 2. Physical inputs - Planting materials - Concentrates/supplements - Vaccines and vet drugs - Proven breeding stock 3. Credit	• Improved crop and animal husbandry • Food-feed crop improvement • Perennial forages • High-yielding forages • Improved animal husbandry • Water harvesting to produce and utilize feed • Processing crop residues and forages • Better feed storage • Balancing rations to improve SR productivity

Table 7.3: Priority feed-related investments to support pro-poor development of small ruminant production in West and Southern Africa

As the purchasing of feed (crop residues as well as more nutrient-rich feeds) is becoming more common, improving access to market information and how feeds are marketed will support the production and productivity of SR meat and improve the market value of breeding and finishing stock, consistent with the issues highlighted for beef production (**Table 6.4; Table 7.3**). Similarly, interventions to improve the utilization of feeds and reducing seasonal scarcities will be required through, for example, improving storage and processing and the balancing and targeting of rations (**Utilize better; Table 7.3**).

In common with the diagnoses for smallholder dairy and beef production (**Chapters 5 to 6**), SR producers will require an improved knowledge base (education and access to services) built through institutional capacity building and the BDS (business development service) model with private sector participation and public-private partnerships (**Table 7.3**). The "hub" model currently being tested in East Africa (**Appendix 4**) is suggested as a good option to be explored. An important element of the service delivery will be recognizing and supporting the potential advantages for feed utilization and profitability arising from stratification of the key stages of the SR production life-cycle. The functioning of such hubs

is likely to differ from those currently being used for dairy in East Africa and they may also have functions in mitigating the potential for compromising soil fertility (Tarawali et al., 2011). For Southern Africa, critical for the successful implementation of the interventions will be the issue of weak institutional capacity. In common with the other SSA regions, national agricultural R&D programs in southern Africa have had little or no staff recruitment for some 20 years resulting in the lack of appropriately trained personnel (Mozambique is a prime example). Staff productivity is further challenged by the significant lack of linkages amongst research and development activities.

In summary, therefore, the principal feed-related investment opportunities to support poverty alleviation through more productive and profitable SR meat production in the complex of systems in West and Southern Africa are:

1. Developing community-based strategies and land tenure systems to improve the management of natural resources (water, land and vegetation) for intensifying crop and SR production (West Africa especial);

2. Improving the knowledge base through institutional capacity building and developing business development services;

3. Institutionalizing multi-dimensional approaches to improving food-feed crops and improving their input markets.

As has been stressed for the dairy and beef value chains (**Chapters 5 to 6**), the inter-related nature of the proposed interventions require addressing policies, institutions, knowledge systems and technologies (**Table 7.3**). Their interactions highlight the critical importance of taking an integrated approach to investments that seek to support the continued development of market-driven SR meat production and the important role that it can play in improving the livelihoods of millions of poor West and Southern Africans, particularly women for whom SR production is often an important enterprise. Addressing feed issues in isolation will not be effective: required is an integrated approach to public investment with strong NGO and private sector partnerships to resolve the policy, knowledge and technology constraints and to deliver the inter-related components presented in **Table 7.3.** With feed development central to a comprehensive programme, the well-coordinated targeting of these key constraints would be expected to deliver pro-poor development of market-driven SR meat production in West and Southern Africa.

8. An introductory analysis of returns to investment in feed

8.1 Introduction

Following (a) the analysis of needs primarily for feed based interventions of selected animal production systems, to enhance animal productivity during a 20-year transition and defined by known drivers of change; and (b) the forms of enabling investments anticipated to enhance feed availability (quality and quantity) in the earlier chapters, the current chapter applies an investment-oriented approach to these findings. The analysis is confined to elements of the impact of the types of investment discussed elsewhere in this report with the key variables being classified as: policies; knowledge and service provision; and technologies.

Policies are interpreted here as government (local and national) activities that create an enabling environment for better production and use of livestock feed: including improving land tenure functionality through improved legal environments (policies) for managing communal rangelands; establishment of standards for feed quality and trading arrangements. Such investments are interpreted as one dimension of reducing transaction costs. This extends to overarching public investment issues such as infrastructure including rural roads, which have many uses but are also vital in feed and animal product distribution as well as facilitation actions such as capacity building and institutional support.

Knowledge and service provision refers to facilitation by government, aid-funded or private sector agencies of the means of improving the production and use of livestock feed. This includes dissemination of information and skills through training, the injection of working capital into livestock systems to facilitate feed production or purchase, and the organisation of systems (such as BDS – **Appendix 4**) for service delivery and information access. Such investments are likely to relate in changes in the rate and extent of technology uptake.

Technologies include seeds for new fodder crops (improved crop varieties with enhanced feed qualities; or forage species), feed storage and transport strategies, but also extend to new management procedures (e.g. separation of stock classes to better target diverse types of feed), new organisational forms (e.g. collective action) and new skills (primarily an investment of time). Other agents than producers are also potential investors, in specialist feed transport, processing or handling equipment, for example. These investments that primarily are expended and benefited from within an enterprise are referred to here as "private investment", although the investments may be funded by loans or grants to the investor.

The representation of these types of investment in the following analytical process is approximate and indicative, to motivate comparisons and examine issues, rather than to offer prescriptive advice on investments. The analysis is focused only on the impact of an

investment, or combinations thereof, without tracing what are undoubtedly complex impact pathways or simulating the biological and economic bases.

8.2 Background

Thus far several key themes have emerged, particularly the prominence of facilitation actions such as capacity building and institutional support, and policy change such as improving land tenure functionality to both livestock producers and those involved in a nascent feed industry. A guiding consideration has been the potential for increased animal productivity through investment in animal nutrition at the levels described above. A further recurrent theme is the need to channel investment to sets of complementary interventions, citing past experience of single-issue investments overcoming one constraint only to encounter another and thus yield no return. Yet another theme has been the prominent role played by market forces in creating and transmitting "market pull" in the sense of incentives within and beyond livestock systems as well as providing the context for concerted action, access to services, inputs, information and output markets.

To support these efforts, this chapter summarises the results of a set of scenario analyses that seek to:

1. quantify returns to investment across a range of forms and combinations of interventions; and
2. interpret those results in terms of the opportunities and constraints faced in each livestock system.

The focus here is on the returns likely to arise from investment: the magnitude of the investment (i.e. its cost) is not addressed. Further, the impacts of the investment are expressed in terms of indicators of livestock- and feed-related costs and benefits; these invite questions in terms of endogeneity: does improved feed "cause" enhanced production or is improved feeding induced by livestock producers' pursuit of market returns? In the analysis that follows, these issues will be addressed only where impacts of investments are in question. The analysis ignores many details of the livestock systems and their market environments: these are described in depth in the foregoing chapters and are not required here. A consistent and robust model of the full range of livestock systems considered here is beyond the scope of this study, and of its limited resources of time and data. The analysis does not seek to model the economic or biophysical elements of the livestock systems: the input-output relationship between feeding and production is simplified to linear equations and there is no solution mechanism such as market equilibrium or household/enterprise optimisation. The need for such a model is one of the conclusions of this investment analysis exercise, and recommendations for its nature and focus are presented below.

8.3 Approach taken

Detailed description of the analytical construct, data and scenarios is provided in Annex 10. In summary, scenarios that represent the key impacts of feed-related investment are

analysed, through a number of "runs" of a spreadsheet-based analysis. The components of the analysis are:

- a representation of each livestock system considered in the foregoing chapters, including the projected transition for the period 2010-2030. This entails animal numbers disaggregated by productive animals and followers, productivity levels, feed consumption across feed types, and prices of animal products and feeds ;
- a formulated impact of investment types, primarily the formulae representing changes in some of the key variables above (e.g. an estimated increase in feed yields due to private (individual) investment in improved varieties), but also changes in extent and rate of technology uptake across the animal population of specific livestock systems (an extension or facilitation investment in knowledge and service systems) and changed policies such as might result in reduced transaction costs.
- technical assumptions, specifically about the metabolic rate (as an indicator of quality) of feed increases (production, maintenance, increases in animal numbers);
- a set of assumptions about the timing and sequencing of change, which draws on chapters 5-7 for transition in feed sources and types, while employing assumptions about the trajectory of that transition and the timing of systems' response to change. Notably, these assumptions can be changed for analytical purposes , primarily to represent the impacts of "public investment" in policy change or knowledge services;
- a constructed measure of return to feed use, which is projected over a 20 year period (2010-2030) and evaluated as Net Present Value at a discount rate of 6%. This return is simply the margin between livestock sales and feed costs, which is a proxy for profitability that is used, without loss of generality, in the absence of a consistent set of data on costs in all livestock systems.

Data for the scenarios are assembled from several sources, and are consistent with the assumptions underlying the previous chapters. These are the IMPACT model (Rosegrant et al., 2005) for patterns of increase in animal numbers, consumption of animal-sourced foods, and cropped areas; and ILRI's Sustainable Livestock Futures Team's baseline of animal numbers and production (Herrero et al., 2011), and the allocation of such data to the regions and species that define the livestock systems studied here. Technical parameters of feed nutritive value and animal productivity are drawn from expert consultations, primarily amongst the authors of this report with most direct experience of the systems.

Scenarios feature several "layers" of change, with top layers represented as a 1% change in technology related variables such as feed yield or quality, animal productivity or animal numbers. Scenarios' lower layers envisage different conditions prevailing for technology adoption and market access. These mimic the impacts of public policy related interventions (e.g. reduced transactions costs due to infrastructure investment) or investments in knowledge and services that generate public goods (institutional development, knowledge delivery systems and feed quality standards). Their impacts are represented as simple changes

in adoption, market behaviour, and price margins so as to generate measurable changes in the simplified representations of the livestock systems described above. Still lower layers address price change. All scenarios are a comparison over the period 2010-2030 at annual intervals. In common with all investment analysis, both the baseline and the investment scenarios are projections into the future: one projection is compared to another and there is no inference of comparing a known result with a projection. This feature of the analysis is employed as strength in a data-poor environment in that errors that are common to both the projections can (with care) be ignored in order to gain inference from a meaningful net result.

To the extent that the scenarios represent increases in feed availability (either in Dry Matter or in Nutritive Value), the mechanism by which this is turned into production is the product of underlying assumptions. For each livestock system, such assumptions are employed to channel feed into one of three uses:

- additional animals in total
- additional productive animals
- raised productivity of main product (milk, meat)

8.4 Results

8.4.1 Results derived from runs across all investment scenarios

The results of the "runs" are provided in the form of rankings of importance. There rankings are WITHIN livestock systems: for each system the intervention ranked 1st provides the highest return from the 1% shock associated with each intervention. A rank of 11th is assigned to the intervention generating the lowest return for that system. Detailed results of the rankings and the investment returns under different scenarios for each system are available in Annex 10

For all runs, somewhat unsurprisingly, the interventions that tend to be ranked highest are increasing the numbers of animals and increasing animal productivity. In the dairy systems, investment in additional animals yields the highest return, while in the ruminant meat systems the highest return is to animal productivity. This is an intuitively appealing result, as discussed above, as these two variables define much actual investment behavior at farm level and in primary processing. Indeed, development practitioners are often faced with livestock producers' calls for "more animals", due in part to livestock's multiple uses and in part to ignored externalities such as environmental pollution or degradation of communal grazing resources. Similarly, breeding and animal health interventions are often seen as quick fixes in development. However, in what follows "investments" in numbers of animals or increasing animal productivity will be afforded limited consideration for two main reasons:

- increasing numbers of animals is, in many systems, infeasible given the resource and environmental constraints. The analysis used here does not extend to full

representation of those constraints, but instead focuses on the returns on alternative investments. In general, the investments (and combinations of investments) needed to out-perform "more animals" are of interest here. A more pragmatic concern is that increased animal numbers is an investment that may need to be argued against in many extensive systems (see for example Blümmel et al., 2009a; 2010; Tarawali et al., 2011), and the analysis here opens up some of the required lines of argument; and
- increasing animal productivity is highly endogenous to decisions (and ultimately investments) regarding feed levels and animal numbers.

Some of the key notable outcomes and leaving aside numbers of animals and productivity are:

- For *dairy systems*, returns on feed investments tend to be influenced by the feeding regimes in force. The feed-diversified East African dairy systems rank the area in feed at 3rd (after number of animals and increased animal productivity), while the South Asian Dairy systems assign 3rd ranking to improved productivity or quality in crop residues. Although such investments in crop residues rank low (8th) for East African dairy systems, those for planted forages and cut-and-carry forage arrangements rank 4th and 5th, respectively, again as a consequence of the prevailing feed characteristics of these systems. These results are insensitive to the lower layer scenarios in runs 1-7 (knowledge services, transaction costs, and market participation). It should be noted that these investments do affect NPV (see sections below), but do so in such a way as to leave rankings unaltered.

- For more *intensive ruminant meat systems*, investments in improved crop residues, crop by-products and other by-products tend to occupy ranks 3rd-5th. For the extensive systems, 3rd rank is assigned to area in feed: particularly the predominant feed source (communal grazing). This last result needs to be interpreted with caution, as not only is little additional area likely to be available to smallholder producers due to property rights and tenure constraints, but the opportunity cost of land may mean that any additional grazing areas would be of low productivity and/or available at higher cost than is represented here. These considerations motivate the recommendations for West African intensive beef and small ruminant systems, as policy changes to land and water management systems. Policy dimensions here may also become increasingly important in the future in relation to the so-called "land grabs" (see for example Cotula and Vermeulen, 2009). The rankings assigned in this analysis of ruminant meat systems are sensitive to the lower layers of investment: essentially public investments. Accelerated adoption (modeled as increased numbers of animals benefitting from the changes) makes investment in larger numbers of animals less appealing, but favors interventions to raise quality or utilization of specific feeds, for some systems (e.g. improved food-feed crops in the West African intensive small ruminant system). This kind of result demonstrates the advantages to be gained from

combinations of interventions on one hand, and more specifically the role of extension and knowledge systems (modeled here for their adoption-acceleration impact) on the other. Both these points have been emphasized in earlier chapters.

- The apparent importance of investments to *improve the quality or yield of crop residues*, distinct from other feed types, is an important result. This indicates that feed-related investment strategies are closely tied to the development of farming systems that are either crop-livestock integrated, or are livestock systems that are closely integrated with crop based markets. These results support the foregoing analysis, both in relation to the focus of the present study on crop livestock systems in general (and related publications such as Herrero et al., 2009a; 2009b; 2010a; 2010b), as well as the importance of such investments as highlighted in the various commodity value chain assessments.

- The importance of *"trajectory"* is demonstrated in Annex 10 tables 2.2 a and b. Results from "slow" and "fast" scenarios offer inference on the urgency with which investments could or should be made. In general (comparing run 3 with run 4; and similarly run 5 with run 6), a fast trajectory (i.e. transformation early in the 20-year interval) is associated with relatively higher returns accruing to investments in selected feed types, than under a "slow" trajectory. Examination of foregoing chapters also informs this result: those feed types for which greater demand is envisaged in the future also offer high returns on investment via improvements in productivity or quality (such as crop by-products and other by-products in Southern African intensive small ruminant systems – see comparisons of runs 3 and 4, in light of the projected feed profile transition detailed in Annex 10 Table3.9.1). These initial trajectory-related results will be examined further below, with reference to individual systems and the relative urgency with which certain investments might be relevant to certain systems.

These initial results convey three important messages.

- First, the private investment may well favor more animals and more productive animals, despite biological, environmental and institutional constraints that could prevent an adequate return on such investments, or preclude the sustainability of such approaches (Blümmel et al., 2009a; 2010b; Tarawali et al., 2011). Strategies to bring about pro-poor improvements through livestock feed investments are likely to confront this preference. One target of public investment then may be to create an environment where returns from enhanced feed utilization exceed those from more and more animals. An example is the facilitation of increased off-take of animals through reduced transactions costs and organised marketing (see chapter 7 for Southern African small ruminants), with demonstrated and disseminated benefits to

producers: this will in turn require feed-related investments at farm level. Subsequent sections explore such possibilities.

- Second, increased area in feed is ranked highly in many systems across scenarios. In light of competition from other land uses this option is not generally available. Similar to the comment above on increased animal numbers, the main inference for these results is that investment strategy for feeds should aim to change the underlying structure of profitability, rather than to enable incremental change in variables that may be appropriate only at a limited number of localities.
- Third, the highest return on investments in improved productivity or quality of feeds is generally associated with crop residues, rather than feed crops or forage species. This result is encouraging for most of the ruminant meat systems studied here (e.g. intensive and agro-pastoral West African beef systems as discussed in chapter 6), crop production is a major source of household income, with crop and livestock enterprises closely intertwined. The conditions under which these investments can be promoted (both in terms of ranking assigned, and as an extension task) will be examined in subsequent analysis.

8.5 Conclusions

8.5.1 Overview

This chapter presents a preliminary quantitative analysis of feed-related investments in nine livestock systems as described in detail in the opening chapters of the report. The analysis focuses on comparing returns to investment in each system. The analysis supports the conclusions drawn from earlier chapters, in several key ways:

1. Complementarity between public (promoting institutional change and providing public services such as extension) and private (technology adoption) investments is shown to offer synergies to the extent of significantly influencing returns on technical investments. In particular:
    a. judicious public investments can be effective in this way regardless of the trajectory of change in the feed system: both fast and slow trajectories can yield the benefits of the investment;
    b. demand drivers such as feed/animal-sourced food price ratio and the competition for land can negatively affect the returns in feed investments, but these can also be offset to some extent by complementarity between public and private investment;
2. Investment returns tend to reflect the contribution of feeds to systems' performance, both currently and during transition to new feed profiles. Specific results include:
    a. fast change trajectories favour investments in feed quality and productivity ;
    b. slow change trajectories favour investments in increases in animal numbers and aggregate areas in feed;

   c. systems for which increased market-sourcing of feeds is projected are most influenced by investments that reduce transactions costs and enhance market participation.
3. The quantitative analysis has provided evidence of the mechanisms by which bundling of investments, particularly public and private investments can generate benefits in excess of the sum of the individual investments. This conclusion supports the use of innovation systems in feed development, and will be discussed further in the next chapter.
4. Business Development Services similarly offer a synergy between market development and the best use of the newly-developed markets as well as enhanced access to knowledge and services. The preliminary quantitative analysis has demonstrated the centrality of improved market function in generating benefits from investments in feeds, much as projected by the qualitative analysis.

Additional considerations, not arising from the earlier chapters' recommendations, are:

5. Simplistic analysis generates a consistent and robust preference for investments in increased animal numbers and increased animal productivity. Although intuitively appealing at a single-household level, such investments are not feasible at any level of aggregation due to resource and environmental constraints (Blümmel, 2010a; Blümmel et al., 2009a; Tarawali et al., 2011), and cause-and-effect simultaneity with other investments. A key finding, also supported by the recommendation from the qualitative analysis is that complementarity in investments, as described above, can establish the mechanisms by which fundamental change in the profitability of feed use is achieved, thus offsetting incentives for accumulation of ever greater numbers of ill-fed animals;
6. Increasing market participation is enabled by investments that influence transactions costs, and positive returns to such investments have been projected. This result confirms the qualitative statements made in earlier chapters. Credit availability is not modelled in the current analysis, but would obviously play a catalytic role in increasing market participation, which both the qualitative and quantitative analyses have shown to be a vital factor in mobilising feed for enhanced livestock incomes. Again, Business Development Services could play a key role in credit access, as could other forms of farmer organization.

8.5.2 *Recommendations for further analysis*

The type and form of investments studied here require a deeper set of analyses, leading to two recommendations for further research:

1. An accounting-based model of investment, extended to the valuation of public goods and services, and the quantification of spillovers of costs and benefits between stakeholder groups.
2. A model of livestock systems that incorporates both biophysical and economic response functions and constraint specification.

9. Enabling innovation for improved feed resources

Emerging clearly from **Chapters 5** to **7** and their analyses of feed constraints in the five priority livestock commodity value chains and the public investment opportunities that these constraints represent is the critical need for improving the knowledge base of smallholder livestock producers and their market agents through institutional capacity building and developing business development services. The key investment target for supporting improved feed resources and their utilization in these and similar value chains is, therefore, to support institutional changes underpinning this requirement. In addition, our companion study on pro-poor livestock investment opportunities (Baker et al., 2011) reports three significant influences on project success, that are relevant here. First, targeting beneficiaries at multiple points in the value chain pre-disposes to success. Second, achieving success is often not attributable to specific interventions, but rather to the package of interventions made: feed-related interventions are often associated with marketing success, for example. Third, processing of information within a project during its life is conducive to its success. This latter result is supported in case study work which identifies information sharing as a key element of success.

This tailors well with the increasing recognition by many research and development agencies that technology driven approaches alone with a "top down" dissemination paradigm simply do not work for sustained developmental outcomes and impacts. In response, a range of approaches aimed at strengthening institutional mechanisms have emerged including innovation systems (Rajalathi et al., 2008), the use of multi-stakeholder alliances (Lundy et al., 2008), work focused on identifying and facilitating involvement of boundary partners (Kristjanson et al., 2009), participatory and action research (Scoones and Thompson, 2009). In this chapter, the term "innovation systems" is used in a broad sense to capture these (**Box 9.1**), and other related approaches, which are explored in relation to the feed context of the present study.

Box 9.1 What are innovation platforms?

"Innovation platforms are networks or loose coalitions of individuals and organizations who come together to share experiences, knowledge, skills, resources and ideas with the objective of addressing problems and opportunities of mutual interest in new ways. In a developmental context, the objective would be to achieve beneficial and equitable outcomes which target poor people, including ["emphasizing" better/] women and other vulnerable groups.

In the example of an innovation platform focused on improved production and marketing of an agricultural commodity, members might include those along that commodity value chain – e.g. individual farmers, farmers' organizations, large-scale producers, women's groups, CBOs, NGOs, FBOs, local government officers, traders, transporters, processors, input and service providers, micro-financiers and insurance agents, retailers and wholesalers, agri-businesses, researchers and journalists amongst others. Innovation platforms evolve with time; members of the platform change as incentives and need for their participation change.

Innovation platforms need to be effectively facilitated. Innovation brokers, who can come from the research or development community, can play this important role. Ideally they ensure effective networking between platform members, act as conduits for knowledge, capacity building and finance, provide conflict resolution services, and negotiate deals and alliances, amongst other roles.
Innovation platforms are transitory arrangements. The success of an innovation platform should not be judged on whether or not it is sustainable. On the contrary, successful innovation platforms often evolve into different types of entity, such as farmers' organizations, cooperatives, businesses or contracted arrangements. It is, however, desirable that innovation capacity is enhanced and remains available locally so this can be galvanized and targeted to address future needs."

Source: More milk, meat and fish, for and by the poor. CGIAR Research Programme 3.7 proposal. http://livestockfish.wordpress.com

Supporting innovation systems approaches: Innovation systems approaches to enabling knowledge generation, use and innovation, facilitates collective action and knowledge exchange among the diverse actors, e.g. smallholders, landless livestock keepers, input and output market agents (public and private), research and development agents who engage in livestock commodity value chains (World Bank, 2006; Rajalahti, 2009). Innovation systems include the incentives and resources available for collaboration and having in place the conditions that enable adoption and innovation. Consequently such approaches are attracting considerable interest from both the development and research communities aimed at improving the efficacy of research and development investments. The box describes innovation platforms in a value chain context.

Field examples: Two ILRI supported projects, recently completed, their backgrounds, and the lessons that have been learnt so far, are summarised here.

The *Fodder Innovation Project* www.fodderinnovation.org, funded by DFID and implemented by ILRI, was designed to address the challenge of fodder scarcity in mixed crop-livestock systems in India and Nigeria, through nurturing networks to build innovation capacity within crop-livestock systems. In the two countries the project was operational in five sites representing diverse agro-ecologies and livestock systems at different stages of intensification. The project started out being technology-driven in its first phase, but evolved to be much more process-driven, building capacities of local rural systems to assess constraints, identify entry points and test innovative interventions to address fodder scarcity challenges. The project worked with a range of Key Partner Organizations (KPOs) including government, NGO and semi-government groups who brokered the formation of innovation networks. These KPOs jointly with their network members identified themes for action-research and to focus the efforts of network members. Often these themes were broader than just fodder and related to the broader value chain context. Based on the themes selected, context-specific feed-related interventions were identified, along with others

spanning areas of breeding, feeding, animal health, access to markets, institutional arrangements and, capacity building in all the sites, highlighting the fact that addressing fodder alone in such interventions will not be effective and that one needs to look at the value chains. Based on priorities of network members, feasible entry points were identified to kick-start the action and generate some quick wins which would keep them motivated and demonstrate the utility of the network. Different innovation trajectories evolved as a result and different outcomes, too. The immediate livestock- and fodder-related outcomes have been mainly in the form of:

a) improved access to fodder – from common-property resources like grazing reserves and forests; from enhanced use of dual-purpose (food-feed) crops; increased production of crop residues due to enhanced fertilizer use; and, through use of improved varieties of forage and food-feed crop seeds;
b) organization of communities to build social capital and access services and inputs more efficiently;
c) enhanced capacities of various actors, especially poor and women livestock keepers;
d) enhanced access to markets through the networks created;
e) enhanced access to services – veterinary services, agro-inputs like fertilizers and chemicals, veterinary drugs and vaccines, credit, knowledge through extension services and linkages with other actors like marketers and dairy co-operatives, etc.

In addition, institutional outcomes have been evident, which include:

a) more efficient service delivery systems;
b) changing collaborative habits and practices of actors;
c) changing institutional arrangements to make additional fodder available to women and landless, poor livestock-keeping households;
d) evidence of demand being generated for fodder- , breed- and other livestock-related knowledge and technologies; and,
e) the KPOs institutionalizing/mainstreaming the approach in their other activities/ across the organization.

The '*Fodder Adoption Project*' was funded by IFAD and implemented by ILRI with CIAT and ICARDA in Ethiopia, Syria and Vietnam http://fodder-adoption-project.wikispaces.com. Research here included developing coalitions of actors involved in the livestock sector in learning sites across the three countries to address feed scarcity. The form of these coalitions differed by country: in Vietnam, for example, formal stakeholder platforms were never established but stakeholders joined specific activities depending on need. In Ethiopia, stakeholder platforms were used more consciously to facilitate joint learning and joint action. In both cases, introduction of fodder options was used as a catalyst for arousing interest of local stakeholders and as an entry point for livestock development in relation to specific commodity value chains, in this instance beef in Vietnam and dairy in Ethiopia. Again, in both cases, planted fodder options were the starting point but the issues addressed by stakeholder groups broadened to include a wider set of issues. In Vietnam, organizational

innovations emerged that involved arrangements for small-scale cattle trading. In Ethiopia, fodder technologies gave way to discussion on arrangements for milk marketing and provision of improved animal genetic material to upgrade livestock productivity (Ergano et al.,2010).

The use of stakeholder coalitions to address livestock development issues has shown some promise across the project countries. However, experience shows that facilitating such platforms can be challenging and demanding of resources http://fodder-adoption-project.wikispaces.com; Duncan et al., 2009). Furthermore, such platforms were much more likely to have positive benefits in areas where market access for livestock products was high and where a wide range of stakeholders was already active. While the use of innovation system approaches has proved useful for diagnosing weak points in the innovation system, finding ways of transforming entrenched institutions is a much bigger challenge. Further research should examine incentives and disincentives in government line departments for working with a range of external stakeholders including piloting of new incentive and reward mechanisms.

In a separate study, positive deviance approaches were used to study farmers in four different agro-ecological niches in Ethiopia with the aim of unravelling processes, factors and conditions underlying the observed pockets of success in forage technology adoption. The study (Kiggundu and Mengistu, 2009) found that pockets of success (meaning where feed technologies were being successfully used) were mostly in intensifying crop-livestock systems and, pockets of successful users tend to be highly concentrated in a few locations around different forms of infrastructure and urban centers. The feed technologies appear to have the greatest likelihood of being used productively either because of geographical suitability, ecological imperatives, sense of urgency (pressure of intensification), potential for tapping into livestock value chains or good history of risk-taking and associated local capability in the area. The positive deviance was attributed to the interplay of factors and ways of working that were generally not well addressed in typical feed technology transfer arrangements. Facilitating factors included:

a) improved incentive regimes for local actors;
b) functional partnerships with early adopters;
c) destocking of less productive breeds and pro-active efforts to provide access to improved breeds;
d) improved ways of managing feed;
e) improved smallholder organization for joint action; and
f) an improved enabling environment and support system at the local level.

It is noteworthy that the lists above resonate well with many of the issues highlighted in the foregoing chapters as crucial underpinnings of investment portfolios in the regional livestock commodity value chains.

Policies and investments: Translating the principles of innovation systems into practice requires policies and investments that create an enabling environment to support the actors and networks involved and, the brokering/boundary spanning organizations. Such an environment should allow flexible management during implementation to deal with emerging challenges and opportunities and spaces for reflective learning. The accompanying study on pro-poor livestock investments (Baker et al., 2011) has revealed the importance of functioning markets as part of the enabling environment. Other essential elements to be considered in project- or programme-based funding for creating such an enabling environment are as follows:

Implementation time-line*	POLICIES (local, regional, national)	INVESTMENT IN DEVELOPMENT
Short term (up to 5 Years)	-**Understanding** local-level incentive systems and institutional arrangements and designing and testing more effective alternatives	- **Mapping** of crop-livestock value chains and corresponding innovation systems; - **Identify** missing actors and functions and invest in their development with a special focus on private sector and Livestock Advisory Services - **Identify** appropriate organizations/ actors who can play the brokering/ network facilitation function (based on social capital, legitimacy and credibility they bring) and invest in their capacity building
Medium term (up to 10 years)	- **Policies** and implementation strategies to enhance innovation capacity in the livestock sector – linkages or co-ordination amongst different departments and actors, especially private sector - **Institutionalize** boundary spanning function in appropriate organizations (context specific) with systems for continuous capacity development - **Changes** in performance evaluation and incentive systems to support change in behaviours and new ways of working -**Develop** project management systems	-**Develop** effective service delivery systems with a special focus on knowledge and capacity building - **Develop** national small-scale enterprise bodies to provide business development support for small-scale rural

	that can be flexible and nimble to respond to emerging opportunities and challenges and, avoid tendencies to follow blueprint approaches while scaling up and out - **Provide** an enabling environment for a more vibrant private-sector entrepreneurs.	
Long term (up to 20 years)	-**Provision** of an overall enabling environment and infrastructure	-**Develop** and maintain infrastructure and effective and efficient pluralistic service delivery systems

*time-line assumes a zero baseline, which is rarely the case.

Research/knowledge gaps: Facilitating stakeholder platforms and building innovation capacities is time-consuming and monitoring the processes and the changes is not a trivial task. It is often difficult to demonstrate change, especially where this is dependent on complex processes and interactions among diverse organizations and the coming together of individuals. In addition, outcomes and impacts cannot be pre-determined or predicted precisely. Furthermore there is a geographical disconnect between interventions and impact (which can be quite diffuse) and, outcomes are not necessarily linear. The fact that innovation system approaches aim at changes in habits, practices and behaviours, which do not lend themselves to quantification, complicates this issue. As the Fodder Innovation and Adoption projects have demonstrated, technical changes and institutional and organizational changes reinforce each other, hopefully leading to livestock system upgrades that will result in livelihood impacts. It is difficult to draw causal links in such complex adaptive systems and to attribute specific changes to specific interventions. Existing impact assessment frameworks and methodologies are inadequate to demonstrate the impacts and proof of concepts, and we need to invest in developing and testing more appropriate ones.

While identifying weaknesses in the innovation system is relatively straightforward, finding ways of altering entrenched habits and practices of organizations, especially those in the public sector, is more difficult. The accompanying study on pro-poor livestock investment opportunities (Baker et al., 2011) has also highlighted the importance of transfer of project information: converting M&E into project management data in real time, and using extension services for topics beyond technical production. That study's case study material identifies the frequent disparities between the views and perceptions of different stakeholders, while documenting their universal support of participatory project design and management. Notably, research elements in projects are particularly enabling of market-related outcomes, possibly because of a congruence of research results with the needs of market actors: the needs of public organizations are different, and usage s on a different time schedule. Adjusting incentive structures and overcoming bureaucracy to allow public

organizations to be more nimble and responsive could pay dividends in terms of allowing innovation to happen, but further research on the sorts of arrangements that might work is needed.

It is in this context of the lessons learnt from major projects and the ongoing process of institutional change within international and national research and development systems and their partnerships, the priority investment for supporting improved feed resources and their utilization should be through efforts to embed innovation systems approaches within the development and research processes.

10. Conclusions

The study described in this report identified five livestock commodity value chains in which certain types of investment have exceptionally high potential to raise the productivity of smallholders and reduce poverty. These five value chains were further divided into nine subsystems, and assessed using a framework that was applied to a variety of scenarios. The findings suggest that purposeful investment in the development of feed markets in these areas is likely to enable very large numbers of smallholders to participate in these value chains.

Perhaps unsurprisingly, applying the assessment framework to the different value chains led to similar results and pointed to similar sets of issues. Some of the nuances that differentiated the respective value chains related to the intensity of the production base. For example, when beef and small ruminant value chains in West Africa were sourced with feed from more extensive supply systems, issues related to common property resources and their management tended to be more prominent. These issues were far less prominent in more intensive systems, in which market access and business development were more important. The quantitative assessments of scenarios in each of the value chains pointed to important investment options in each. The results of the assessments are also useful in prioritizing these somewhat lengthy and undifferentiated listings.

The overall results of the study suggest a number of issues that need to be assigned priority when targeting investments aimed at increasing the availability of feed to smallholders. These can be summarised as follows.

- Addressing feed related issues in the context of evolving value chains requires combinations of public and private investments: policies, strategies that facilitate adoption and market engagement with reduced transactions costs such as improved access to knowledge and services for smallholder producers and other market agents together with adoption of improved feed technologies.
- Technological feed improving solutions, often implemented as private investments (farm/household) provide an underpinning to this intersection of policies and institutional dimensions, but are, in themselves inadequate and need to be bundled with other investments. Innovation systems approaches are important in this context.
- While increasing animal numbers is often perceived as attractive to the private investor, there are severe environmental implications, and incentives to increase per animal productivity will be important. Combining private investment in better feeding with institutional arrangements that reduce transaction costs (both to access the feeds and to participate in product markets) has the potential to provide such incentives.

- Business Development Services – interpreted in the broadest sense are a key to facilitating access to feeds, markets and for reducing transaction costs. Effective development of such mechanisms demands enabling policies, institutional capacity building (for a variety of development, extension, small scale private sector and individual actors). The potential of such services to impact on access to information, inputs, services, credit and social capital is highlighted.

The details and nuances of these issues are highlighted in the preceding chapters. Below is a summary of the major investment types according to the three interacting categories of policies, access to knowledge and services and technologies.

Policies

Public investment in appropriate policies is important especially for influencing transaction costs and providing an enabling environment, and promoting institutional change. Included here are:

- the enabling environment for business development services;
- regulations and tariff barriers for livestock products;
- development of public-private consortia to promote the development and availability of food feed crops;
- regulatory environment for feeds.
- National and local policies impacting on the governance of natural resources, land tenure, grazing and water management are especially important for systems that are transitioning from more extensive management.
- Policies enabling smallholders to benefit from payment for environmental services should be further explored.
- Agricultural credit and lending facilities and the ability of smallholders to benefit from these are likely to be impacted by the policy environment.

These same challenges of overcoming institutional and disciplinary barriers will have to be addressed through investments directed at putting in place effective governance of feed and water quality issues. These are key elements in achieving improved utilization of scarce and increasingly expensive feeds, leading to more productive livestock production (see, e.g. **Tables 5.4 and 7.5**). Again innovation systems principles will be important in engaging the key stakeholders and in motivating institution building of, e.g., national associations of millers and feed manufacturers, and watershed– and community-based associations of water users.

The other priority policy issues requiring investment that were identified included supporting effective community-based governance of natural resources issues related to customary and national land tenure and grazing management, particularly in the pastoral and agro-pastoral systems (see, e.g. **Tables 6.4** and **7.4**). A related priority was supporting livelihood options for agro-pastoral communities through ecosystem service payments. These

recommendations are consistent with and would require the actions presented in the Minding the Stock report for developing a range of property, regulatory and financial instruments in support of improved natural resource management and smallholder equity (World Bank, 2009).

Knowledge and service provision

Various institutional arrangements, loosely termed business development services, but intended to include a diversity of institutional arrangements that strengthen the capacity of various stakeholders to interact and co create solutions to feeds (Chapter 9) in the context of livestock commodity value chains are central to facilitating a positive transition of smallholder based livestock production systems. Included here is improved access to a range of knowledge products that have the potential to enhance access to better feeds (such as how to obtain seeds and planting material for food feed crops, forages), how to use and combine them (balancing local feed resources with those purchased from the market for example), and how to combine improved feeding with other productivity enhancing technologies which requires access to animal breed and health services for example. It is anticipated that functional institutional arrangements that enhance in a sustainable way such service and input access will enhance the rate and extent of uptake of feed based innovations.

An embedded innovation systems approach will serve to improve research and development processes but, as was emphasised in **Chapter 9**, to be successful it will require parallel investments in capacity building of the relevant public sector institutions and their partners. Integrated and innovative approaches to capacity building will be needed to achieve effective complementary roles and responsibilities amongst the public, NGO and private sector actors in their efforts to improve and sustain the competitiveness of market-oriented livestock production by resource-poor households. The analyses in **Chapters 5** through **7** highlighted the importance of feed-related investment in institutional capacity building and developing business development services within a value-chain approach. From their detailed analysis, Baker et al (2011) report that access to affordable and high quality inputs and services (feed, breeding, animal health, credit, transport, and market infrastructure) were key factors in the success of livestock-related development projects. They point out that the local context will dictate the relative roles and responsibilities and the investment needs of public and/or private sector actors.

In the same way, the recent Minding the Stock report (World Bank, 2009) concluded that support for institution-building, investments (on a matching-grant basis) in improvements in the value chains, training of the different stakeholders in the value chain and support to research and advisory services, are needed to bring about enhanced access to and utilization of markets, including through collective action, by resource-poor smallholders. In the present study, the elements of the investments in knowledge and service provision related to

improving the availability and utilization of feed resources were summarized for each of the priority regional commodity value-chain chapters, e.g. in **Table 5.4** for the S. Asia dairy value chain and **Table 7.4** for the small ruminant meat chain in southern Africa, which capture the commonalities and the regional specificities.

Technologies

There is no shortage of information on potential feed technologies that can impact on animal productivity (see for example the recent on line discussion: http://www.fao.org/ag/againfo/home/en/events_archive/Messages_E-conf_0910.pdf); Shelton et al. (2005), however, much of this is largely anecdotal. The present assessment has highlighted in particular the importance of feeds based on crop residues and the opportunities to enhance animal productivity from such resources such as through combinations of different crops (cereals, legumes), processing (chopping, densification) and strategic additions of other nutrients. High yielding forages, grasses in particular have some niches (such as in dairy systems in East Africa) which may be further developed using similar approaches as those for crop residues.

Given the expected development scenario to 2030 of smallholder agricultural systems, the priority for investment in a specific feed technology is clear: the large majority of resource-poor households will continue to depend on the residues and by-products of crops (mainly the food staples) as a major source of livestock feed (Herrero et al, 2009b; Parthasarathy Rao and Birthal, 2008; **chapters 5 to 7** of this report). Therefore, critical for improving and sustaining the competitiveness of production by resource-poor households in each of the priority value chains is ensuring the multi-dimensional genetic improvement of food-feed crops and improving their husbandry and their input markets.

To address the strategic challenge of how to improve the feed as well as the food yields of the major smallholder staple crops, cost-effective phenotyping to screen large entries of cultivars for relevant fodder traits has been developed (Blümmel et al., 2010a). The screening of a wide range of cultivars of rice, wheat, maize, sorghum, pearl millet, cowpea, groundnut, pigeon pea and chickpea has shown that differences of 3-5% units in digestibility can be exploited without detriment to grain yield (Blümmel et al., 2009c). Conventional and molecular breeding techniques for improving the food and feed traits simultaneously are more expensive but have higher impact potential because full genetic crop variability can be explored and utilized (Blümmel, 2010). Impact pathways for seeds from superior food-feed cultivars are short compared, e.g., to planted forage technologies (which generally demand quite decisive adoptive changes in systems), and where competitive private seed industries exist to deliver the cultivar types.

Short-term investment (up to 5 yrs implementation) should develop NARES capacity to use the phenotyping to identify cultivars for specific crop-livestock contexts and to support

innovation systems principles that would embed the research in the development context. This should include supporting an enabling environment for the private sector, particularly the seed sector and fodder market agents. In the medium term (up to 10 yrs), investment should support the development of capacity (infrastructure, networks and skills) in NARES for using molecular breeding techniques and the concomitant development of the other links in the value chain discussed earlier, market infrastructure and services - breeding, animal health, knowledge, to motivate investments in better feeding. These priority investments in institutional change to support the increased and more efficient feed production from the major staple crops by resource-poor households will require coordinated capacity building across the crop/livestock, development/ research and public/private sector divides. In many instances there is an opportunity to improve the use of local resources, and the potential of developing further the FEAST tool, (Feed Assessment Tool https://sites.google.com/a/cgxchange.org/feast) with the approach used in the present study could be further explored.

Two other related dimensions regarding feed sourcing and technology are noteworthy, but are not addressed in detail in the present report. There is a need both at a macro level, but also at regional and more local levels, to improve our understanding of the fundamental biophysical potential of feed in relation to numbers and productivity of animals. Making assumptions about animal productivity in relation to anticipated demands for livestock products without basing this on an empirical assessment of the potential of the natural resources to provide the nutritious biomass required could result in unsustainable solutions. The second dimension is that there is a need for an improved understanding of this issue in relation to the proportions of feed used for maintenance versus productivity, which also has implications regarding the focus of efforts towards improving either quantity or quality of feed. It is, important to recognize that not all of today's smallholder ruminant producers will remain so in the coming decades, a mosaic of options is likely to emerge, some of which will entail being involved in other aspects of marketing, producing feed, processing products etc. Others may leave the sector entirely (FAO, 2009) and the importance of social structures to support such a diversity of transitions needs to be emphasised.

Finally we re-emphasize the main conclusion that was reached from the analysis of the five priority commodity value chains and their feed-related constraints and opportunities and the results of the companion study on pro-poor livestock investment opportunities (Baker et al., 2011). That is, we contend that addressing feed issues in isolation will not be effective. Rather what is required is an integrated approach to public investment allied to strong public, NGO and private-sector partnerships to resolve the inter-related policy, knowledge and technology constraints and to deliver on the opportunities.

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Appendices

Appendix 1: Crop types providing livestock feed

Crop types include: (staple) grain cereals; grain legumes; leguminous forages; roots and tubers; pasture grasses; cut-and-carry grasses.

Genera that are significant sources of livestock feed include:

- **Betae**: sugar-beet; mangold; fodder beet
- **Brassicae**: turnip; swede; kale; forage and oilseed types of rape and mustard
- **Compositae**: sunflower; safflower
- **Convolvulceae**: sweet potato
- **Dioscoreaceae**: yams
- **Euphorbiaceae:** cassava
- **Gramineae**: oats; millet; sorghum; rice, wheat; teff; triticale; maize; sugarcane; temperate and tropical grasses
- **Leguminosae**: groundnut; pigeonpea; chickpea; cowpea; soybean; lentil; alfalfa; beans; peas; clovers; tropical forage legumes (including MPTs)
- **Musa**: banana
- **Palmae**: coconut; oil palm;
- **Polygonaceae**: buckwheat

In addition **various vegetables,** including potato, cabbage, pumpkin, gourd and squash, are sources of livestock feed.

Another important source of leaf fodder and seedpods are **trees**.

Appendix 2: Glossary of terms related to feed resources

Term	Definition (and source)	Alternative	
***Ad-libitum* feeding**	Continuous access to feed/s that permits livestock to satisfy their appetite for that available feed/s (WT)	Consumption by an animal of a feed or forage offered in excess of what the animal can consume (3)	Diet offered free-choice, allowing animals to eat as much as they desire; typically allows for 10% leftover from a daily allotment (5)
Agro-industrial by-products	Feeds produced during the industrial processing of plants and their seeds, e.g. brewing and distillery residues from grains and molasses from sugarcane (4)		
Balanced diet	A combination of feeds that provides the animal with the correct amount of all the different nutrients it requires to remain healthy and productive (2)		
Balanced ration	The daily food that provides all required nutrients in proper proportion for normal health, maintenance (of body weight), growth, reproduction, lactation or work (1)	A 24-hour feed allowance that provides an animal with appropriate amounts and proportions of all nutrients required for a given level of performance (5)	
Basal diet	The feed/s forming the largest component of a ration; in smallholder crop-livestock systems this is generally		

	grazed natural pasture and/or the crop residue (stover/straw) of the staple food (e.g. maize or rice) (WT)		
Bran	Coarse outer grain coating, separated during processing (5)		
Carrying capacity	The maximum stocking rate, i.e. animals per ha (or acre), that will achieve a target level of animal performance, in a specified grazing method, that can be applied over a defined period of time without deterioration of the eco-system (3)		
Compounded (or complete) feed	**T**horoughly blended mixture of different feed ingredients formulated to meet specific nutrient requirements that allows for greater efficiency in feeding and provides better control of nutrient intake. A complete feed may or may not include the roughage portion of the ration (5)		
Concentrates	Feeds (e.g. grains or their by-products) that are low in crude fibre and moisture content but high in digestible nutrients (1)	Concentrate feeds are high in energy and low in fibre (<18%). They usually contain less than 20 % protein and more total digestible nutrients, e.g. grains, brans, cakes, etc. *Grains:* cereals, millets and legumes. *By-products:*	Classification of feedstuffs high in energy and low in fibre, usually further divided into energy and protein concentrates. Often used interchangeably with supplement (e.g., corn, barley,

		wheat bran, rice bran, gram chuni, rice husks, etc. *Oil cakes:* cotton seed cake, copra cake, groundnut cake, mustard cake, linseed cake, etc. (4)	soybeans) (5)
Crop residues (from grain/cereal crops)	The dry, above-ground remains of a cereal crop after the grain has been removed/harvested (WT)	Portion of plants remaining after seed harvest; said mainly of grain crops such as maize stover or of small-grain straw or stubble (3)	
Crop residues (from root/tuber crops)	Portion of plants remaining after removal of food component, e.g. the peelings of cassava roots and the foliage of the cassava plants (modified from 3 above)		
Crop by-products	Materials produced as wastes in the preparation of human food from crops, that may be used as livestock feed (1)		
Diet	The sum of food consumed by the animal (7)		
Feed	Sources of nutrients for livestock (WT)	Materials of nutritional value fed to livestock. Each species has a normal diet composed of feeds or feedstuffs which are appropriate to its kind of alimentary tract and which are	

		economically sensible as well as being nutritious and palatable (6)	
Feed efficiency	The amount of feed required to produce a unit gain in live weight or a given quantity of eggs or milk (1)		
Fodder	Green or cured plants such as maize and sorghum, browse as small stems, leaves, flowers and fruits of shrubs, trees or woody vines (4).		
Food	Sources rich in nutrients for humans (WT)		
Forage	Edible parts of plants, other than separated grain, that can provide feed for grazing animals or that can be harvested for feeding, including browse, herbage and mast (3). *Usage:* generally the term refers to the more digestible material relative to the less digestible **roughage**.	Aerial plant material, primarily grasses and legumes, containing more than 18 per cent crude fibre on a dry matter basis (4)	Plants or plant parts fed to, or grazed by, domestic animals. Forage may be fresh, dry or ensiled (e.g., pasture, green chop, hay, haylage) (5)
Hay	Grasses and forage legumes that have been cut and dried for livestock feed (WT)	Forage preserved by field drying to moisture levels low enough to prevent microbial activity that leads to spoilage (3)	
Maintenance	The condition in which the body weight of livestock does not increase or decrease and no production or work		

	is done (1)		
Monogastrics (non-ruminants)	Organisms with a simple single-chambered stomach (whereas ruminants have a four-chambered complex stomach); pigs and poultry are monogastrics (7)		
Nutrient requirements	Minimum amounts of nutrients (energy, protein, minerals and vitamins) necessary to meet an animal's needs for maintenance, growth, reproduction, lactation or work; does not include a margin of error in ration formulation (5)		
Oilseed cakes and meals	The residual material after oil is removed from oilseeds by pressure (extrusion) or by use of a solvent (extraction). The latter removes more of the oil and the residue is a cake; a meal is produced by extrusion. Both are generally high in protein (4)		
Ration	The feed given to an animal (livestock) in 24hr, whether it is fed at one time or in portions at different times (1)	Fixed allowance of total feed for an animal for one day. Usually specifies the individual ingredients and their amounts and the amounts of the specific nutriments such as carbohydrate, fiber, individual	

		minerals and vitamins (6)	
Restricted diet	Limited access to feed/s that does not permits livestock to satisfy their appetite for the available feed/s (WT)		
Roughages	Livestock feeds that are low in digestible energy and high in fibre (such as hay, stover and straw) (1)	Bulky feeds that are low in weight per unit volume with high fibre content (>18 % crude fibre) and low in energy, e.g. straws, stovers and tree leaves (4).	Feed high in fibre (greater than 18% crude fibre); tends to be bulky, coarse and low in energy (5)
Ruminant	A sub-order of mammals having a multi-chambered stomach, the largest chamber of which is the rumen, the site of microbial fermentation; uses forages primarily as feedstuffs (3)		
Silage	A way of preserving grass or other forage/s through fermenting the grass or forages (2)	Forage conserved at low pH in a succulent condition due to production of organic acids by partial anaerobic fermentation of sugars in the forage (3)	
Stall-feeding	A management system in which all feed is taken to livestock that are confined to a stall or pen (1)		
Stover	The dry remains of a cereal crop (generally maize) after the ears (cob) are removed/harvested (1)		
Straights	A crop by-product or oilseed cake or		

	meal; *usage* when referring to available concentrate feeds (WT)		
Straw	The dry remains of a cereal crop (e.g. rice or wheat) after the ears are removed/harvested (1)		
Supplement	Nutritional additive intended to improve nutrition balance and remedy deficiencies in the diet (3)	Feed or feed mixtures used to improve the nutritional value of basal feeds. A supplement is rich in one or more of protein, energy, vitamins, minerals or antibiotics, and is combined with other feeds to produce a more complete feed. Often used interchangeably with concentrate (5)	
Tropical Livestock Unit	TLU is a common unit in which populations of different kinds (e.g. cattle, sheep and goats) and age classes of livestock can be compared in units of 250kg live weight (WT)		
Voluntary feed intake	*Ad-libitum* (free will) intake of a feed achieved when an animal is offered an excess of that feed (3)		
Zero-grazing	See Stall-feeding		

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Appendix 3: Land areas and human populations in the four farming systems and the seven regions, 2000 and projected to 2030 (Herrero et al, 2009b)

Farming systems vs area and population					
Farming System	Region	Area 2000 ('000,000 sq. km)	Area 2030 ('000,000 sq. km)	Population 2000 ('000,000 people)	Population 2030 ('000,000 people)
(Agro-)Pastoral	CSA	6.0	6.0	116.8	165.3
	EA	6.1	6.1	160.5	187.1
	SA	0.9	0.9	88.7	133.7
	SEA	0.6	0.6	30.9	42.4
	SSA	15.5	15.5	244.6	458.8
	WANA	10.6	10.6	135.4	241.8
	Others	5.5	5.5	59.7	72.7
Total		**45.3**	**45.2**	**836.6**	**1301.8**
Mixed Extensive	CSA	2.9	2.9	66.8	104.3
	EA	1.0	1.2	98.6	144.5
	SA	0.9	0.9	228.2	334.6
	SEA	0.8	0.6	59.1	57.0
	SSA	3.3	3.2	150.7	275.3
	WANA	0.6	0.6	45.4	62.1
	Others	9.4	9.4	648.8	977.9
Total		**18.7**	**18.8**	**1297.7**	**1955.7**
Mixed Potentially Intensify	CSA	2.0	1.9	142.5	187.9
	EA	1.8	1.6	795.6	877.7
	SA	1.7	1.7	823.5	1221.4
	SEA	0.9	1.1	308.7	438.3
	SSA	0.8	0.8	86.5	174.5
	WANA	0.6	0.6	148.4	248.6
	Others	2.4	2.2	193.6	217.1
Total		**10.2**	**9.9**	**2498.7**	**3365.6**
Other	CSA	9.2	9.1	157.4	217.2

	EA	2.0	1.9	228.8	263.3
	SA	0.8	0.8	167.5	243.9
	SEA	1.9	1.8	75.4	99.8
	SSA	4.3	4.3	134.5	233.2
	WANA	0.2	0.2	31.2	45.3
	Others	5.7	5.7	244.6	291.6
Total		**24.1**	**23.9**	**1039.3**	**1394.3**

Appendix 4: Business development services for smallholder dairy

Issue: Building Business Development Services for smallholder dairy producers - examples and experiences from the hub approach of the East Africa Dairy Development (EADD) project.

Description: The EADD project seeks to improve on-farm productivity by increasing milk production and milk quality by providing access to production inputs, information and quality feed resources through markets in Kenya, Uganda and Rwanda (www.eadairy.org). Market-access is being improved by developing local hubs of business delivery services (BDS) and chilling (or bulking) plants to link producers to dairy processors and to increase the benefit to producers from traditional dairy markets.

Why will access to and utilizing BDS make a difference? The challenge for improving dairy productivity and profitability through the EADD is how to ensure that both the 'pull' factors of improving output markets and the 'push' factors of improving farmers' feed strategies and access to feed markets evolve appropriately. Due to current market failures in the project's target areas, the BDS approach has the potential of making a difference by:

Meeting information gaps:

- Clustering of input services through hubs enhances access to knowledge on feeds, BDS and market information useful to agribusiness entrepreneurs, crop farmers and dairy producers when making decisions about sourcing and marketing feeds.

Increase the availability of high quality, cost-effective feed resources:

- Through field days, workshops and seminars the hubs facilitate interactions amongst feed producers/suppliers and buyers/users at farm and community levels. They can increase competition leading to better and innovative service delivery, e.g. micro-sizing of products, and may catalyze formation of feed traders associations to increase bargaining, purchasing and borrowing power. Clear operating guidelines are required to avoid the formation of cartels.
- Hubs can also facilitate the formation of Dairy Farmers Business Associations (DFBAs) to sustain business-oriented dissemination of technologies through rural advisory services, e.g., farmers serving as trainers of their peers. This enhances the adoption of improved feed technologies (creates market pull that enhances technology uptake).
- The hubs can enhance the market for milk sales and allow farmers credit against milk sales for feed purchases to improve milk production (check-off system).

What do we know? Where has it worked and why? Business delivery services have worked in EADD in the following ways:

Fodder-producing farmers:

- Setting up mechanisms to facilitate the emergence of a fodder market - EADD identifies large-scale farms outside the project area that produce hay and links them to DFBAs with whom they negotiate a contract to supply hay. Within the community, farmer trainers and/or training of trainers help dairy farmers with excess fodder or without livestock to supply fodder to those in need.
- Promoting community seed and planting material production by farmer trainers through group-led demonstration plots - EADD partners the Rwanda Agricultural Development Authority (RADA) to contract farmers to produce forage seed that RADA purchases and sells to other farmers in EADD sites. Training is provided on forage production as a business. Dissemination of smut-resistant Napier varieties through bulking plots with farmer groups and training centres has been successful in central Kenya and is being replicated by EADD at its other sites through group demonstration plots.
- Encouraging entrepreneurs who trade in forage seed to form associations, for example, the Kenya Association of Trees, Nursery and Seed Organisation (KATRESNO) which sources and supplies forage seed in most parts of Kenya: traders buy and sell fodder tree, oat, sorghum, mucuna and lablab seeds at the EADD sites.

Commercial feed trading:

- EADD-assisted dairy farmers in Muki and Kieni link with hay producers in irrigated schemes outside EADD sites, such as Thika, to supply fodder on a contract basis.
- There is evidence that EADD farmers are buying more feed through DFBA agro-vet shops at the hubs. A reason is that DFBAs in Kenya, such as Kabiyet, Siongiroi and Kipakaren, have also begun to buy feed, e.g. hay in bulk, hence saving on transport and passing on the saving to farmers. Another is that farmers are able to source feed closer to their households. Another reason is that micro-sizing of dairy concentrates into 10 kg bags makes the concentrates affordable.

Small-scale feed-mills/choppers/pulverisers:

- A small-scale feed mill was set up in Kiboga DFBA in Uganda in 2009: it is currently mixing and selling feeds to farmers. Rwanda is putting a feed mill in Rwamagana district.
- EADD is promoting feed choppers (commonly known as pulverisers) by assisting procurement by service providers via project loan schemes, setting up BDS through hubs and providing technical back-up. The pulverisers improve the utilization of crop residues and roughages. When the project started there were about 20 pulverisers in use; now there are over 800.

Policies and investments

Quality and enforcement of standards: To enhance use of BDS approaches in promoting use of commercial concentrate feed and supplements there is the need:

- To enforce feed standards through, probably, involving associations of feed manufacturers whose role would be to monitor standards on behalf of the government to eliminate variation in feed quality;
- To ensure concentrate feed use is attractive to farmers, regulatory bodies need to enforce feed standards through random sampling of feed from the market for testing to ensure all commercial feeds on the market meet required standards;
- Alongside this, there is the need for farmers or their BDS hubs to have access to cost-effective, simple equipment for testing feed quality.

Recognition of small-scale feed producers

- There are numerous small-scale feed compounders in Uganda, especially around Kampala city, who operate 'illegally', i.e. they are not recognised by the law. They could trade the abundant raw material from Uganda to Kenya, which imports the bulk of its feed ingredients from Uganda. Recognition by the government of these small-scale traders through training and certification can support the growth of the feed market, possibly reducing prevailing market prices.

Investment in development

Integrated BDS hubs, rather than piecemeal approaches, seem to be working:

- They enhance development of markets for livestock products allowing farmers to obtain credit facilities against milk sales to invest in improved feed production;
- They cluster input services that enhance access to knowledge on feeds, BDS and other information useful to agribusiness entrepreneurs;
- They provide a mechanism through which farmers/farmer groups (e.g. DFBAs) are the vehicle for scaling-up technologies.

Research/knowledge gaps

- Absence of resistant varieties to Napier smut and stunt diseases continue to pose a big threat to the dairy industry in East Africa;
- There are grey areas regarding the long-term sustainability of the BDS approach as well as the determinant factors, e.g., critical volume of business required, opportunities for bundling with other BDS, etc;
- Facilitation of BDS providers may create monopolies in some areas resulting in, possibly, increased prices and/or lower quality of products.

Other issues

- "Hub" stakeholder workshops that promoted feed technologies increased interactions amongst stakeholders and identified constraints to dairy production that were technological and institutional in nature but that also raised some issues that were broader, e.g. roads that were inadequate. Stakeholders suggested building coalitions to address animal health, breeding, water and milk marketing, etc, rather

than just feed/fodder alone, emphasising the need for an integrated approach to improving farm and dairy productivity.

Appendix 5: Interventions for improving feed resources in East Africa dairy

<u>Tabulated results of expert consultation sessions:</u>

Potential interventions by type and source of feeds for increasing the availability of feed on-farm (*Produce more*) or through the market (*Import*) and for improving the utilization of the feed (*Utilize better*) for pro-poor dairy production in East Africa.

EAST AFRICA DAIRY	PRODUCE MORE	IMPORT	UTILIZE BETTER
Natural grazing			
On (own) farm			
Community			
Market		Hay prod. and transport from outside the system	
Policy & Institutional			
Planted pastures			
On (own) farm			
Community		Large farms producing hay for the market	
Market		Hay prod. and transport from outside the system	
Policy & Institutional			
Planted (non-pasture) forages			
On (own) farm	Napier Other grasses (Brachiaria etc)		Herb. legumes, trees Processing (of excess) – e.g. silage for Napier (which does not work – labour, hassle factor)
Community	Community niches (eg stream-banks) where fodder could be grown	Community niches (eg stream-banks) where fodder could be grown	
Market	Support private sector-based seed system and intermediate	Napier, etc , as cash crops	Potential for econ. of scale, e.g. silage. BDS

	options, e.g. farmer associations		
Policy & Institutional	Planting material system issues (eg quality control of Napier planting material). Facilitating seed systems	Support for fodder farmers: technical advice, institutional arrangements.	Planting material system issues Knowledge systems: better utilization
Crop residues			
On (own) farm	Crop husbandry Food-feed crops Impact of crop changes in relation to, e.g., food security, climate change, specialisation.		Crop husbandry Food feed crops Post harvest processing (storage, chopping, urea treatment, baling) Feed combinations
Community		Transport from surplus to deficit areas	
Market	Food-feed crop varieties Dual-purpose crop seed systems	Trading crop residues – market operation; price-quality relationships Cost of transport vs price of product	Opportunities for BDS – processing, e.g. maize stover choppers & packaging. Seasonal opportunity, including transport-worthiness/ease
Policy & Institutional	Institutionalise food-feed crop approaches – facilitating seed systems Accommodation of crop specialisation	Institutionalise food feed crop approaches Governance of feed quality issues, e.g. aflatoxins in crop residues, feed standards	Institutionalise food feed crop approaches Knowledge systems: better utilization
Crop by-products			
On (own) farm	Adoption of new varieties (food-feed)		Balancing the rations (feeding strategies)
Community			
Market	Adoption of new varieties (food-feed)	Delivery, e.g. from maize mills to feed manufacturers,	Opportunities for BDS – processing, e.g. feedmills/ packaging. Seasonal

		then through to farmer.	opportunity including transport-worthiness/ ease
Policy & Institutional	Institutionalise food-feed crop approaches	Regulation of quality Aflatoxins in oil cakes	Regulation of quality Knowledge systems: better utilization
Other by-products			
On (own) farm			Balancing rations
Community		Community level access to brewers grain and poultry waste	
Market		Brewers grain – how to process and incorporate into feed rations Waste from green beans BDS	Opportunities for BDS – processing/packaging. Seasonal opportunity including transport-worthiness/ease Identifying other at present unused by-products
Policy & Institutional		Pesticide contamination of the bean waste Governance of feed quality issues, e.g. Feed safety re poultry waste	Knowledge systems: better utilization
Grains			
On (own) farm	Crop husbandry and varieties		Balancing rations
Community			
Market		Lupin seed promoted by feed manufacturers - thro' contract farmers in areas away from the dairy area	Storage issues, e.g. feed quality (aflatoxins, etc)
Policy & Institutional		Aflatoxins – food and feed safety	Knowledge systems: better utilization
Roots and tubers			
On (own) farm	Adoption of new varieties (food-feed)		Balancing the rations (feeding strategies)
Community			

Market	Adoption of new varieties (food-feed)		Opportunities for BDS – processing/ packaging. Seasonal opportunity including transport-worthiness/ease
Policy & Institutional	Institutionalise food feed crop approaches		Regulation of quality Knowledge systems: better utilization
Mineral/vit. suppls			
On (own) farm			Balanced rations Targeted feeding according to animal status
Community			
Market		Micro-sizing of these products through agro-vets, village shops etc	
Policy & Institutional		Governance of feed quality issues, specially quality standards from village to market level	Knowledge systems: better utilization
Balanced concentrates			
On (own) farm			Balanced rations Targeted feeding according to animal status
Community			
Market		Micro-sizing of these products through agro-vets, village shops etc	Opportunities for BDS – processing/packaging. Seasonal opportunity including transport-worthiness/ease
Policy & Institutional		Governance of feed quality issues, specially quality standards from village to market level	Knowledge systems: better utilization
Water			

On (own) farm	Water-harvesting		Water-harvesting Targeting
Community	Water-harvesting Targeting	Connect to public grid	Water-harvesting Targeting
Market		Water traders	
Policy & Institutional	Knowledge systems: better capture	Governance of water issues, including Public schemes Quality standards from village to market levels	Knowledge systems: better utilization

*BDS - business development services

Appendix 6: Interventions for improving feed resources in South Asia dairy

<u>Tabulated results of expert consultation sessions:</u>

Potential interventions by type and source of feeds for increasing the availability of feed on-farm (*Produce more*) or through the market (*Import*) and for improving the utilization of the feed (*Utilize better*) for pro-poor dairy production in South Asia

SOUTH ASIA RAIN-FED CROP-DAIRY			
	PRODUCE MORE	IMPORT	UTILIZE BETTER
Natural grazing (trees included)			
On (own) farm			
Community			
Market			
Policy & Institutional		Possible impacts of community based management schemes are likely to be limited. There are some dynamics here related to use of CPR and forests.	Common property rights for indigenous trees.
Planted pastures			
On (own) farm			
Community			
Market			
Policy & Institutional			
Planted (non-pasture) forages			
On (own) farm	Shift from staple foods to planted forages. And the opportunity to sell as a cash crop.		
Community			
Market			
Policy & Institutional	Economies of scale for forage production at smallholder level. Stimulated by the increasing value of		

	fodder in relation to grain. Need to address transport-worthiness issue (if fodder is being transported).		
Crop residues			
On (own) farm	Improved quality and quantity of crop residues through breeding; crop management. Storage issues need to be addressed to smooth the seasonality	Transport worthiness.	Simple processing (chopping etc). Balancing rations (simple combinations with eg legumes etc). Storage issues (facilities and techniques) need to be addressed to smooth the seasonality
Community			
Market		Improved market forces/options	Improved market forces/options.
Policy & Institutional	Promotion of existing varieties that have better quality and quantity parameters. "Institutionalizing" the food-feed crop approaches.	Infrastructure improvement. Promotion of existing varieties that have better quality and quantity parameters. "Institutionalizing" the food-feed crop approaches.	Promotion of existing varieties that have better quality and quantity parameters. "Institutionalizing" the food-feed crop approaches.
Crop by-products			
On (own) farm			
Community			
Market	Information. New by -products appear on the scene (e.g. maize stover, chickpea haulms). Are there opportunities to speed up the appropriate use of this? Market information about value of different stovers (and the economics of this). Need to overcome	Information. New by-products appear on the scene (eg maize stover, chickpea haulms). Are there opportunities to speed up the appropriate use of this? Market information about value of different stovers (and their economics). Need	Information. New by products appear on the scene (eg maize stover, chickpea haulms). Are there opportunities to speed up the appropriate use of this? Market information about value of different stovers (and the economics of this). Need to overcome hurdles of govt/exten to make sure that the

	hurdles of govt/exten to make sure that the information and opportunities reach the farmers.	to overcome hurdles of govt/ exten to make sure that the info' & opportunities reach the farmers.	information and opportunities reach the farmers.
Policy & Institutional	Improving knowledge services	Improving knowledge services	Improving knowledge services
Other by-products			
On (own) farm			
Community			Decentralised, community based feed manufacturing – new opportunities. E.g. chopping ..... (hub)
Market		Transport worthiness. If transport costs more, then what is transported will have higher value (so eg needs to be densified – compare blocks with stover)	Processing to blocks...appropriate mixes of local and added feed ingredients.
Policy & Institutional			Recognition by govt/extn of the potential of small scale entrepreneurs. Subsidies and incentives can influence this (and distort)! In reality, the investment needs to be from the private sector. What could be investments that provide appropriate incentives? And the need for an appropriate regulatory environment.
Grains			
On (own) farm			
Community			
Market			
Policy &	Institutionalisation of		Quality issues, including

Institutional	food feed crops. Competition with mono-gastrics (poultry) and how this influences availability of grain. This could also influence the role of farmers in these systems, who may grow crops as feed. Minimum support price is a big driver of staple crops (rice and wheat). This dampens real market signals and slows down or stops the system's response to market demand, which includes the relative price of grain and stover. Caps on GHGs? Could influence grain use for feed.		related to mycotoxins and regulatory/monitoring....
Roots and tubers			
On (own) farm			??New – sugar beet introduced as a potential biofuel. Could be opportunities of by product use for feed. Or direct use of sugar beet as feed?
Community			
Market			
Policy & Institutional			
Mineral/vit. suppls			
On (own) farm			
Community			
Market			
Policy & Institutional			Knowledge issues. Becomes more important as production intensifies – e.g. higher

			demanding cows.....as these start to become limiting factors. Lack of information and empirical data of what is really needed/what is an issue.
Balanced concentrates			
On (own) farm			Appropriate balanced rations
Community			
Market			
Policy & Institutional	Infrastructure investments.		Regulation of quality. Dairy cooperatives can contribute to this issue as they have interest. Relative prices of feed (concentrate in this case) and milk - is it worth buying the better quality more costly concentrate. In general credit does not seem to work (the buyer sees it as a right), some of which may be cultural .. (e.g. towards private sector). The vertical integration has not totally worked! Cargill – did not work.....made "optimal supplements" but no one buys them. Need to understand WHY!
Water			
On (own) farm	Irrigation may contribute even 30% in some rain-fed systems. Bore-wells have to be deeper. So this supplementary irrigation reduces. Drip irrigation limited by need for constant electricity. Uneven rainfall		

	demands water harvesting structures. Potential for drought tolerant varieties – which also links to the overall physiology and food-feed crops		
Community			
Market			
Policy & Institutional			

S ASIA DAIRY IRRIGATED CROP-LIVESTOCK			
	PRODUCE MORE	**IMPORT**	**UTILIZE BETTER**
Natural grazing			
On (own) farm			
Community			
Market			
Policy & Institutional			
Planted pastures			
On (own) farm			
Community			
Market			
Policy & Institutional			
Planted (non-pasture) forages			
On (own) farm	Short duration, water use efficient, multi-cut forages – need to identify/ introduce, eg. millets, legumes (which could also be important for sustainability issues). Identification of appropriate quality material. Implications of short cycle in relation to animal demands?		Balanced rations; seasonality
Community			
Market			
Policy & Institutional	Seed supply, information, innovation systems, knowledge	Good market incentives from potential	

	management/access. Management of sustainability in rice-wheat systems especially water, SOM. Good market incentives from potential international suppliers of hybrid seeds.	international suppliers of hybrid seeds (e.g. US, Australia) are really developing these things.	
Crop residues	(same issues for rainfed)		
On (own) farm			Horticultural by-products. Potentially new by-product. New information needed on appropriate use and balancing of rations.
Community			
Market			
Policy & Institutional			
Crop by-products			
On (own) farm			Opportunity for hay making? Big range of technical issues here too.
Community			
Market			
Policy & Institutional	Policies about electricity and water pricing. Impact all crop products. Can impact on rice management systems – may encourage multi purpose crop varieties, short duration forages etc.		
Other by-products			
On (own) farm			
Community			
Market			
Policy & Institutional			Licensing rules about molasses.
Grains	**As for rainfed**		
On (own) farm			Mycotoxins...etc
Community			

Market			
Policy & Institutional			
Roots and tubers			
On (own) farm			
Community			
Market			
Policy & Institutional			
Mineral/vit. suppls			
On (own) farm			
Community			
Market			
Policy & Institutional			
Balanced concentrates	**As for rainfed.**		
On (own) farm			Balanced rations.
Community			
Market		Input service delivery, BDS (this belongs in other places too).	Quality controls, packaging, feed standards. Information and knowledge systems
Policy & Institutional	Credit issues...(as above)		
Water			
On (own) farm			
Community			
Market			
Policy & Institutional	Water pricing. Water-efficient fodder crops. Energy pricing.	Water pricing. Water-efficient fodder crops. Energy pricing.	Water pricing. Water efficient fodder crops. Energy pricing.

Appendix 7.1: West Africa Beef – Pastoral Feed Types and Sources

Estimates of the proportion of feed by source and type used by pastoral households for cattle in West Africa currently (2010) and projected to 2030.

West Africa beef - pastoral	**Source of feed** (% of DM) **2010**			**Est. share (%) of annual herd feed***
Type of feed	**Own farm**	**Community**	**Market**	**Total**
Natural grazing		89.5		**89.5**
Planted pastures				**0**
Planted forages				**0**
Crop residues		10		**10**
Crop by-products			0.5	**0.5**
Other by-products				**0**
Grains				**0**
Roots and tubers				**0**
Mineral/vit suppls				**0**
Balanced concs				**0**
TOTAL	**0**	**99.5**	**0.5**	**100**
		2030		
Type of feed	**Own farm**	**Community**	**Market**	**Total**
Natural grazing		88		**88**
Planted pastures				**0**
Planted forages				**0**
Crop residues		10		**10**
Crop by-products			1.5	**1.5**
Other by-products			0.5	**0.5**
Grains				**0**
Roots and tubers				**0**
Mineral/vit suppls				**0**
Balanced concs				**0**
TOTAL	**0**	**98**	**2**	**100**

* DM – dry matter

Appendix 7.2: West Africa Beef – Feed Issues and Investment Opportunities

Tabulated results of expert consultation sessions:

1. **Intensive crop-livestock systems**

WEST AFRICA BEEF	PRODUCE MORE	IMPORT	UTILIZE BETTER
Natural grazing			
On (own) farm	-		
Community	-CB NRM strategies e.g. bush fire management; tsetse control. -water harvesting -Water points development	-Better organization of community to transport feed resources (e.g. bush hay)	-
Market	-		
Policy & Institutional	-Land tenure systems – reconciling customary with national law		-Implementation of local conventions for community natural resources
Planted pastures			
On (own) farm	-Planted pastures may be feasible with appropriate inputs such as seed, fertilizer, technical advice; -Labour will be a major constraint		
Community	-No planted pastures at community level.		
Market			
Policy & Institutional			
Planted (non-pasture) forages			
On (own) farm	-Participatory identification of niche in response to demand		

Community			
Market			
Policy & Institutional	-Access to knowledge and input services		
Crop residues			
On (own) farm	-Access to high yield food-feed crop varieties		-Balancing cereal and legume residues ratios -Better storage methods -Matching feeding with productive status of the animals -More productive breeds
Community	-Access to high yield food-feed crop varieties and other inputs		-Community processing e.g. small-scale feed-mill
Market	-Reducing availability of crop residues		-Community processing e.g. small-scale feed-mill
Policy & Institutional	-Better delivery of input services -Timing of access	-Access to credit, support to small-scale enterprise (BDS)	-Knowledge services
Crop by-products			
On (own) farm	-High yielding varieties -Better processing technologies		-Balancing cereal and legume residues ratios -Better storage methods -Matching feeding with productive status of the animals -More productive breeds
Community		-Bulk buying by CBO	
Market	-Better processing technologies -Investment incentives	-Better transport to market and to the farm	-Information on feed composition -Feed recommendations and seasonality -Matching requirements with

			supply
Policy & Institutional	-Incentives for production		-Knowledge services -Feed quality control and regulations
Other by-products			
On (own) farm			
Community			
Market	-Better processing technologies	-Better transport to market and to the farm	-Information on feed composition -Feed recommendations and seasonality -Matching requirements with supply
Policy & Institutional	-Investment incentives -Better transport (road networks)		
Grains			
On (own) farm	-On-farm diversification		
Community			
Market	-High yielding food-feed crop varieties		
Policy & Institutional	-Price incentives	-Regional market price information	
Roots and tubers			
On (own) farm			
Community			
Market			
Policy & Institutional	-Information on use of cassava residues as feed		
Mineral/vit. suppls			
On (own) farm			
Community			
Market			-Access
Policy & Institutional			-Knowledge information systems
Balanced concentrates			
On (own) farm			
Community			
Market		-Better transport	-Information on

		to market and to the farm	concentrate composition -Feed recommendations and seasonality -Matching requirements with supply
Policy & Institutional			-Knowledge Information Systems
Water			
On (own) farm			
Community	-Access to more water e.g. small reservoir	-Transport by donkey	-Better management and utilization -Awareness building
Market			
Policy & Institutional	-Supportive policies -		

2. Agro-pastoral/extensive crop-livestock systems

WEST AFRICA BEEF	PRODUCE MORE	IMPORT	UTILIZE BETTER
Natural grazing			
On (own) farm	-		
Community	-CB NRM strategies e.g. bush fire management; -water harvesting -Water points development	-Better organization of community to transport feed resources (e.g. bush hay)	-
Market	-		
Policy & Institutional	-Land tenure systems – reconciling customary with national law.	-Early warning systems for meeting feed deficit	-Implementation of local conventions for community natural resources -Livestock mobility regulations -Land use plans (POAS)
Planted pastures			
On (own) farm			
Community	-No planted pastures at community level.		
Market			
Policy & Institutional			
Planted (non-pasture) forages			
On (own) farm			
Community			
Market			
Policy & Institutional			
Crop residues			
On (own) farm	-Access to high yield food-feed crop varieties		-Balancing cereal and legume residues ratios -Better storage methods -Matching feeding with productive status of the animals -More productive

			breeds
Community	-Access to high yielding food-feed crop varieties and other inputs		
Market			
Policy & Institutional	-Better delivery of input services -Timing of access	-Access to credit, support to buy feed and high yielding crop varieties	-Knowledge services
Crop by-products			
On (own) farm	-High yielding varieties -Better processing technologies		-Balancing cereal and legume residues ratios -Better storage methods -Matching feeding with productive status of the animals -More productive breeds
Community		-Bulk buying by CBO	
Market			
Policy & Institutional	-Incentives for production		-Knowledge services -Feed quality control and regulations
Other by-products			
On (own) farm			
Community			
Market	-Better processing technologies and storage	-Better transport from market to the farm -Appropriate packaging	-Information on feed composition -Feed recommendations and seasonality -Matching requirements with supply
Policy & Institutional	-Investment incentives -Better transport (road networks)		
Grains			
On (own) farm			
Community			
Market		-Access to grains	

Policy & Institutional	-Price incentives	-Regional market price information	
Roots and tubers			
On (own) farm			
Community			
Market			
Policy & Institutional			
Mineral/vit. suppls			
On (own) farm			
Community			
Market			
Policy & Institutional			
Balanced concentrates			
On (own) farm			
Community			
Market			
Policy & Institutional			
Water			
On (own) farm			
Community	-Access to more water e.g. small reservoir -Development of water points – wells, boreholes, small water reservoir -Water lifting technologies	-Transport by donkey	-Better management and utilization -Awareness building -Better management of bas fonds, fadama
Market			
Policy & Institutional	-Supportive policies for investment in development of water points -Pricing policy for water use		

3. <u>Pastoral systems</u>

WEST AFRICA BEEF	PRODUCE MORE	IMPORT	UTILIZE BETTER
Natural grazing			
On (own) farm			
Community	-CB NRM strategies e.g. bush fire management; -water harvesting -Water points development	-Better organization of community to transport feed resources (e.g. bush hay)	-Diversification of species
Market	-		
Policy & Institutional	-Land tenure systems – reconciling customary with national law.	-Early warning systems for meeting feed deficit	-Implementation of local conventions for community natural resources -Livestock mobility regulations -Policy support for livelihoods diversification and commercialization of pastoralism -Livelihood options through payment for ecosystem services
Planted pastures			
On (own) farm			
Community	-No planted pastures at community level.		
Market			
Policy & Institutional			
Planted (non-pasture) forages			
On (own) farm			
Community			
Market			
Policy & Institutional			
Crop residues			
On (own) farm			
Community	-High yielding food feed crop varieties of the host community		-Conflict management to ensure access to crop residues

			(mutually beneficial) -Sourcing alternative feeds
Market			
Policy & Institutional	-Timing of access		-Knowledge services -Identifying mutually beneficial issues *-Incentives*
Crop by-products			
On (own) farm			
Community			
Market			
Policy & Institutional	*-Incentives for production*		-Knowledge services -Feed quality control and regulations
Other by-products			
On (own) farm			
Community			
Market			
Policy & Institutional	*-Investment incentives* -Better transport (road networks)		
Grains			
On (own) farm			
Community			
Market			
Policy & Institutional			
Roots and tubers			
On (own) farm			
Community			
Market			
Policy & Institutional			
Mineral/vit. suppls			
On (own) farm			
Community			
Market			
Policy & Institutional			
Balanced concentrates			
On (own) farm			
Community			

Market			
Policy & Institutional			
Water			
On (own) farm			
Community	-Access to more water e.g. small reservoir -Development of water points – wells, boreholes, small water reservoir -Water lifting technologies	-Transport by donkey/carts	-Better management and utilization -Awareness building -Better management of bas fonds, fadama
Market			
Policy & Institutional	-Supportive policies for investment in development of water points -Pricing policy for water use		

Appendix 8: West Africa small ruminant meat

Tabulated results of expert consultation sessions:

Feed Types and Sources

8.1: Estimates of the proportion of feed by source and type used by pastoral households for small ruminants in West Africa in 2010 and projected to 2030.

West Africa SR - pastoral	**Source of feed** (% of DM) **2010**			**Est. share (%) of annual flock feed***
Type of feed	**Own farm**	**Community**	**Market**	**Total**
Natural grazing	0	80	0	**80**
Crop residues	0	19	0	**19**
Crop by-products	0	0	1	**1**
Other by-products	0	0	0	**0**
TOTAL	**0**	**99**	**1**	**100**
2030				
Natural grazing	0	75	0	**75**
Crop residues	0	19	0	**19**
Crop by-products	0	0	4	**4**
Other by-products	0	0	2	**2**
TOTAL	**0**	**94**	**6**	**100**

8.2 Estimates of the proportion of feed by source and type used by agro-pastoral and extensive crop-small ruminant households in West Africa in 2010 and projected to 2030.

West Africa SR – agro-pastoral/ extensive crop –liv.	**Source of feed** (% of DM) **2010**			**Est. share (%) of annual flock feed***
Type of feed	**Own farm**	**Community**	**Market**	**Total**
Natural grazing	0	55	5	**60**
Planted forages	0	0	0	**0**
Crop residues	10	21	0	**31**
Crop by-products	5	0	0	**5**
Other by-products	0	0	4	**4**
Mineral/vit suppls	0	0	0	**0**
Balanced concs	0	0	0	**0**
TOTAL	**15**	**76**	**9**	**100**
2030				
Natural grazing	0	45	5	**50**
Planted forages	0	0	1	**1**
Crop residues	12	15	8	**35**
Crop by-products	4	0	4	**8**
Other by-products	0	0	4	**4**
Grains	0	0	1	**1**
Balanced concs	0	0	1	**1**
TOTAL	**16**	**60**	**24**	**100**

Feed Issues and Investment Opportunities

8.3 Intensifying crop-livestock systems

WEST AFRICA Small Ruminants	**PRODUCE MORE**	**IMPORT**	**UTILIZE BETTER**
Natural grazing			
On (own) farm	-		
Community	-CB NRM strategies e.g. bush fire management; tsetse control. -water harvesting -Water points development	-Better organization of community to transport feed resources (e.g. bush hay)	-
Market	-		
Policy & Institutional	-Land tenure systems – reconciling customary with national law		-Implementation of local conventions for community natural resources
Planted pastures			
On (own) farm	-Planted pastures may be feasible with appropriate inputs such as seed, fertilizer, technical advice; -Labour will be a major constraint		
Community	-No planted pastures at community level.		
Market			
Policy & Institutional			
Planted (non-pasture) forages			
On (own) farm	-Participatory identification of niche in response to demand		
Community			
Market			
Policy & Institutional	-Access to knowledge and		

	input services		
Crop residues			
On (own) farm	-Access to high yield food-feed crop varieties		-Balancing cereal and legume residues ratios -Better storage methods -Matching feeding with productive status of the animals -More productive breeds (sheep) -Innovation in processing
Community	-Access to high yield food-feed crop varieties and other inputs		-Community processing e.g. small-scale feedmill
Market	-Reducing availability of crop residues		-Community processing e.g. small-scale feedmill
Policy & Institutional	-Better delivery of input services -Timing of access	-Access to credit, support to small-scale enterprise (BDS)	-Knowledge services
Crop by-products			
On (own) farm	-High yielding varieties -Better processing technologies		-Balancing cereal and legume residues ratios -Better storage methods -Matching feeding with productive status of the animals -More productive breeds -Innovation in processing
Community		-Bulk buying by CBO	
Market	-Better processing technologies -Investment incentives	-Better transport to market and to the farm	-Information on feed composition -Feed recommendations and seasonality -Matching requirements with

			supply
Policy & Institutional	-Incentives for production		-Knowledge services -Feed quality control and regulations
Other by-products			
On (own) farm			
Community			
Market	-Better processing technologies	-Better transport to market and to the farm	-Information on feed composition -Feed recommendations and seasonality -Matching requirements with supply -Innovation in processing
Policy & Institutional	-Investment incentives -Better transport (road networks)		
Grains			
On (own) farm	-On-farm diversification		
Community			
Market	-High yielding food-feed crop varieties		
Policy & Institutional	-Price incentives	-Regional market price information	
Roots and tubers			
On (own) farm			
Community			
Market			
Policy & Institutional	-Information of use of cassava residues as feed		
Mineral/vit. suppls			
On (own) farm			
Community			
Market			-Access
Policy & Institutional			-Knowledge information systems
Balanced concentrates			
On (own) farm			

Community			
Market		-Better transport to market and to the farm	-Information on concentrate composition -Feed recommendations and seasonality -Matching requirements with supply
Policy & Institutional			-Knowledge Information Systems
Water			
On (own) farm			
Community	-Access to more water e.g. small reservoir	-Transport by donkey	-Better management and utilization -Awareness building
Market			
Policy & Institutional	-Supportive policies -		

8.4 Agro-pastoral/extensive crop-livestock systems

WEST AFRICA Small Ruminants	PRODUCE MORE	IMPORT	UTILIZE BETTER
Natural grazing			
On (own) farm			
Community	-CB NRM strategies e.g. bush fire management; -water harvesting -Water points development	-Better organization of community to transport feed resources (e.g. bush hay)	
Market	-		
Policy & Institutional	-Land tenure systems – reconciling customary with national law.	-Early warning systems for meeting feed deficit	-Implementation of local conventions for community natural resources -Livestock mobility regulations -Land use plans (POAS)
Planted pastures			
On (own) farm			
Community	-No planted pastures at community level.		
Market			
Policy & Institutional			
Planted (non-pasture) forages			
On (own) farm			
Community			
Market			
Policy & Institutional			
Crop residues			
On (own) farm	-Access to high yield food-feed crop varieties		-Balancing cereal and legume residues ratios -Better storage methods -Matching feeding with productive status of the animals -More productive breeds

Community	-Access to high yielding food-feed crop varieties and other inputs	-Community storage facilities	
Market		-Transport infrastructures	-Access to market information -Innovation in processing
Policy & Institutional	-Better delivery of input services -Timing of access	-Access to credit, support to buy feed and high yielding crop varieties	-Knowledge services
Crop by-products			
On (own) farm	-High yielding varieties -Better processing technologies		-Balancing cereal and legume residues ratios -Better storage methods -Matching feeding with productive status of the animals -More productive breeds
Community		-Bulk buying by CBO	
Market		-Transport infrastructures	-Access to market information -Innovation in processing
Policy & Institutional	-Incentives for production		-Knowledge services -Feed quality control and regulations
Other by-products			
On (own) farm			
Community		-Storage facilities	
Market	-Better processing technologies and storage	-Better transport from market to the farm -Appropriate packaging	-Information on feed composition -Feed recommendations and seasonality -Matching requirements with supply -Innovation in processing
Policy &	-Investment		

Institutional	incentives -Better transport (road networks)		
Grains			
On (own) farm			
Community			
Market		-Access to grains	
Policy & Institutional	-Price incentives	-Regional market price information	
Roots and tubers			
On (own) farm			
Community			
Market			
Policy & Institutional			
Mineral/vit. suppls			
On (own) farm			
Community			
Market			-Information on composition -Access to price information
Policy & Institutional			
Balanced concentrates			
On (own) farm			
Community			
Market			
Policy & Institutional			
Water			
On (own) farm			
Community	-Access to more water e.g. small reservoir -Development of water points – wells, boreholes, small water reservoir -Water lifting technologies	-Transport by donkey	-Better management and utilization -Awareness building -Better management of bas fonds, fadama
Market			
Policy & Institutional	-Supportive policies for		

	investment in development of water points -Pricing policy for water use		

8.5 Pastoral systems

WEST AFRICA Small Ruminants	PRODUCE MORE	IMPORT	UTILIZE BETTER
Natural grazing			
On (own) farm			
Community	-CB NRM strategies e.g. bush fire management; -water harvesting -Water points development	-Better organization of community to transport feed resources (e.g. bush hay)	-Diversification of species
Market	-		
Policy & Institutional	-Land tenure systems – reconciling customary with national law.	-Early warning systems for meeting feed deficit	-Implementation of local conventions for community natural resources -Livestock mobility regulations -Policy support for livelihoods diversification and commercialization of pastoralism -Livelihood options through payment for ecosystem services
Planted pastures			
On (own) farm			
Community	-No planted pastures at community level.		
Market			
Policy & Institutional			
Planted (non-pasture) forages			
On (own) farm			
Community			
Market			

Policy & Institutional			
Crop residues			
On (own) farm			
Community	-High yielding food feed crop varieties of the host community		-Conflict management to ensure access to crop residues (mutually beneficial) -Sourcing alternative feeds
Market			
Policy & Institutional	-Timing of access		-Knowledge services -Identifying mutually beneficial issues -Incentives
Crop by-products			
On (own) farm			
Community			
Market			
Policy & Institutional	-Incentives for production		-Knowledge services -Feed quality control and regulations
Other by-products			
On (own) farm			
Community			
Market			
Policy & Institutional	-Investment incentives -Better transport (road networks)		
Grains			
On (own) farm			
Community			
Market			
Policy & Institutional			
Roots and tubers			
On (own) farm			
Community			
Market			
Policy & Institutional			
Mineral/vit. suppls			

On (own) farm			
Community			
Market			
Policy & Institutional			
Balanced concentrates			
On (own) farm			
Community			
Market			
Policy & Institutional			
Water			
On (own) farm			
Community	-Access to more water e.g. small reservoir -Development of water points – wells, boreholes, small water reservoir -Water lifting technologies	-Transport by donkey/carts	-Better management and utilization -Awareness building -Better management of bas fonds, fadama
Market			
Policy & Institutional	-Supportive policies for investment in development of water points -Pricing policy for water use		

<u>8.6 Peri-urban/Urban systems</u>

WEST AFRICA Small Ruminants	PRODUCE MORE	IMPORT	UTILIZE BETTER
Natural grazing			
On (own) farm			
Community			
Market			
Policy & Institutional		-Transport infrastructures of bush hay from rural to urban areas	
Planted pastures			

On (own) farm			
Community			
Market	-Market information		
Policy & Institutional			
Planted (non-pasture) forages			
On (own) farm			
Community			
Market			
Policy & Institutional			
Crop residues			
On (own) farm			
Community	-High yielding food feed crop varieties of the suppliers		
Market	-Market information	-Market information for import from rural areas	
Policy & Institutional			-Knowledge services
Crop by-products			
On (own) farm			
Community	-High yielding food feed crop varieties of the suppliers		
Market	-Market information	-Market information for import from rural areas	
Policy & Institutional			-Knowledge services -Feed quality control and regulations -Knowledge services
Other by-products			
On (own) farm			
Community	-High yielding food feed crop varieties of the suppliers		
Market	-Market		

	information		
Policy & Institutional			-Knowledge services -Feed quality control and regulations
Grains			
On (own) farm			
Community			
Market		-Access to grains	
Policy & Institutional	-Price incentives	-Regional market price information	
Roots and tubers			
On (own) farm			
Community			
Market		-Transport facilities to the market	
Policy & Institutional			-Innovation in processing
Mineral/vit. suppls			
On (own) farm			
Community			
Market			
Policy & Institutional			
Balanced concentrates			
On (own) farm			
Community			
Market	-Market information		
Policy & Institutional			-Knowledge services -Feed quality control and regulations
Water			
On (own) farm			
Community			
Market			
Policy & Institutional	-Supportive policies for investment in development of water points and public health related issues		

	-Pricing policy for water use		

Note: Regulating livestock movement to improve public health/sanitary issues

Appendix 9: Southern Africa small ruminant meat

Tabulated results of expert consultation sessions:

Feed Issues and Investment Opportunities

9.1 Intensive crop-livestock systems

SOUTHERN AFRICA **Small Ruminant Meat**	**PRODUCE MORE**	**IMPORT**	**UTILIZE BETTER**
Natural grazing			
On (own) farm			Grazing management to address health issues; health and nutrition interaction.
Community			
Market			
Policy & Institutional			
Planted pastures			
On (own) farm			
Community			
Market			
Policy & Institutional			
Planted (non-pasture) forages			
On (own) farm	Introduction of perennial planted forages (shrubs?) – would require protection for establishment. Identification of non-competitive (with crops) niches Live fences an option		Balanced rations or combinations. How these "new" materials would really be used. Conservation opportunities.
Community			
Market	Seed supply		
Policy & Institutional	Significant requirement for knowledge services, BDS. These things are knowledge intensive.		Knowledge/ information access about efficient and appropriate use.
Crop residues			
On (own) farm	Food-feed crops; drought resistant, water efficient. Short duration varieties?		Appropriate ration mixes – especially combining the different residues. Storage issues

			Processing significant eg chopping etc
Community	Food-feed crops; drought resistant, water efficient. Short duration varieties?		
Market	Seed supply		
Policy & Institutional	Appropriate promotion.... knowledge services etc.		Information on best combinations
Crop by-products			
On (own) farm	As above re HY varieties		Appropriate combinations with other feeds. Storage, processing mycotoxins,
Community			
Market	Seed supply		
Policy & Institutional	Appropriate promotion.... knowledge services etc.		Information on best combinations
Other by-products			
On (own) farm			Information on use
Community			
Market	Infrastructure, market access, communication		
Policy & Institutional			Knowledge on use etc
Grains			
On (own) farm	Food-feed crops; drought resistant, water efficient. Short duration varieties?		Storage issues, mycotoxins,
Community	Food-feed crops; drought resistant, water efficient. Short duration varieties?		
Market	Seed supply		Market information
Policy & Institutional	Appropriate promotion.... knowledge services etc.		
Roots and tubers (cassava, sweet potato)			
On (own) farm	Possibly SP & Cassava HYV etc Little potential as a new crop – only where already traditional.		Appropriate combinations, seasonality KS; storage/ processing (silage); balancing. Potential trade off with use as food.
Community			

Market			
Policy & Institutional	Planting material supply & KS		KS
Mineral/vit. suppls			
On (own) farm			
Community			
Market			
Policy & Institutional			Specific min deficiencies?
Balanced concentrates			
On (own) farm			
Community			Community level mixing of balanced concentrates. Major information issue here. Community based organisation, hub models.....
Market			New input supply models, competitive pricing (eg in relation to animal product prices)
Policy & Institutional	Delivery systems **(applies to some of the above as well).** This is knowledge as well as input supplies. There may be quite a lot of location specificity. Need some different business models and something about the criteria of where different ones work.		Delivery systems **(applies to some of the above as well).** This is knowledge as well as input supplies. There may be quite a lot of location specificity. Need some different business models and something about the criteria of where different ones work.
Water			
On (own) farm	Water harvesting Drought resistant varieties; water efficient varieties. CPWF in Limpopo.		
Community			
Market			
Policy & Institutional	Improved management of community water supplies. Pricing policies.		Better conservation and use of water resources.

9.2 Agro-pastoral/extensive crop-livestock systems

SOUTHERN AFRICA Small Ruminant Meat	PRODUCE MORE	IMPORT	UTILIZE BETTER
Natural grazing			
On (own) farm			Introduction of herbaceous legumes tried for ages, but in general has never worked. Some examples (eg IPMS Ethiopia) where this now works because of changed land pressure and animal demand.
Community	Improved grazing management practices. Offtake of animals – incentives for this requires good market opportunities.		
Market			
Policy & Institutional	Infrastructure, reducing market transaction costs, improved market information.		Policies on access to communal resources.... collective action rules. Improved access to water.
Planted pastures			
On (own) farm			
Community			
Market			
Policy & Institutional			
Planted (non-pasture) forages			
On (own) farm	Introduction of perennial planted forages (shrubs?) – require protection for establishment.		Balanced rations or combinations. How these "new" materials would really be used.
Community			
Market	Seed supply		
Policy & Institutional	Significant requirement for knowledge services, BDS. These things are knowledge intensive.		Knowledge/ information access about efficient and appropriate use.
Crop residues			

On (own) farm	Food-feed crops; drought resistant, water efficient. Short duration varieties?		Appropriate ration mixes Storage issues Processing e.g. chopping etc
Community	Food-feed crops; drought resistant, water efficient. Short duration varieties?		
Market	Seed supply		
Policy & Institutional	Appropriate promotion.... knowledge services etc.		Information on best combinations
Crop by-products			
On (own) farm			
Community			
Market			
Policy & Institutional			
Other by-products			
On (own) farm			
Community			
Market			
Policy & Institutional			
Grains			
On (own) farm	Food-feed crops; drought resistant, water efficient. Short duration varieties?		Storage issues (may not be huge in these dry environments?)
Community	Food-feed crops; drought resistant, water efficient. Short duration varieties?		
Market	Seed supply		
Policy & Institutional	Appropriate promotion.... knowledge services etc.		
Roots and tubers			
On (own) farm	Possibly SP & Cassava HYV etc		KS; storage/ processing; balancing
Community			
Market			
Policy & Institutional	Planting material		KS

	supply & KS		
Mineral/vit. suppls			
On (own) farm			
Community			
Market			
Policy & Institutional			Specific min deficiencies?
Balanced concentrates			
On (own) farm			Best use of combinations with other feeds.
Community			
Market			
Policy & Institutional	Delivery systems (applies to some of the above as well). This is knowledge as well as input supplies. There may be quite a lot of location specificity. Need some different business models and something about the criteria of where different ones work.		Delivery systems (applies to some of the above as well). This is knowledge as well as input supplies. There may be quite a lot of location specificity. Need some different business models and something about the criteria of where different ones work.
Water			
On (own) farm	Water harvesting Drought resistant varieties; water efficient varieties. CPWF in Limpopo.	Location of watering points	
Community			
Market			
Policy & Institutional	Location of watering points...and policies/ institutions for utilising and accessing water better	Location of watering points...& policies/ institutions for utilising & accessing water better. Management of conflicts around water. Pricing policies?	Location of watering points...and policies/ institutions for utilising and accessing water better

Appendix 10: Detailed description on the methodology on assessing animal feed investment options and impacts

This annex describes in detail the methodology summarized in chapter 8.

1. Analytical construction and data

Nine livestock systems (table 1.1) are examined here, as it is deemed necessary to subdivide some systems as presented earlier, according to key investment-related characteristics that arise from the projected transition between 2010 feeding and that of 2030.

<table>
<tr><th>System</th><th>Description (chapter in which the full description appears)</th><th>Definitional notes</th></tr>
<tr><td>EA DAIRY</td><td>East African dairy systems (chapter 5)</td><td>All dairy systems in East African countries</td></tr>
<tr><td>SAs DAIRY IRR</td><td>South Asian dairy systems using irrigation to produce feed and other crops (chapter 6)</td><td rowspan="2">All dairy systems in South Asia, subdivided by estimates of numbers of animals in each of irrigated and rain-fed locations</td></tr>
<tr><td>SAs DAIRY RF</td><td>South Asian rain-fed systems with dairy animals (chapter 6)</td></tr>
<tr><td>WA BEEF INT</td><td>Intensive West African beef systems (chapter 7)</td><td rowspan="2">All beef systems in West Africa, subdivided by estimates of numbers of animals in regions associated with intensive and extensive systems</td></tr>
<tr><td>WA BEEF AGRP</td><td>West African agropastoral beef systems (chapter 7)</td></tr>
<tr><td>WA SMRM</td><td>West African small ruminant agropastoral systems (chapter 8)</td><td rowspan="2">All small ruminant systems in West Africa, subdivided by estimates of numbers of animals in regions associated with intensive and extensive systems</td></tr>
<tr><td>WA SMR PU</td><td>West African small ruminant peri-urban systems (chapter 8)</td></tr>
<tr><td>SA SMRM EXT</td><td>Southern African extensive small ruminant systems (chapter 9)</td><td rowspan="2">All small ruminant systems in Southern Africa, subdivided by estimates of numbers of animals in regions associated with intensive and extensive systems</td></tr>
<tr><td>SA SMR INT</td><td>Southern African intensive small ruminant systems (chapter 9)</td></tr>
</table>

Table 1.1 Livestock Systems

As described above, systems are represented by a limited number of variables (table 1.2 below, with explanatory notes on data sources and projection mechanisms). The underlying physical data is taken from ILRI's Sustainable Livestock Futures (SLF) team's summary for

the year 2000, projected forwards using indices of production results derived from IFPRI's IMPACT model. Prices of products and feed are drawn from a variety of sources, primarily the research results of experts involved in the study.

Variables	Explanatory notes	Data source
No. Producing Animals (1000 TLU) No. Following animals (1000 TLU)	Baseline data represent the same proportions as in 2000, with investment projections reflecting allocation of feed according to management practice.	ILRI SLF for 2000, inflated by IMPACT-based indices for 2010-2030
Production/ TLU (kg)	Maintained static except as impact of feed interventions	ILRI SLF for 2000
Q main product 1000 MT Q other product 1000 MT	Productivity multiplied by animal numbers: main product as producing animals, other products as all animals	ILRI SLF for 2000
Q feed 1000 MT DM	Feed DM consumption per TLU, multiplied by animal numbers	ILRI SLF for 2000 as rates per TLU
NV Natural Grazing NV Planted pastures NV Planted forages NV Planted forages CC NV Crop residues NV Crop by-products NV Other by-products NV Grains NV Roots and tubers	Nutritive values (in Megajoules of Metabolizable Energy per kg of Dry Matter) is used in order to mobilise changes in animal productivity, animal numbers and cost of feed, as well as being the route for improved utilisation.	DM as above allocated to feed types according to systems as defined and described in chapters 4-9. Nutritive Value calculated using a broadly accepted set of conversions from DM to Megajoules of Metabolizable Energy for each feed type.
NV Mineral vit. Suppl NV Balanced concs	Transitions 2010-2030 have beginning and end points as defined in chapters 4-9, but trajectories are varied according to scenarios	
PSE – Product PSE – Feed MIS – Product MIS – Feed	Parameters representing subsidisation of systems (via price measures), and margins charged on feed and products	Taken from IMPACT model
Product revenues 1000 USD	Calculated as quantities multiplied by prices	Prevailing (variously 2007-2011) prices as provided by expert informants

Feed cost 1000 USD

Table 1.2 Variables assembled for systems

All variables are assessed for a 20-year period 2010-2030, for both a baseline and intervention case. The annual net differences between baseline and intervention are then discounted and expressed as Net Present Value at a discount rate of 6%. The proxy measure of "profit" is the return over feed costs: effectively the additional revenue generated, minus the additional cost of feeds used.

2. Scenarios

Scenarios are introduced by introducing deviations from the baseline in the form of arbitrary 1% changes in the variables shown in table 10.2 above. Each such deviation is then accompanied by responses in production, productivity and other variables of interest. This is achieved by entering the appropriate formulae in the Excel spreadsheet. Scenarios examined (table 10.3) fall into several categories, or "layers" as described above.
Scenarios are run either as combinations of interventions 1-16 below, or as single interventions. For convenience, automated runs examine the same set of interventions across all nine livestock systems.

Intervention: Top layer		Explanatory notes
1	Number of animals	In general, system-wide increases in numbers of animals are viewed as infeasible. However, experience suggests that individual producers view such increases as desirable. The analysis presents that view, which ignores the very high costs involved. This scenario's main function is to act as a comparator for returns available from alternative scenarios, and combinations of scenarios.
2	Area in feed	This applies to the area in all feeds, including communal pastures. The analytical mechanisms is to provide a 1% increase in the Dry Matter production of all feeds, with a 1% increase in the prices of feeds to reflect increasing marginal costs as less desirable areas are brought into feed.
3	Feed yield or quality Planted pastures	In all cases the nutritive value derived from the scenario-specific feeds are increased by 1%, with no change in feed prices. Benefits associated with concentrates are apportioned from adjustments imposed on grains.
4	Feed yield or quality Planted forages	
5	Feed yield or quality Planted forages (cut and carry)	
6	Feed yield or quality Crop residues	
7	Feed yield or quality Crop by-products	
8	Feed yield or quality Other by-products	

9	Feed yield or quality Grains	
10	Feed yield or quality Roots and tubers	
11	Increase animal productivity	This intervention is ostensibly concerned with animal breeding or improved husbandry (e.g. housing, animal health or more precise grazing management). However, animal productivity is endogenous to feeding systems as discussed above, so any increase in productivity is balanced out in the analysis by increased feed consumption, adjusted for nutritive value and an arbitrary adjustment in implied feed conversion.
Intervention: second layer		
12	Knowledge/service systems	Baseline adoption is set at 55%, which takes effect in year 5. Investment in an improved knowledge system is represented as a change to adoption, with the new parameters at 80% adoption at year 2.
13	Transactions costs	Investment in reduced transaction costs is represented as a 1% increase in product price and a 1% reduction in feed prices. This approach mirrors the IMPACT model.
14	Policy	Policy change is reflected in measures of market participation. Variables refer to numbers of animals in systems rather than number of producers, but are arbitrarily defined as 70% participation markets (calibrated to existing data) without the investment and 100% following the intervention. This numerical change is arbitrary and is designed to generate a measurable system response, rather than mimic the behaviour of economic or physical systems.
Intervention: third layer		
15	Trajectory of changes in feed types	Chapters 5-9 lay out a transition between one set of feed types and origins in 2010 and another in 2030. However, no trajectory for this change was proposed. The scenarios allow "slow" (year 16) or "fast" (year 4) as transition years.
16	Price ratios	In recognition of the various demand drivers (rising demand for human foods, biofuels and other competitors for animal feeds) this scenario forces change into the system by way of shifting the ratio 1% (raising feed prices and lowering product prices). A negative impact on feed/product price ratio is used to mimic an increase in feed prices (due, for example, to increased demand for human food or biofuel), with animal product prices held constant.

Table 2.1 Scenarios

Annex Tables 2.2 and b presents results from a formulated set of runs that systematically examine every top level intervention in every system. The integers in table report the rankings WITHIN livestock systems: for each system the intervention ranked 1st provides the highest return from the 1% shock associated with each intervention. A rank of 11th is assigned to the intervention generating the lowest return for that system.

System	Number of animals	Area in feed	Feed yield or quality Planted pastures	Feed yield or quality Planted forages	Feed yield or quality Planted forages CC	Feed yield or quality Crop residues	Feed yield or quality Crop by-products	Feed yield or quality Other by-products	Feed yield or quality Grains	Feed yield or quality Roots and tubers	Increase animal productivity	
	Top layer interventions											
RUN 1												
EA DAIRY	1	3	9	4	5	8	7	6	9	9	2	**Lower layers**
SAs DAIRY IRR	1	4	8	6	8	3	5	8	7	8	2	Standard adoption
SAs DAIRY RF	1	4	9	7	9	3	5	8	6	9	2	Reduced price margins
WA BEEF INT	2	4	7	7	7	3	5	6	7	7	1	Standard participation in markets
WA BEEF AGRP	2	3	7	7	7	4	5	6	11	7	1	
WA SMRM	2	4	8	8	7	3	5	6	8	8	1	Trajectory = SLOW
WA SMR PU	10	11	6	5	6	2	3	4	8	9	1	Price ratios = Standard
SA SMRM EXT	2	3	7	6	7	4	7	7	5	7	1	
SA SMR INT	2	5	10	7	10	3	4	6	8	9	1	
RUN 2												
EA DAIRY	1	3	9	4	5	8	7	6	9	9	2	**Lower layers**
SAs DAIRY IRR	1	4	8	6	8	3	5	8	7	8	2	Accelerated adoption
SAs DAIRY RF	1	4	9	7	9	3	5	8	6	9	2	Standard price margins
WA BEEF INT	2	4	7	7	7	3	5	6	7	7	1	Standard participation in markets
WA BEEF AGRP	2	3	7	7	7	4	5	6	11	7	1	
WA SMRM	2	4	8	8	7	3	5	6	8	8	1	Trajectory = SLOW
WA SMR PU	5	11	7	6	7	2	3	4	9	10	1	Price ratios = Standard
SA SMRM EXT	2	3	7	6	7	4	7	7	5	7	1	
SA SMR INT	2	4	10	7	10	3	5	6	8	9	1	
RUN 3												

EA DAIRY	1	3	9	5	4	8	7	6	9	9	2	**Lower layers**
SAs DAIRY IRR	1	4	8	6	8	3	5	8	7	8	2	Standard adoption
SAs DAIRY RF	1	4	9	8	9	3	5	7	6	9	2	Standard price margins
WA BEEF INT	3	11	6	6	6	2	5	4	6	6	1	Standard participation in markets
WA BEEF AGRP	2	3	7	7	7	4	5	6	11	7	1	
WA SMRM	2	4	8	8	7	3	6	5	8	8	1	Trajectory = FAST
WA SMR PU	10	11	6	5	6	2	4	3	8	9	1	Price ratios = Standard
SA SMRM EXT	2	3	7	5	7	4	7	7	6	7	1	
SA SMR INT	2	7	10	6	10	3	4	5	8	9	1	
RUN 4												
EA DAIRY	1	3	9	4	5	8	7	6	9	9	2	**Lower layers**
SAs DAIRY IRR	1	4	8	6	8	3	5	8	7	8	2	Standard adoption
SAs DAIRY RF	1	4	9	7	9	3	5	8	6	9	2	Standard price margins
WA BEEF INT	2	4	7	7	7	3	5	6	7	7	1	Standard participation in markets
WA BEEF AGRP	2	3	7	7	7	4	5	6	11	7	1	
WA SMRM	2	4	8	8	7	3	5	6	8	8	1	Trajectory = SLOW
WA SMR PU	10	11	6	5	6	2	3	4	8	9	1	Price ratios = Standard
SA SMRM EXT	2	3	7	6	7	4	7	7	5	7	1	
SA SMR INT	2	5	10	7	10	3	4	6	8	9	1	

Table 2.2a Basic run, part 1

System	Top layer interventions											
	Number of animals	Area in feed	Feed yield or quality Planted pastures	Feed yield or quality Planted forages	Feed yield or quality Planted forages CC	Feed yield or quality Crop residues	Feed yield or quality Crop by-products	Feed yield or quality Other by-products	Feed yield or quality Grains	Feed yield or quality Roots and tubers	Increase animal productivity	
RUN 5												
EA DAIRY	1	3	9	5	4	8	7	6	9	9	2	**Lower layers**
SAs DAIRY IRR	1	4	8	6	8	3	5	8	7	8	2	Accelerated adoption
SAs DAIRY RF	1	4	9	8	9	3	5	7	6	9	2	Reduced price margins
WA BEEF INT	2	6	7	7	7	3	4	5	7	7	1	Enhanced participation in markets
WA BEEF AGRP	2	3	7	7	7	4	5	6	11	7	1	
WA SMRM	2	4	8	8	7	3	6	5	8	8	1	Trajectory = FAST
WA SMR PU	5	11	7	6	7	2	4	3	9	10	1	Price ratios = Standard
SA SMRM EXT	2	3	7	5	7	4	7	7	6	7	1	
SA SMR INT	2	4	10	7	10	3	5	6	8	9	1	
RUN 6												
EA DAIRY	1	3	9	4	5	8	7	6	9	9	2	**Lower layers**
SAs DAIRY IRR	1	4	8	6	8	3	5	8	7	8	2	Accelerated adoption
SAs DAIRY RF	1	4	9	7	9	3	5	8	6	9	2	Reduced price margins
WA BEEF INT	2	4	7	7	7	3	5	6	7	7	1	Enhanced participation in markets
WA BEEF AGRP	2	3	7	7	7	4	5	6	11	7	1	
WA SMRM	2	4	8	8	7	3	5	6	8	8	1	Trajectory = SLOW
WA SMR PU	2	11	7	6	7	3	4	5	9	10	1	Price ratios = Standard
SA SMRM EXT	2	3	7	6	7	4	7	7	5	7	1	
SA SMR INT	2	4	10	7	10	3	5	6	8	9	1	
RUN 7												

EA DAIRY	1	3	9	4	5	8	7	6	9	9	2	**Lower layers**
SAs DAIRY IRR	1	4	8	6	8	3	5	8	7	8	2	Standard adoption
SAs DAIRY RF	1	4	9	7	9	3	5	8	6	9	2	Standard price margins
WA BEEF INT	2	4	7	7	7	3	5	6	7	7	1	Enhanced participation in markets
WA BEEF AGRP	2	3	7	7	7	4	5	6	11	7	1	
WA SMRM	2	4	8	8	7	3	5	6	8	8	1	Trajectory = SLOW
WA SMR PU	5	11	7	6	7	2	3	4	9	10	1	Price ratios = Standard
SA SMRM EXT	2	3	7	6	7	4	7	7	5	7	1	
SA SMR INT	2	4	10	7	10	3	5	6	8	9	1	

Table 2.2b Basic runs, part 2

3. Detailed scenarios for each system

Following the generalised scenarios applying all investments to all systems to generate rankings (above), in what follows a small number of system-specific scenarios are examined. The scenarios chosen are defined in relation to descriptions of the systems and recommendations for change, as presented in chapters 5-9. Values presented for NPV are of interest primarily in their relative, rather than actual magnitudes, and the discussion therefore focuses on comparisons of options within systems rather than between systems and based on monetary values.

3.1 Close examination of East African Dairy systems

For East African dairy systems, public investment in infrastructure and knowledge services have been recommended in chapter 5, in association with improved feed technologies and credit. Table 3.1.1 presents results of an analysis of alternative private investments (more animals, more productive forages) under different combinations of public and private investment, in the context of both fast and slow trajectories of change in feeding systems. This analysis addresses the aforementioned challenge of investments that deal with the underlying profitability of feeding systems: essentially providing incentives for enhanced productivity rather than simply increasing animal numbers.
Under standard conditions for public investment and action on knowledge dissemination (reflected in rates of adoption, market participation and levels of transaction costs), investments in improved forage yield a NPV of just 62% of that available from increasing animal numbers. However, the combination of public (left hand column) and private investment yields a substantially higher return, and also a substantially-increased forage investment return relative to that in additional animals (74% as opposed to 62%).

This result also yields some insight into the conditions under which such blends of public and private investment can be used. With no public investment and under a slow trajectory

of change, returns to forage improvement shrink to just 48% of that from increased animal numbers. However, the blend of public and private investment appears to generate conditions under both slow and fast change trajectories, such that forage improvement generates returns to investment of about 74% of that of increased animal numbers. However, the enhanced market participation and adoption would be difficult to achieve without improvements in credit availability, further reinforcing this key recommendation from chapter 5.

Public investment and market environment	**Private investments**	**Trajectory**	
		NPV of investment (1000 USD)	
		FAST	SLOW
Standard adoption Standard market participation Standard transaction costs	Increased animal numbers	11,939	12,152
	Enhanced yield or quality of forages (planted and cut and carry)	7,388	5,892
Return on investment in forage quality: % of return on investment in animal numbers		62%	48%
		FAST	SLOW
Accelerated adoption Enhanced Market participation Reduced transaction costs	Increased animal numbers	92,695	92,691
	Enhanced yield or quality of forages (planted and cut and carry)	71,442	68,505
Return on investment in forage quality: % of return on investment in animal numbers		77%	74%

Table 3.1.1 East African Dairy: combinations of investments and feed system change trajectory

3.2 Close examination of South Asian Irrigated Dairy systems

Recommendations in chapter 6 (on South Asian dairy systems) feature investments in improved forage and feed-food crop genetics, along with improved access to these improvements and to knowledge services. In particular, a Business Development Services approach is recommended to both promote and utilise better-functioning markets.
The results of the analysis (table 3.2) project a positive NPV from investments in enhanced food-feed crop productivity or quality, and similarly from forages (both planted and cut and carry). Table 10.6 emphasises the increase in the return that is available from accompanying investments to boost uptake of the new technologies and from increasing overall participation in feed and dairy markets: essentially an 8-fold increase in return on investment. These results again support the proposed complementarity of investments in technology with those in knowledge and service provision, as well as policy support for improved infrastructure and transaction governance (see table 6.4). The apparent multiplier effects of improved market function and producers' accelerated adoption are here particularly relevant

to BDS as a development approach, and would require the infrastructure and governance investments as pre-requisites for BDS implementation. Several models have been explored in India in the context of Operation Flood (Guatam et al., 2010) and in relation to the operations of BAIF (Gokhale et al., 2007), with the latter clearly demonstrating the opportunity for decreasing animal numbers in relation to improved per animal productivity and other support services. In such situations, public investment needs to target adaptive research, sustained organisations and infrastructure to facilitate the delivery of increased knowledge and services to farmers.

Public investment and market environment	Private investments	NPV of investment (1000 USD)
Standard adoption Standard market participation	More food-feed crops, more forages (planted and cut and carry)	324,711
Accelerated adoption Increased market participation	More food-feed crops, more forages (planted and cut and carry)	2,971,728
Increase Return on investment in forage and food-feed crops		> 800%

Table 3.2.1 South Asian Dairy – Irrigated: forage and by-products in combination with enhanced access and knowledge systems

3.3. Close examination of South Asian Rain-fed Dairy systems

For both south Asian dairy systems, chapter 5 draws considerable attention to the importance of utilising crop by-products and developing food-feed crops. For South Asian rain-fed dairy systems, greater opportunity exists for increasing areas in feed, than is the case in irrigated systems. Table 3.3.1 shows the NPV projections for a comparison between a 1% increase in feed area (across all feeds) and a 1% increase in the quality or productivity of food-feed crops, and of forages. The superior return results from improved quality or productivity of these feeds

One reason for this result is that the feed productivity increases under consideration target the feeds with highest contribution to the system (via nutritive value and use in the system). A factor not included in the analysis that would reinforce the result is that returns to food-feed crops are high due to demand for food and costs of land area increases are high due to opportunity costs. Also beyond the scope of this analysis is the consideration of spillover benefits from improved feed genetics beyond the livestock system in question.

Private investments	NPV of investment (1000 USD)
More food-feed crops, more forages (planted and cut and carry)	245,180
Increased area in feed	188,193

Table 3.3.1 South Asian Dairy – Rain-fed: investments in forage and areas in feeds

3.4 Close examination of Intensive West African Beef systems

The widespread use of cattle as draught power in West Africa favours mixed crop-livestock systems, in which crop residues will play an important feeding role for the small numbers of animals in the production systems (see chapter 6). The recommendations for West African Beef systems feature a shift from community and own-farm sources of additional feed, to the market. This raises two challenges: securing additional feed; and making the market more attractive to livestock-keeping households.

Reducing transactions costs is emphasised in chapter 6, and new feeds were also identified, particularly the use of by-products from sources other than crops grown on the farm (e.g. processing by-products). The projections shown in table 3.4.1 below anticipate a positive return on a 1% increase in availability of these feeds, which is increased almost 10-fold (to a NPV of some 98 million USD) by a 1% reduction in transactions costs. The spatial separation of West Arica's ruminant meat-consuming populations (urban, and in a coastal belt) from remote supply areas, pre-disposes to this result in that transaction costs constrain market participation, a feature that was highlighted by the studies of Williams et al (2006).

Public investment and market environment	**Private investments**	**NPV of investment (1000 USD)**
Standard transaction costs	Improved production or utilisation of processing by-products	10,993
Reduced transaction costs	Improved production or utilisation of processing by-products	98,110

Table 3.4.1 West African Beef – Intensive: investments in other by-products and in influencing the transaction environment

3.5 Close examination of Agro-Pastoral West African Beef systems

Beef-producing agropastoral systems in West Africa are projected to require significantly increased quantities and/or qualities of crop residues, crop by-products and other by-products. Chapter 6's conclusions emphasise the importance of knowledge transfer systems, particularly in promotion and uptake of technologies for storage and processing. Table 3.5.1 suggests knowledge provision can increase the NPV of a 1% increase in the productivity or quality of the aforementioned feed sources, by about 35%.

As seen above for East African dairy systems, it is notable that this relative return on blends of public and private investment is available regardless of whether the changes to the system's feed profile are on a "fast" or "slow" trajectory. However, other factors not included in this analysis come into play that favour a fast trajectory for West African beef production. Chief amongst these may be management of water, soil and vegetation, which chapter6's recommendations couch in terms of community-based strategies.

Public investment and market environment	**Private investments**	**Trajectory**
		NPV of investment

		(1000 USD)	
		FAST	SLOW
Standard adoption	Increased yield or quality of crop residues, crop by-products and other by-products	2,685	2,263
Accelerated adoption	Increased yield or quality of crop residues, crop by-products and other by-products	3,620	3,036
Increase in NPV due to accelerated adoption (%)		35%	34%

Table 3.5.1 West African Beef – Agro-pastoral: investments in feed sources, accompanied by knowledge systems

3.6 Close examination of West African Intensive Small Ruminant systems

Chapter 7's presentation of West African small ruminant systems features a transition from natural grazing toward confinement and use of other feeds. In particular, increased use of crop by-products and other by-products are anticipated. In this context, table 3.6.1 below addresses the earlier discussion of incentives to increase animal numbers. The relatively low per-head purchase prices of small ruminants, and the ease of deferred sales of animals, is likely to promote this as a feature of non-housed small ruminant systems. According to results of this analysis, the NPV of a 1% increase in the number of animals kept is projected to be around 44 million USD. In contrast, a 1% increase in the productivity or quality of crop by-products and other by-products is projected to be about 27 million USD. However, the return on the feeds improvement can be almost doubled to 49 million USD by investments in knowledge systems and other promoters of more rapid and more widespread adoption. This figure is higher than that available from increased animal numbers.

This analysis identifies West African small ruminant systems as ones in which investment in policy and facilitation of knowledge flows can be used to create fundamental change in the underlying profitability of feed, so as to generate incentives for improved production and utilisation of feeds that exceed those available from ever-larger numbers of animals.

Public investment and market environment	Private investments	NPV of investment (1000 USD)
Standard adoption	Increased animal numbers	44,204
Standard adoption	Improved production or utilisation of crop by-products and other by-products	27,594
Accelerated adoption	Improved production or utilisation of crop by-products and other by-products	49,010

Table 3.6.1 West African Small Ruminants – Intensive crop-livestock systems: investments in feed sources, accompanied by knowledge systems

3.7 Close examination of Peri-Urban West African Small Ruminant systems

This system is one of the few for which the analysis (see chapter 7) projects increased uses of grains and balanced concentrates. These feed sources are likely to be influenced in the future by food-feed competition, as well as by biofuel demand and use. This is also a system in which few feeds are sourced on the farm, and for which reliance on the market as a source of feed, is likely to increase. These systems as presented in chapter 8 feature a diverse feed profile, so that scenarios addressing the transaction environment necessarily address a number of feeds at the same time. Table 3.7.1 below presents results from selected scenarios in which the system is subjected to a 1% negative change in the ratio of feed to product prices. This change is then projected under scenarios of increased productivity of selected feed types, and then a combination of these feed types with an improved transaction environment (modelled as a reduction in transaction costs).

Scenarios suggest that investment in productivity or quality of grains and various by-products can almost offset the significant decline in NPV brought about by a change in feed/food price ratios. Moreover, public investments in policy change for the transaction environment can more than compensate for the reduced prices, yielding a positive NPV for the combined scenario.

Public investment and market environment	**Private investments**	**NPV of investment (1000 USD), under changed feed/product price ratios**
Standard transactions		-29,581
Standard transactions	Improved production or utilisation of crop by-products, other by-products, and grains	-1,060
Reduced transaction costs	Improved production or utilisation of crop by-products, other by-products, and grains	12,746

Table 3.7.1 West African Small Ruminants – Peri-urban systems: price changes, investments in feed sources, and public investment in the transaction environment.

3.8 Close examination of Extensive Small Ruminant systems in Southern Africa

Extensive Southern African small ruminant systems are expected to source little feed from the market, with the most pronounced changes expected to be in the composition of feed used, particularly by way of reduced reliance on pasture. The focus on own-farm production requires some consideration of investment in areas used for feed production, as opposed to investment in feed productivity or quality as projected in chapter 7. Table 3.8.1's results summarise results indicating that a 1% increase in feed area would yield a NPV double that available from a 1% improvement in the selected feeds' yield or quality.
The cost of increasing feed area (both in terms of cash and as opportunity cost) is likely to be higher than that associated with the productivity change proposed in the scenario examined here, particularly in terms of provision of public goods and services as knowledge systems. Indeed, the cost of additional community grazing may be prohibitive or its acquisition infeasible. However, the result indicates that systems that currently rely heavily

on community grazing would also favour investments in more community grazing, and this may well be a barrier to adoption of technologies inherent in alternative investment. There are however, examples of improved community management of common grazing resources that give impressive returns for animal productivity (see for example Gebremehdin et al., 2010)

Private investments	**NPV of investment (1000 USD)**
Increased area in feed	8,224
Increased productivity or quality of forages, crop residues and grains	3,770

Table 3.8.1 Southern African Small Ruminants – Extensive systems: increased areas in feed, and investments in feed sources.

3.9 Close examination of Intensive Small Ruminant systems in Southern Africa

Intensive Southern African small ruminant systems are projected to rely substantially more on grains and roots and tubers in the future, than is currently the case. Table 3.9.1 presents scenarios for investments in increasing the productivity or quality of these feeds, under fast and slow trajectories of change. The investments yield a 19% higher return, where a fast trajectory applies, than under a slow trajectory. This result indicates that within such systems, those producers that are already in transition would benefit most from the investments proposed. Similarly, the knowledge products and services provided to produces would ideally target the stage of transition between feeding systems that applies in each context.

Private investments	**NPV of investment (1000 USD)**
Yield or quality of grains, and roots and tubers – Fast trajectory	7,291
Yield or quality of grains, and roots and tubers – Slow trajectory	5,900
Increase in NPV due to a fast vs slow trajectory	19%

Table 3.9.1 Southern African Small Ruminants – Intensive systems: investment in grains, and roots and tubers; and the trajectory of feed system change.

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