Promising options for improving livestock production and productivity in developing countries

ILRI PROJECT REPORT

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October 2019

ILRI thanks all donors and organizations which globally support its work through their contributions to the CGIAR Trust Fund

Editing, design and layout—ILRI Editorial and Publishing Services, Addis Ababa, Ethiopia.

Cover photo—ILRI/Susan MacMillan and ILRI/Paul Karaimu

ISBN: 92–9146–232–2

Citation: Enahoro, D., Herrero, M. and Johnson, N. 2019. *Promising options for improving livestock production and productivity in developing countries*. ILRI Project Report. Nairobi, Kenya: ILRI.

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Abbreviations and acronyms

AI	artificial insemination
CBPP	contagious bovine pleuropneumonia
CCAFS	CGIAR Research Program on Climate Change, Agriculture and Food Security
cm	centimetres
DM	dry matter
ECF	East Coast fever
ha	hectare(s)
IBLI	index-based livestock insurance
IFPRI	International Food Policy Research Institute
ILRI	International Livestock Research Institute
IMPACT	International Model for Policy Analysis of Agricultural Commodities and Trade
ITM	infection-and-treatment
kg	kilogram(s)
LWP	livestock water productivity
m	metre
MAI	marker-assisted introgression
N	nitrogen
OTC	oxytetracycline
PIM	CGIAR Research Program on Policies, Institutions and Markets
PPR	Peste des Petits Ruminants
SFFF	Safe Food, Fair Food project
t	tonne(s)
TLU	tropical livestock unit

Acknowledgements

This project received funding from the Bill & Melinda Gates Foundation (grant number OPP1164455) through a research agreement (contract number 2009X444.ILR) between ILRI and the International Food Policy Research Institute (IFPRI). For their invaluable input and time, special thanks are due to the following researchers at ILRI: Okeyo Mwai, Julie Ojango and Karen Marshall (who provided information on genetics and animal reproduction), Phil Toye and Henry Kiara (for information on livestock diseases and vaccines), Michael Blümmel, Alan Duncan and Ben Lukuyu (on livestock feeds) and Delia Grace (on zoonotic diseases and food quality and safety). The authors assume full responsibility for errors and omissions.

Disclaimer

This report was completed at ILRI as an output of the Global Futures and Strategic Foresight (GFSF) project. It contributes to the CGIAR Research Programs on Policies, Institutions and Markets (PIM) Livestock Agri-food systems (Livestock) and Climate Change, Agriculture and Food Security (CCAFS). The report is an expanded version of a document earlier submitted to GFSF management and the Bill & Melinda Gates Foundation. Much of the material was collated prior to 2012 and has not been updated to reflect possible advances in various fields.

The report has not undergone peer review. Opinions expressed belong to the authors and do not necessarily reflect those of the Bill & Melinda Gates Foundation, CGIAR or ILRI. The authors assume full responsibility for errors and omissions.

1. Summary

An earlier strategy report to inform donor investments in international agricultural research highlighted the importance of animal-source foods in human nutrition in poorer countries as well as the strategic positioning of the livestock sector for meeting globally identified objectives for human development. That report presented a selection of intervention options with potential for improving outcomes in low-resource livestock production systems that centered on technological solutions to enduring challenges of animal nutrition and health, as well as options for securing the livestock assets of producers under adverse environmental and climate conditions. In this updated report, an expanded selection of technologies with promise for delivering food security, employment generation and related dividends in smallholder livestock settings is presented. The report details suggested approaches to the development and deployment of vaccines for key cattle and small ruminant diseases, advances addressing broader issues of animal health, associated human health and food safety. Focus is also placed on technologies related to animal nutrition and genetics and to the management of the natural resource base. Beyond scientific advancements, the report highlights policy and market changes, and other adjustments that are needed to address pressing constraints to livestock sector development in lower income countries. The full report was compiled following extensive consultations with scientists and managers at the ILRI and associates.

2. The global livestock sector

The global livestock sector contributes up to 40% of the total value of world agriculture, accounting for upwards of 50% of agricultural gross domestic production in industrialized countries, and 33% on average in developing regions (FAO 2003). Livestock production is in addition a major employer of labour, retaining up to 1.3 billion people worldwide, many of whom are poor or smallholder livestock keepers and reside in developing countries (Staal et al. 2009). It is estimated that 23% of the total calories consumed per person in developed regions comes from animal sources while protein from livestock sources contributes 10% of unit calorie intake in developing regions (FAO 2003). There is significant variation in the consumption of livestock products across developing regions. While animal-source foods make up nearly 20% of calorie intake in South America, only about five per cent of the per capita calorie consumption in sub-Saharan Africa is of livestock origin. Total intake of meat, milk and eggs adds up to 174 kilograms (kg) on average per person per year in Central America and 227 kg in South America but is quite low in southeast Asia and in Africa, at 52 kg and 67 kg per person on average, respectively (Table 1).

Table 1: Consumption of meat, milk and eggs in selected countries and regions in 2011 (kg/person/year)[1]

Country/region	Meat	Milk	Eggs	Total intake
Burkina Faso	16.25	21.6	2.7	40.55
Vietnam	57.6	15.08	3.55	76.23
India	4.13	84.22	2.38	90.73
Nicaragua	27.43	79.93	4.4	111.76
Kenya	16.63	99.86	1.87	117.76
Brazil	92.97	150.78	8.75	252.5
United States	117.61	256.77	13.89	388.27
Southeast Asia	29.16	17.85	5.47	52.48
Africa	18.62	46.17	2.47	67.26
Central America	53.98	104.88	15.33	174.19
South America	78.38	140.2	9.23	227.81
World	42.36	90.73	8.95	142.04

Source: FAOSTAT 2015

Although there is global concern about potential negative effects of animal-source protein production and consumption, e.g. on human health and the environment, there remains substantial scope for improving nutrition and health outcomes in countries with historically low animal-source protein consumption through increased and efficient utilization of livestock (Herrero et al. 2013a; ILRI 2019). Studies on low-income countries have linked increased consumption of livestock food products to improved physical and mental health outcomes, particularly among children, with some reporting that the introduction of even minimal increases in the intake of animal-source

1 Burkina Faso, Kenya, India, Vietnam and Nicaragua have been important countries for ILRI research. Data for Brazil and the United States are included as benchmarks for emerging and developed countries, respectively. At the time of compiling this report, 2011 was the most recent year for which data (FAOSTAT) was available for all selected countries.

foods offer huge potential for stemming nutrition-related illnesses and diseases (Murphy and Allen 2003; Speedy 2003; Dror and Allen 2011). The statistics suggest that there is already a boom in the demand for livestock products in emerging and developing countries. This trend, driven by increasing incomes and populations, and by such factors as globalization, urbanization and changing consumer tastes, is expected to persist in the coming decades. Projections to 2050 tend to agree that the demand for livestock products will likely double from levels observed in the early 2000s, with global supplies needing to expand to meet this demand (Delgado et al. 1999; Steinfeld et al. 2006; Thornton 2010).

Global livestock production has seen substantial growth in recent decades. Meat production is estimated to have grown by more than three times from the early 1980s to the late 2000s (FAOSTAT 2015). Much of this expansion has been in the fast-growing economies in east and southern Asia. By year 2009, China and India were the top two producing countries in the world for meat, milk and eggs (Table 2). Among developed countries, the United States, Japan, Russia and Germany rank highest in the production of livestock products, while China, India and Brazil dominate production in developing regions.

Table 2: Meat milk and egg production in the five highest-producing countries ('000 tonnes (t))

Meat		Milk		Eggs	
Country	Production	Country	Production	Country	Production
China	78,118	India	110,936	China	27,773
United States	41,643	United States	85,880	United States	5,349
Brazil	20,100	China	40,385	India	3,324
Germany	7,884	Pakistan	34,362	Japan	2,508
Russia	6,570	Russia	32,565	Mexico	2,360

Source: FAOSTAT 2015

Given its strategic role in many developing countries, opportunities may exist to harness growth of the livestock sector towards more general national development. In addition to employing livestock sector development in meeting food and nutrition security objectives, there may be room for improving the incomes and livelihoods of smallholder and poor livestock keepers in developing countries by enhancing their participation and competitiveness in formal markets for livestock and livestock products (Herrero et al. 2013a, Herrero et al. 2009; Staal et al. 2009). Thornton (2010), however, pointed out that the potential for smallholder production systems to take advantage of the unfolding livestock revolution was neither well understood nor guaranteed.

2.1 Livestock production and productivity in smallholder systems

While agriculture in general accounts for a substantial proportion of livelihoods and incomes in developing regions, smallholder operations form the bulk of the production. Technological, resource, market and policy challenges faced by this group of agricultural operators have quite far-reaching implications for national food security and economic stability. In the case of livestock production, it has been estimated that there are more than 900 million poor livestock keepers, i.e. living on less than two United States dollar (USD) per day, in south Asia and sub-Saharan Africa (Staal et al. 2009). For these smallholders, livestock play multiple functions that range from the provision of vital diet protein to the supply of soil nutrients and draught power for agricultural production. In addition, livestock may fulfill diverse ceremonial and cultural roles, form the base of household assets, and are a primary tool for financial and risk management. However, productivity in smallholder livestock operations in developing countries tends to be severely constrained. For example, the volume of milk produced per animal in smallholder (typically rural) dairy systems in developing countries may be on average only about 25% of the yields observed in developed regions, even under similar agroclimatic conditions (Herrero et al. 2013b).

The dynamics of livestock production can vary substantially with agro-ecological and related conditions, so that a sound understanding of global livestock production systems provides a good entry point for assessing the potential for livestock technology development in developing countries. Sere and Steinfeld (1996) classified global livestock production into 11 broad systems that account for heterogeneity in agro-climatology, type of livestock under management (e.g. monogastrics or ruminants) and for ruminant animals, the use of grasslands as a livestock feed source. This classification system and variations of it have been widely applied in livestock systems research, including in the mapping of livestock-oriented agricultural systems, the assessment of demand-induced changes in agro-ecological services and the disaggregation of country-level livestock data to test assumptions of technological change (Kruska et al. 2002; Herrero et al. 2009; Robinson et al. 2011). At ILRI, variations of the Sere and Steinfeld (1996) classification of livestock production systems has also been applied to the assessment of the role of livestock development as a tool for improving rural livelihoods in Africa and Asia.

Priority-setting exercises (including Staal et al. 2009) have resulted in the selection of a number of livestock production systems as priority areas for research at ILRI. These systems include dairy production in east Africa and south Asia, pig production in south Asia, beef in west Africa and small ruminant meat production in west and southern Africa. In general, livestock provides important sources of food, income and livelihoods for resource-poor populations in the priority regions. These regions and systems account for much of the specific livestock activity globally (Table 3).

Table 3: Livestock populations in selected regions, 2000[1,2]

	Bovine dairy ('000 TLU)	Bovine other ('000 TLU)	Sheep and goat dairy ('000 TLU)	Sheep and goat other ('000 TLU)
East Africa	12,853	44,785	6,651	11,358
South Asia	42,376	140,642	5,387	24,363
West Africa	3,321	19,586	1,576	13,677
Southern Africa	3,032	21,844	30	5,968
World total	169,342	787,373	33,289	147,907

Source: Herrero et al. 2009.

[1]Animal numbers reported here do not include replacement, e.g. heifers, in dairy cattle herds.

[2]A tropical livestock unit (TLU) assumed roughly equivalent to 250 kg of body weight.

The bovine dairy population in east Africa and south Asia makes up more than 30% of the recorded numbers of dairy bovine animals worldwide. Similarly, small ruminant dairy animals in these two regions are 36% or more of the global population of dairy sheep and goats. Small ruminants kept for nondairy purposes (mostly meat production) in west and southern Africa are up to 15% of this category of livestock worldwide. The key constraints to livestock production in these regions and smallholder systems include low performance of the gene stock, high incidence and severity of livestock diseases, limited cash flow and capital resources, scarce natural resources and vulnerability to environmental vagaries such as the immediate and long-term effects of changes in the global climate. Further, unfavourable market and price conditions, poor institutions, and the lack of adequate policy design and implementation hamper production.

2.2 Options for improving livestock productivity in developing countries

Options for increasing the productivity and production of livestock in developing countries have rightly focused on tools for improving animal genetics and breeding, livestock nutrition, and animal disease prevention, diagnostics, treatment and control. In the context of many developing countries, however, the use of advanced technologies are useful only to the extent to which they can be adapted and made available to smallholder settings. As such, this report focuses on technologies identified as having been specifically developed for, or being easily adaptable to, use in smallholder livestock systems.

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3. Livestock health

Livestock diseases and other sources of poor animal health are major constraints to livestock production, imposing a huge economic burden in many developing countries. Diseases such as animal sleeping sickness, bovine pneumonia and East Coast fever (ECF) kill thousands of livestock in Africa each year. More generally, livestock ailments cause a high number of livestock deaths in developing countries and reduce the productivity of surviving animals. In addition, certain livestock diseases have the potential to exclude poorer farmers from mainstream livestock markets because of negative effect on food quality. Strategies to improve livestock productivity in developing countries must necessarily include animal health components, including efficient disease identification and control mechanisms. This perhaps becomes more apparent within the context of a changing global climate where disease dynamics (including type, incidence, spread and interactions) are likely to undergo quite dramatic changes in response to changes in climate patterns and vegetation. Currently, ECF is a disease with huge economic impacts throughout the regions of eastern, central and southern Africa. Contagious bovine pleuropneumonia (CBPP) also imposes heavy burdens on incomes and livelihoods in the region, while peste des petites ruminants (PPR) is a major cause of low productivity in small ruminants throughout sub-Saharan Africa. Strategies for the control of these identified diseases include the development of effective vaccines that are adapted for use in low-input or smallholder systems. However, as is the case for high-impact human ailments like malaria and diseases caused by the human immunodeficiency virus HIV, the development of effective vaccines for the most important livestock diseases in developing countries could be costly, take considerable effort and span several years.

3.1 Vaccines

ECF

Theileriosis or ECF is a vector-transmitted disease caused by the intracellular protozoan, Theilera parva. Exotic cattle breeds such as Bos (B.) taurus and calves of indigenous or adapted breeds such as the Zebu cattle (B. indicus) are particularly predisposed to contracting the disease (Di Giulio et al. 2009). ECF is found in up to 11 countries in the east, central and southern Africa regions. Among pastoral communities, 30 to 60% of unvaccinated calves could be lost to the disease every year (Homewood et al. 2006). While accurate data on the economic implications of ECF and more generally of livestock diseases in Africa are hard to come by, earlier studies (Mukhebi et al. 1992) placed the ECF disease fatalities in endemic regions at 1.1 million cattle annually and associated economic losses at USD 168 million per year. Further, up to 28 million cattle, or close to 20% of the total cattle population in the affected region, were considered at risk (McCleod and Randolph 2000). Table 4 characterizes the scope of application for a new multicomponent ECF vaccine.

Breeding for genetic resistance, the use of acaricides to curb tick infestation, treatment of identified clinical cases and the use of vaccines have been the standard tools employed in combination to combat tick-borne diseases such as ECF. Of these scientific approaches, the development of effective disease vaccines may be most economical and sustainable (Minjauw and McLeod 2003). In many developing countries, for example, the use of the acaricides has proven especially difficult to sustain owing to resistance development in ticks, constraints on the capital and financial resources required to maintain dipping facilities, and food safety and environmental health concerns (Martins et al. 2010; Di Giulio et al. 2009). Alternative control based on the use of live ECF vaccines has also been employed in the endemic regions. Notable of this is the 'infection-and-treatment' immunization method (ITM) developed by the east African community, Kenya Agricultural Research Institute and ILRI.

Table 4: Cattle populations in ECF endemic areas in east, central and southern Africa

Country	Country cattle population (heads in millions)	Cattle population in theileriosis risk areas (heads)	Cattle population in theileriosis risk areas (%)
Kenya	52.68	9.44	18
Tanzania	50.38	8.86	18
Zimbabwe	16.24	1.75	11
Zambia	7.33	1.76	24
Uganda	16.00	4.74	30
Others in region*	4.00	1.80	45
Region totals	146.64	28.35	19

Adapted from McCleod and Randolph (2000).

*Rwanda, Democratic Republic of Congo, Malawi and Mozambique

The basis of the ITM, established more than 30 years ago, lies in the scientific ability to harvest sporozites of the ECF disease from carrier ticks, preserve the material in stable form using very low temperatures and induce protective immunity in cattle by simultaneous injection of the stabilate with appropriate dosages of oxytetracycline (OTC). While cattle so infected typically experience asymptotic or mild reactions to the induced infection, the long-acting OTC antibiotic is able to stem further development of the disease (Di Giulio et al. 2009). Although available much earlier, the ITM did not garner much support with scientists and authorities and was not deployed on a large scale until the late 1990s, in Tanzania. In that first successful mass administration of the vaccine, more than 250 million pastoralist Zebu calves were vaccinated in Northern Tanzania over a ten-year period (from 1998 to 2008). Calf mortality reductions of up to 95% were reported from the trial and livestock owners were reported to receive up to 50% more from the sale of vaccinated animals following observable live-weight gains of vaccinated cattle over unimmunized animals. There has been substantial demand for the ILRI08 live vaccine (also known as Muguga cocktail) used in that trial and it has been registered for use in Tanzania, Kenya and Malawi (Di Giulio et al. 2009).

Future research and development

As outlined, effective vaccines for ECF control have been developed following the (live vaccine) infection-and-treatment (ITM) methods. Technology for the bulk production of these vaccines is also available, as outlined (in Di Giulio et al. 2009, for example). Current challenges to the widespread use of ITM vaccines in affected regions lie in the areas of dissemination to end users, including the development of relevant partnerships with private-sector actors that can build effective product distribution channels. In addition, opportunity for further success in ECF control in affected regions may lie in the development of a multicomponent recombinant vaccine with marked advantages over the current live vaccine methods. For example, deployment of live vaccines for ECF control has sometimes been accompanied by very high financial and administrative costs associated with monitoring adverse reactions in vaccinated animals. The reactions in themselves can also prove to be quite costly. In an early ITM trial in Tanzania, up to 44% of vaccinated calves in the Kilimanjaro region showed severe reactions (i.e. developed clinical ECF). There may also be benefits to accrue from eliminating the stringent cold-chain requirements of distributing live vaccines for mass use. McLeod and Randolph (2000), in a business plan developed to assess the potential for a nonlive, multicomponent recombinant vaccine for ECF, estimated a real retail market value of USD 6.4 million by the year 2025. The greatest scope for adoption was among smallholder dairy and large commercial livestock operators. The vaccine, it was estimated, could lead to reductions in economic losses due to ECF disease of up to USD 10.1 million yearly in the affected countries. The value of milk production was also expected to go up by USD 1.7 million, with a 52% probability of project success.

CBPP

CBPP is caused by a parasitic bacterial species, Mycoplasma mycoides subspecies mycoides Small Colony. It is a contagious disease affecting the lungs and pleura of cattle and is not known to affect humans. High mortality rates are often associated with CBPP disease outbreak, with serious economic consequences in Africa, India and China. The disease used to be prevalent in the United States, the United Kingdom and Australia, but has been absent in these regions since the end of the nineteenth century (from 1973 in the case of Australia). More recent outbreaks, however, have occurred in France, Italy, Portugal and Spain. Economic losses associated with CBPP follow from reduced productivity, illness-related deaths and slaughter of animals as a control mechanism. Detailed data are not readily available, but country studies could provide some indication of the potential magnitude of CBPP-related economic losses globally. For example, it is estimated that USD 11 million was lost to the economy of Tanzania following the CBPP outbreak in 1990. Botswana saw a loss of USD 100 million in direct costs incurred in the slaughter of 320,000 cattle and another USD 400 million in indirect costs attributed to the disease.

The major mechanism by which CBPP has been eliminated in developed countries is through the slaughter of infected and exposed animals. Carcasses of infected animals are also condemned at slaughter. In the case of Africa, control of CBPP has seen mixed results with initial successes in the 1960s followed by reversals in the trend since then. CBPP control is most effective where there is adequate animal health monitoring including physical inspection and/or blood testing of new entrants, and where cattle movements can be controlled. In these cases, risks of introduction of the disease are minimized. However, a control policy for CBPP that is solely dependent on euthanasia might not be a viable alternative in endemic areas, particularly where the income, livelihoods and food security of the poor are very closely tied to their ownership of cattle, and where adequate compensation mechanisms are not readily available. In these areas and where cattle movements are largely uncontrolled, effective measures for sustained CBPP control could rely on the use of vaccines. The direction of CBPP research at ILRI is towards the development of improved diagnostic tests and vaccines. The identification in the sera of infected animals of novel immunogenic proteins with varying antibody responses to CBPP may hold much promise for diagnostic tools and vaccines (Jores et al. 2009). In addition, diagnostic tools and vaccines for livestock diseases in developing countries are best developed as part of a wider program to improve livestock monitoring systems and the provision of animal health services, particularly in low-input and extensive systems. Better control of cross-border cattle movements in affected regions is also necessary in the case of diseases like CBPP.

PPR

A highly contagious viral disease, PPR mostly affects sheep and goats. The PPR virus has also been linked to fatalities in camels and is known to cause asymptomatic infection in cattle and wildlife (Elsawalhy et al. 2010). However, it is not known to have zoonotic effects. To date, PPR has been found in parts of the Middle East, Africa and south Asia, with significant threats of spread to North and southern Africa, central Asia and southern Europe. More than half of the small ruminant livestock population at risk is found in East and southeast Asia (57%). Africa (23%) also has significant populations of small ruminants in areas with high PPR threat. Table 5 presents a summary by region of small ruminant populations with PPR risk. Where the disease has been observed, livestock mortalities have typically been quite high, particularly in nonendemic areas where herd losses of up to 100% have been recorded following new infection. A 1979 outbreak in Nigeria recorded an estimated 10 to 20% loss in the national herd, with a (then) current value of USD 75 million (AU-IBAR 2013).

Table 5: Sheep and goat populations at risk of PPR

Region	Small ruminant populations at risk (heads in millions)
Central Asia	43.1
Middle East	171.9
East and southeast Asia	647.5
Africa	264.2
Total at risk	1,126.9
Global small ruminant population	1,801.4

Source: FAO 2010.

The mechanisms for sustained control of PPR in smallholder livestock production systems include a combination of livestock movement controls, active herd surveillance and disease reporting, quarantine and testing of new entrants or other suspects, rapid response including slaughter and disposal, sanitization of infected or exposed areas, and ring vaccination and/or vaccination of all at-risk populations (Elsawalhy et al. 2010; Bett et al. 2008). An effective vaccine for PPR exists in the form of the Nigeria 75/I strain, with successful trial and field use. An important objective for the improvement of the available vaccines is the development of thermal stability properties in the inoculants. The current focus of PPR research at ILRI is the development of vaccine thermostability which could eliminate the need for refrigeration, improve the potential for administration of the vaccine in dispersed locations and reduce overall costs of disease control. As has been the case in west Africa, however, where the first outbreaks of PPR were recorded, and in the sustained control globally of the rinderpest virus (which has similar epidemiology and biology to the PPR virus), the development and use of vaccines may be central only to a more multifaceted approach. Key elements of technical and institutional support are required for effective PPR control in endemic and newly affected areas (personal communication with ILRI scientists 2015). In line with this thinking, Elsawalhy et al. (2010) pointed out the need for research and policy dialogue to develop effective partnerships among private, public and grassroots or community stakeholders for progressive control of the disease, underscoring the usefulness of economic research to analyze incentives for stakeholder participation and the need for epidemiologic research to better understand the dynamics of the disease transmission.

3.2 Diagnostics, monitoring and surveillance

The development of appropriate tools for the diagnoses of important livestock diseases in developing countries goes hand in hand with research to develop tools for control of these diseases. It is important to note, however, that diagnostic tools intended for use in developing countries must be easy to use in the context of require minimal infrastructure. In addition to vaccines and diagnostic tests, effective disease monitoring systems are necessary for successful management of livestock diseases. Given the upsurge in access to telecommunications in rural and urban communities in developing countries, there may be much to gain from adapting available information and communication technology tools to the advances being made in animal health research for smallholder systems. For example, advances in the applications of mobile telephone technology could form the bedrock of animal health and performance monitoring systems, with developments in geographic information systems and spatial analysis holding additional prospects for the management and monitoring of livestock health. Further, there may be the increasing need to investigate important livestock diseases, not in isolation as has been the norm, but within the context of interactions with other diseases (personal communication with ILRI animal health scientists). The direction for livestock disease research at ILRI could thus include increased understanding of the interactions of the livestock diseases that threaten smallholder livestock production systems within the mandate regions.

3.3 Zoonosis, food safety and quality

Linked with agricultural inputs, primary agricultural production, activities related to post-harvest handling and processing, and the preparation of food for the table, agriculture-associated diseases account for much of the total human disease burden in the least developed countries (McDermott and Grace 2011). These diseases include zoonotic diseases (directly transmissible from animals to humans, e.g. avian influenza), water-associated diseases (spread by contaminated water, e.g. cholera, or in water systems, e.g. schistosomiasis), food-associated diseases (such as diarrhea) and occupational diseases (directly linked to agrifood systems, such as from exposure to biological or chemical hazards). Further, livestock-related diseases comprise a substantial proportion of agriculture-related diseases. For example, diarrhea, in many cases is linked to animal-source foods, accounts annually for an estimated 1.4 million deaths in children within poor countries (McDermott and Grace 2011).

Current work at ILRI on relevant but often neglected interactions between livestock systems and human health adopts a multidisciplinary approach that bridges risk analysis, veterinary epidemiology and economics. Zoonotic diseases research includes the development of tools for the monitoring of infectious diseases such as avian influenza in Nigeria and Rift Valley Fever in east Africa. The Early Detection Response and Surveillance of Avian Influenza in Africa project, implemented by ILRI in collaboration with the African Union Bureau for Animal Resources uses risk mapping, value chain analysis and risk assessment to develop tools for targeting scarce resources in areas considered at high risk for avian influenza. ILRI involvement in The German Federal Ministry for Economic Cooperation (BMZ)-funded Safe Food, Fair Food (SFFF) project is focused on building capacity in resource-poor developing countries for risk analysis in food value chains. Since many local farmers are constrained from participating in mainstream markets for livestock products by their inability to meet food safety and quality standards, projects such as this may have important outcomes for livelihoods and incomes (Makita et al. 2010). Countries involved in the SFFF project include Ethiopia, Kenya and Tanzania in east Africa, Mozambique and South Africa in southern Africa, and Côte d'Ivoire, Ghana and Mali in west Africa, where diseases like brucellosis, food poisoning from E. coli and salmonella bacteria, and toxicity in locally processed meat and fish products are under investigation. Future priority research areas include the investigation of local practices such as the harvest of wild animals from natural habitats for human food and the consumption of high-risk raw animal products. More generally, gathering reliable evidence to develop metrics to better estimate the multiple burdens of disease and various costs and benefits of control is considered a priority research area for all agriculture-associated diseases (McDermott and Grace 2011).

4. Genetics and reproduction

Livestock genotypes are formed through time by natural selection and/or human intervention. The genotypes observed in current livestock herds are indigenous, introduced or 'exotic'—that is, developed through crossbreeding of introduced breeds with indigenous animals or derived from systematic crossbreeding of two or more breeds. Alongside management, purposeful breed enhancement is a useful tool for improving productivity in livestock systems. In developing countries, within-breed selection of desirable traits and crossbreeding have been the standard approaches to genetic improvement. Much of the following discussion is based on reports in a special issue of the journal ***Livestock Science*** on animal breeding for poverty alleviation (Thorpe and Dargie 2011*)*. In that report, livestock scientists and others highlight what they consider to be the most compelling direction for future livestock (gene) research and development, including '…the provision of appropriate genotypes in a sustainable manner, underpinned by a good understanding of what breed resources exist that have demonstrated potential, where else they could be used, and how they would be delivered to smallholders*.'* (Rege et al. 2011).

4.1 Marker-based selection

Marker-based selection is a generic term applied to technologies such as marker-assisted selection, gene-assisted selection, marker-assisted introgression and genomic selection (Marshall et al. 2011). In marker-based selection, biological, biochemical, morphological, cytological or DNA-based identifiers are used for indirect selection of the genetic determinant(s) of traits such as productivity and disease resistance. While the benefits to animal improvement of gene-based technologies have long been recognized, resource and organization constraints in smallholder and developing country settings have limited their successful application. Small herd sizes, poor management, low inputs, uncontrolled mating, indiscriminate crossbreeding, large proportions of nongenetic variations and poor records of animal performance and pedigree have been identified as constraints in smallholder settings (Rege et al. 2011; Marshall et al. 2011). Marshall et al. (2011) describe marker-based technologies with potential for success in small-scale livestock production as those that are implemented within the framework programs that take into consideration the socio-economic, infrastructural and institutional constraints peculiar to the systems. Marker-based techniques were considered best explored in smallholder production systems with (1) considerable end-user support for the breeding outcome, (2) institutional support to ensure sustainability and (3) objective traits that do not respond easily to traditional selection procedures. It is also important that the marker options explored have been successfully identified elsewhere (thus reducing the costs of development) and that identified markers explain significant proportions of the genetic variance. Of the different types of marker-based selection technologies, marker-assisted introgression (MAI) and genomic selection may be more suited to smallholder systems. Nimbkar et al. (2007) reported the deployment of MAI in the improvement of reproductive performance in Deccani sheep in India, where weaning rates were increased by up to 50% in Garole sheep by introgression of the allele mutation influencing prolificacy. In the case of genomic selection, however, more work is required to identify the potential for replicating experimental results on farms. Economic studies are also needed to assess the viability of these technologies in smallholder systems. Further, initiatives that facilitate the collective access of smallholder livestock owners to superior genetic material adapted for their use could improve the application of traditional breeding programs.

4.2 Technologies for improved reproduction in livestock

The ability to access improved genetic material for producing the next generation of breeding stock or as productive animals for current livestock (e.g. meat or dairy) is crucial for the medium- to long-term success of livestock production systems. In smallholder systems, reproductive mechanisms can be applied to increasing fecundity of the parent animals, potentially reducing the need for a large parent stock; juvenile in vitro fertilization and egg transfers could be used for early selection and the reduction of generation intervals, while artificial insemination (AI) is already used by farmers to facilitate access to better genetic material (van Arendonk 2011; Marshall et al. 2011; Tegegne et al. 2009). Semen sexing—that is, the ability to sort semen cells to distinguish the sexes—also has potential use in genotype improvement in smallholder systems by making it possible to increase the numbers of offspring of one sex in a closed population (van Arendonk 2011). This technology could allow the farmer, for example, to select a larger number of replacement heifers from her own herd or to select for heifer replacements using superior genetic material only, potentially reducing the lag for improving the genetic level of the entire herd.

4.3 Knowledge management for livestock genetic improvement

Better knowledge of the genetics of local livestock is considered an important step to improving livestock productivity of lower-input livestock systems. While the demand for increased yields and the pursuit of increased incomes can often lead to pressures to replace indigenous animal breeds with imported breed types, challenges in the adaptation of these new breeds to the local environment, as well as limited capacity of many livestock keepers to successfully meet their higher management demands, have kept the conservation of indigenous and adapted breeds on the livestock development agenda. Hanotte et al. (2010) make a case for exploiting the genetic diversity of indigenous cattle breeds in Africa, and Rege et al. 2011 outline the need for improved, extensive and coordinated data collection on the genetics of available livestock breeds and the geo-climatic environments that support them. The objective of such a system would be to match available livestock genotypes to the environments most suitable for their productivity (DAGRIS 2007). Successful gene substitution along these lines includes the introduction of the trypanosomiasis-resistant N'Dama cattle indigenous to tsetse-infested areas in east Africa. However, the capacity of smallholder livestock keepers to monitor genetic improvement through accurate and detailed record taking requires strengthening. Further, extension facilities and services such as farmer training, feed supply chain development and product marketing are needed. On the policy front, government guidelines on the importation and use of livestock genetic material have direct bearing on the extent to which smallholders can benefit from livestock genotype improvement, and in many cases need to be reviewed.[2] Relevant issues have been identified as the need to analyze the local impacts of international agricultural and livestock policies, address policy constraints to the use of livestock genotypes in smallholder systems and environments, improve knowledge and policy development on cross-border resource management, including of animal diseases and transboundary trade, and the development of regional capacities for research on livestock genetics as well for the monitoring of and response to important threats such as livestock disease outbreaks.

2. Rege et al. (2011) outlines research, policy and institutions that support pro-poor livestock breeding.

5. Livestock feeds

Poor quality and limited availability of livestock feeds have been identified as major constraints to improving the production and productivity of low-input agricultural production in developing countries (Birthal and Jha 2005; Herrero et al. 2009). In addition, short-term pressures to intensify agricultural production in some developing regions could threaten the long-term sustainability of feed supply systems. For example, continuous depletion of soil nutrients to support crop production and the use in mixed systems of residue crop material in support of livestock production, with little or no return to the soil as nutrients, could lead to heavy soil degradation, limiting the capacity of the land to support future feed production. In response to the perceived threats that livestock feed constraints pose to smallholder mixed systems, emphasis has been placed on identifying tools for sustainable livestock feeds improvement. Improved fodder production (including grass, legume and food-feed crop cultivar development) and feed utilization and uptake technologies are discussed below.

5.1 Fodder production

Efforts to increase production of high-quality livestock feeds promote the development and use of improved fodder varieties of grasses and legumes. Current work on fodder improvement at ILRI includes the identification and development of forage varieties with increased protein and dry matter (DM) (e.g. from broader leaves) content, and the determination of optimal field management practices given livestock needs for forage and environmental concerns. Grasses under development in the ongoing fodder improvement activities include Guinea, Napier, para and signal. Improved fodder legumes include alfalfa, axillaris and Greenleaf. Highland Leucaena is a tree legume of interest. The management requirements and expected performance of the improved grasses and legumes, respectively, are shown in Appendices 2 and 3. Guinea, Napier, para and signal grasses are good both for grazing and as fresh cut-and-carry fodder. In addition, Napier and signal grass have good hay quality. The grasses under development are well suited to a wide range of soil types, including acidity and low fertility. Their leaves are generally of high palatability. However, guidelines for the proper management of fields under forage production need to be followed closely. Under proper field management, up to 40 tons per hectare (ha) (of fresh forage) can be harvested, with crude protein availability ranging from 6 to 25%. The legumes outlined in Appendix 3 are generally not suited to extended dry periods, although axillaris (Macrotyloma axillare) has good drought tolerance and can withstand a few months of the dry season. Fertilizer requirements for the legumes are like those of the grasses, with legume yields of up to 20 tons per ha of DM. Guinea, Napier and signal grasses also provide good cover for the soil, increasing water infiltration and reducing the potential for wind and water erosion. Highland Leucaena is a good mulching material and can be used to restore fertility that may have been depleted through soil losses and crop harvesting. Further, reduced biomass requirements—a direct consequence of feeding better quality fodder—will potentially reduce the emissions of harmful (greenhouse) gases by the livestock.[3] Axillaris yields have been enhanced by more than five tons per ha/year in field trials. Similar improvements have been recorded for the other forages using combinations of improved seeds and management techniques. Up to 40 tons per ha (fresh) can be expected from Napier grass production while alfalfa can produce 20 tons per ha DM from good field management under favourable agroclimatic conditions (Appendices 2 and 3). The new fodder technologies produce forages with relatively higher protein contents, increasing the livestock feed quality. Feed quantity

3. On the downside, land conversion to improved pasture cultivation could compete directly with crop production for food and the demand for land could encourage deforestation.

and quality could determine the livestock performance in terms of maintenance, growth, reproduction and yields (e.g. milk production). A good livestock feeding regimen at the early stage (e.g. 0–9 months for most cattle breeds) could lock in superior animal productivity potential for later in the life of the animal, all other things being equal (i.e. breeds, animal health, adult animal feeding etc.). By increasing fodder availability and quality, smallholder livestock keepers could boost livestock production per animal with immediate and longer-term effects on farm sales, incomes and livelihoods, participation in local feed markets and food security. Successful field trials have been concluded in Ethiopia and Kenya, with potential for adaptation of the improved cultivars to livestock systems in Uganda, Rwanda and Tanzania.

Research has focused on identifying disease (smut and stunt) tolerant cultivars of Napier for east Africa (Proud 2010); and on matching genetic resources to meeting smallholder farm demands for fodder in the region (Collins 2010). Future research could develop successful combinations of improved fodder varieties and field management for other agro-ecological regions and livestock production systems.

5.2 Food-feed crop cultivars

With increased pressures on agricultural land to meet food and nonfood demand, there is a need to explore livestock feed supply options with minimal requirements for land. The development of food crop varieties with higher fodder quality is one promising strategy for achieving this goal. With food-feed crops, the 'main' product of the cultivated plant, e.g. maize, is harvested for human food and the plant residues, e.g. leaf, stalk and vine, become available for use as soil cover for conservation purposes or as livestock feed. Food-feed crop improvements under development include sorghum and millet breeding in south Asia (India), maize in east and southern Africa, and cowpea in west Africa (Blümmel and Rao 2006; Romney et al. 2003; and Tarawali et al. 2002). Data on feed resources in India show that crop residues are the most important single source of livestock fodder, providing up to 40% of available DM. While traditional fodder sources such as forests, pastures and fallow lands continue to decline, it is estimated that the share of livestock feeds coming from crop residues could reach 70% of the available DM by 2020 (Pattanaik et al. 2010). (Re)allocation of agricultural land under cultivation to dual-purpose crops and improved fodder quality of grown crop varieties underlie the expansion. Where grain cultivars with higher fodder value are developed, obvious advantages ensue for food grain production as well as for overall land use management. By increasing the fodder quantity (i.e. area of stems, leaves and other vegetation) per stand, optimal plant spacing can be maintained to get more crop residue production for a fixed land area. This may be useful for maintaining the integrity of crop grain yields and quality. Cowpea is a very important food crop in west Africa, with more than 10 million ha of the crop.[4] A high number of the smallholders practice mixed (crop-livestock) farming, so that huge potential exists in the region for the adoption of cowpea cultivars with improved food-fodder traits. In the case of east and southern Africa, more than 14 million ha of maize are grown in the region. Dairy production (east Africa) and small ruminant meat production (southern Africa) are quite popular with the low-input pastoralists and mixed-crop livestock farmers. From a natural resource management perspective, the use of dual purpose for livestock feed has potential to reduce the pressure on land from the livestock industry. However, potential soil quality issues arise when available crop residues are used as feed rather than returned to the soil as nutrients (Herrero et al. 2009).

Sorghum, pearl millet, groundnut, maize and cowpea are examples of candidate crops for improved food-fodder traits in dry areas. Blümmel et al. (2010) reported that analysis of new sorghum varieties submitted for cultivar testing and release in India from 2002 to 2006 showed cultivars with superior grain yield, stover yield and stover quality. Sorghum grain yields increased by about four-fold over traditional varieties; stover yields increased by about 37% and digestibility of the crop residues increased by about 12%. Research and improved understanding of the grain-stover relationship of dual-purpose crops and of the options for addressing constraints at the farm, market, institutional and other levels that impede the development and use of improved crop varieties could greatly enhance livestock fodder availability in feed-scarce livestock production systems.

4. Much of the cowpea production in the region is in intercropping (with millet and sorghum in the drier savannahs, and maize, yam and cassava in the more humid areas) systems. Niger alone, with 5.5 million ha in production, accounts for more than half of the cowpea acreage in the region. Nigeria (2.8 million ha) and Burkina Faso (1.3) together represent another 40% of the subregion's cowpea cover (FAOSTAT 2015).

5.3 Feed utilization and uptake

Interventions to improve feed processing seek to improve utilization and uptake of feeds in livestock by enhancing nutritive value of the feeds and improving digestibility. The technologies outlined in this section aim to improve intake of livestock feeds and uptake of the feed nutrients. While not new in the true sense of the word, the application of these technologies to specific livestock feed sources and smallholder systems, and the planned scope of their use in the smallholder production systems, constitute somewhat of a novelty. Appendix 4 summarizes innovations under this category and provides information on the expected outcomes for livestock systems at animal and farm levels. The improved feed sources include chopped or ground straw, dried brewer's grains, maize or other grass silage and hay and treated residue blocs. Although residues from locally grown food crops have long been used as feed in low-input systems, there is potential for improving their utilization among smallholders through the introduction of (simple) mechanization in the form of on-site chopping, grinding or other type of pulverization. In these forms, material that is transported from off-site locations is reduced, potentially lowering the associated costs. Less bulky feeds can also be given to animals. The principles of bulk reduction in feeding and transportation also underlie the encouragement of smallholder livestock keepers to transform grasses, legumes or other plant sources into hay or silage, or to use by-products from food processing as feed. Hay and silage can be stored for short periods, which allows farmers to supplement pasture and other natural vegetation during dry seasons. This is particularly important for small farms that are becoming more intensified (e.g. to take advantage of growing demands for livestock products) and as a strategy for dealing with changing patterns of annual biomass availability in response to increased weather variability or other emerging effects of global climate change. In the case of brewer's grains, while this feed source has long been used with success in industrial systems, it may not be an important feed source in smallholder livestock settings. However, local sources of brewer's grains (and other processing by-products) can be important lower cost options for dense nutrient feed sources (concentrates). The ability to dry the feed grains at the production site further increases cost savings on transportation as the farmer needs to pay only for the portion of the brewer's grains that is useful as feed. To improve digestibility and nutrient value of feeds, treatments such as water, salt and urea have been added to crop residue blocs (Mogus 2011).

6. Socioeconomics and natural resource management

This report has so far outlined mainstream options for improving productivity of meat and milk production in regions identified as important to a pro-poor research for development strategy. However, technology development alone will not guarantee returns to smallholder operators, even when these technologies have been specifically designed or appropriately adapted for use by smallholder livestock keepers. Marshall et al. (2011), for example, opined that the failure of past animal breed improvement programs in developing countries may have occurred not because of inadequate research into animal genetics, but more in response to institutional and related failings. The policy and institutional environment will thus need to evolve appropriately to enable the extension of benefits from the expanding global livestock sector to economically marginalized groups in the livestock value chains of developing countries. Inclusive livestock sector growth in the target countries calls for substantial investments not just in the appropriate technologies to enhance the productivity of livestock, but in the development of the complementary framework of input and product supply systems, policies and regulatory frameworks. Attention will also need be paid to externalities such as the environmental impacts of technological change.

6.1 Markets, institutions and policies

While interventions such as vaccine development reduce disease-related risks of animal mortality and productivity losses, innovative financial management tools can further secure livestock assets against risks. There are also major gains to obtain from the application of advances in information and communications technology. A weather-indexed insurance scheme, index-based livestock insurance (IBLI) was designed for pastoralists in climate-vulnerable regions and has been introduced in northern Kenya and southern Ethiopia (Mude 2010, 2015). This type of insurance is typically used to manage covariate risks, i.e. that affecting many people at one time, and is written against a specific widely observable event such as a flood or a drought. Insurance contracts have been used by farmers in pasture and rangelands in countries with highly developed land management systems (Hazell et al. 2010); and by governments to mitigate agricultural production risks in developing countries (Hazell et al. 2010; Bryla and Syroka 2007). However, the implementation of index-based insurance in the context of smallholder pastoral livestock in a developing country, such as in eastern Africa, was novel. A recent study of the insurance program earlier rolled out in Kenya and Ethiopia suggests benefits of improved economic viability, reduced destructive coping behavior, and productive savings and investments amongst livestock keepers in pastoral areas taking up IBLI policies (Taye et al. 2019) This technology may hold much potential for other Horn of Africa and Sahel countries where livestock production and agroclimatic conditions are similar.

Among other objectives, market research at ILRI has focused on identifying mechanisms for improving the access and participation of smallholders in livestock value chains including those targeted specifically to women, and thecommercialization of smallholder production to improve income and livelihood benefits (Gebremedhin and Jaleta 2010; Nyabila 2011). The East Africa Dairy Development Program in which ILRI has been a strategic research partner, provided useful and timely information and technological innovation, facilitated increased market access for target dairy producers in the region, and through expertise provided by livestock scientists, economists and others within the project, increased productivity and efficiencies of scale within smallholder livestock production systems in eastern Africa. This was achieved by mobilizing farmers into associations to start (or revive) and operate producer companies, assisting producer companies with acquiring infrastructure to pool milk through a 'dairy hub', and providing technical assistance through dairy production (e.g. dairy genetics and AI) and marketing (e.g. dairy product testing) processes. Baseline surveys from the project sites helped to identify constraints to the project production, income and livelihood objectives in the form of livestock disease and health delivery challenges (Njehu et al. 2011), livestock feed supplies (Lukuyu et al. 2011), and constraints to adoption and use of AI and other reproduction technologies (Mburu et al. 2011). Information from these and related studies (Baltenweck et al. 2011; Gelan et al. 2011) are useful for shaping the future of genetics, nutrition and animal health-based interventions in the east Africa region, and in regions with similar economic, political and socio-cultural conditions.

ILRI has led the CGIAR Research Program on Livestock and Fish and one of its two successors, the CGIAR Research Program on Livestock, that integrates a technological platform (for improving livestock production through genetics, nutrition and animal health), with market expansion strategies for a small number of selected production systems and countries (CGIAR Research Program on Livestock and Fish 2011). In a value-chain approach to livestock sector development that is considered more sustainable, as much attention is being paid to the institutional structures influencing the availability and use of new technologies as to the generation and application of the technologies. Further, given the global competition for land, water and other resources, and the potential effects of agricultural activities on the climate and environment, more attention is being paid to these issues (Herrero et al. 2009).

6.2 Managing the resource base

The bedrock of agricultural economies is the land and water resources. Pressures from growing and more affluent populations are exacerbating a natural resource problem while the effects of a changing global climate pose threats of further resource degradation. In the case of livestock, access to water has been described as the most important link to people and the environment, and an important driver of evolution in livestock production systems. With activities related to livestock production accounting for a substantial proportion of agricultural water use, strategies for managing water use in livestock are an important component of the global discussion on the management of natural resources. ILRI research has looked into ways of improving the efficiency of water use for livestock in intensive and extensive production systems alike, as well as throughout the livestock value chain (Ayantunde 2011; van Breugel et al. 2010; Haileslassie et al. 2011). The concept of livestock water productivity (LWP) is particularly relevant to production. LWP quantifies livestock products relative to the water used in their production. In theory, an improved LWP situation results in the halting or reversal of land degradation and in improved environmental resilience. Descheemaeker et al. (2009) outlined livestock, feed and water management options for improving LWP in mixed-crop livestock systems in sub-Saharan Africa. Sustainable livestock management matches livestock breed types to appropriate environments,[5] while good livestock water management ensures optimal use of pasture and grazing lands in support of animal populations. Feed management interventions deal directly with issues of feed type selection and feed quality. Strategies that directly improve LWP include the application of technologies such as alley cropping and agro-forestry management to encourage soil percolation, reduce runoff and improve evapo-transpiration. Other technologies like water harvesting and irrigation directly improve water conservation while initiatives such as payments for ecosystems services can encourage practices that make for better LWP in smallholder systems.

In general, the relationships between livestock, water and other resources need to be better understood for the technologies identified as promising for improved livestock productivity in developing countries to deliver on (economically and environmentally) sustainable options.

5. Well-matched breed-environment combinations should impact positively on water use and feed conversion rates, and animal productivity.

6.3 Economic and social value of promising technologies

Promising technologies for livestock should provide quantifiable benefits that justify both adoption by the end users, and the research and development investment needed by the public and/or private sector to generate and disseminate these technologies. While adoption by end users is typically driven by implementation costs (e.g. in financial and time resources) and benefits (e.g. profits, convenience) that accrue directly to the farming enterprise or household, the objective for entities underwriting global public research for the development of agricultural technologies caters to a much broader set of beneficiaries and tends to extend, in addition to economic viability, to issues considered low priority by unit adopters—intergenerational or offsite effects, including on the environment, equity and inclusiveness. A number of studies have been completed (at ILRI and elsewhere) estimating the economic costs of constraints to livestock production in developing countries, as well as the costs and returns associated with investments in various phases of technology development to address these constraints (Di Giulio et al. 2009; McLeod and Randolph 2000).

In the case of ECF, it is estimated that preventing ECF-related deaths could stem economic losses of up to USD 170 million per year in affected countries (Mukhebi et al. 1992). Further, regional trade in live animals and livestock products is expected to experience a boost as cross-border ECF-related policies are revisited, with important implications for agricultural incomes and livelihoods in the affected countries. Other work assessing data from Tanzania suggested that livestock owners could receive 50% more from the sale of vaccinated animals (Homewood et al. 2006). In addition, measurable gains are expected in nutrition and food security outcomes. In another assessment, McLeod and Randolph (2000) estimated a 22% return on investment made by a commercial partner in the development of a non-live strain of the ECF in east and central Africa. Potential retail sale value of the vaccine was placed at USD 6.4 million. Assessments of the economic value of improved dual-purpose crop cultivars suggested that the cultivars had good economic prospects for the mixed-crop livestock production systems for which they were being developed. Crop residue use is projected at nearly 70% of total feed demand in India in 2020, a 25% increase from current levels (Blümmel et al. 2010). The envisaged expansion should have interesting effects on subnational, national and regional dynamics of the livestock feed trade and input pricing as well as on incomes and livelihoods.

While the above studies measure economic costs and benefits only and to a limited set of beneficiaries (e.g. pastoralists or dairy farmers, private vaccine development enterprise), they provide important input for other work assessing ex ante, long-term and multidimensional costs and benefits to global public investment in the generation and dissemination of selected technologies for improving livestock productivity in developing countries. In follow-up work to the current review, the socio-economic benefits to be obtained from the identified promising technologies for livestock are being assessed within the framework of the International Model for Policy Analysis of Agricultural Commodities and Trade (IMPACT). IMPACT is a partial equilibrium model of the global agriculture sector that was developed in the 1990s at the IFPRI and has undergone several revisions that improve its capacity to analyze global agricultural systems, including of livestock (Rosegrant et al. 2008; Robinson et al. 2015; Msangi et al. 2014). Msangi et al. (2014) report on work done by collaborating economists and modelers at ILRI and IFPRI to improve the quantification of global livestock supply and demand in the economic modeling framework. The improved model specification better reflects consistency with biological realities, including the linking of livestock yield responses to feed quantity and quality, and the inclusion of crop residues and rangeland grasses in the accounting for current and future livestock feed supplies. These improvements to the global economic modeling framework will enhance the model's capacity to assess the long-term returns to livestock research investments, particularly in the context of smallholder production and developing countries, and provide important links between livestock productivity and production, and the natural resource base.

7. Concluding remarks

The rapid growth in demand for livestock products observed in many developing countries in recent decades offers opportunities for livestock sector development in these regions. There is interest in understanding if—and the extent to which—the livestock sector expansion can be harnessed to address food and nutrition objectives (e.g. increased availability and access to food), while providing increased income and livelihood benefits to the millions of poor households and smallholder operations associated with the sector in developing countries. Key to this sectoral development approach will be the design and implementation of tools and processes to improve the productivity and production of livestock, as well as the efficiency and effectiveness of the markets, policies and institutions governing activities in livestock value chains. This report highlights options for improving livestock production and productivity in smallholder production systems in developing countries. The promising technologies include improved livestock genetics and innovations that enhance availability of the improved genetic material, vaccine and other technologies that address animal health, and feed and fodder technologies for enhanced nutrition in support of increased livestock production. Fostering an enabling (policy, market and institutional) environment is as important to improving smallholder livestock production as the research and development strategies generating these 'hard technologies'. In addition, the long-term viability of the environmental and natural resource base stands to be compromised in the pursuit of production strategies that deliver on purely short-term food security and/or economic gains. As such, we conclude that the most valuable of the promising livestock technologies will be those that are generated, developed, disseminated and utilized in line with an overarching strategy for economic, social and environmental sustainability.

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Appendix 1: Indicators of livestock production in smallholder livestock systems

Productivity indicator	Unit of measurement
Dairy (cattle, sheep and goats)	
Average daily weight gain (males)	kg/day
Age at first calving/lambing	days
Calving/lambing interval	days
Daily milk production per cow/ewe	kg
Lactation milk production	kg
Annual female calf/lamb mortality	rate
Annual adult animal mortality	rate
Meat (cattle, sheep, goats and pigs)	
Calving or farrowing	rate
Off-take rate	number, kg
Litter size[1]	number
Time-to-selling or slaughter weight	days
Poultry	
Daily egg production per bird	number
Egg production per bird per clutch	number
Number of clutches per bird per year	number
Time-to-selling or slaughter weight	days

[1]Relevant for small ruminant livestock and pig production.

Source: Authors, from expert roundtable conducted at ILRI.

Appendix 3: Field management and performance of legumes under the ILRI fodder improvement program

Common name	Alfalfa	Axillaris	Greenleaf	Highland Leucaena
Scientific name	Medicago sativa	Macrotyloma axillare	Desmodium intortum	Leucaena diversifolia
Feed use	Grazing, cut and carry—fresh, hay	Grazing, cut and carry—fresh	Cut and carry—fresh, hay, silage	Grazing, cut and carry—fresh
Climate adaptation	Tropical highlands and subtropical regions	Subhumid tropical highlands	Tropical subhumid	Subtropical and highland tropical regions
Drought	Poor drought tolerance	Good drought tolerance	Poor drought tolerance	Poor drought tolerance
Important characteristics	Highly adaptable across climates	Grows well with tall-growing grasses, good tolerance to pests and diseases	Fast growing, withstands lower temperatures than most tropical legumes	Tolerant of heavy cutting, grazing, some ascensions are psyllid resistant
Limitations to use	Not tolerant of continuous grazing, bloat in livestock	Frost sensitive but with quick recovery, intolerant of heavy grazing	No tolerance to salinity, frost or heavy grazing	Not adapted to areas over 2,000 m, frost sensitive
Fertilizer	DAP at 100 kg/ha or 10–15 t/ha manure	Phosphorus and DAP at 100 kg/ha	DAP at 100 kg/ha may be used (requires adequate fertility)	Starter N and phosphorus may be used
Harvesting	Cut alfalfa for hay at 5 cm above ground, at first flowering, can cut monthly if irrigated	Cut above 30 cm, avoid early grazing for improved persistence	First time at flowering–after about 1 year, then possibly cut after every 6 months	Tolerant of regular cutting
Expected yield, fresh or DM	20 t/ha DM, seed production is 100–300 kg/ha under irrigation	With good management and water, 15 t/ha DM	19 t/ha fresh forage	3–4 t/ha
Crude protein, digestibility	20–25% crude protein, 66–70% digestibility	12–23% protein	Crude protein about 18%	25–32% crude protein

Source: Adapted from ILRI 2010 (various publications).

Appendix 2: Field management and performance of grasses under the ILRI fodder improvement program

Common name	Guinea	Napier	Para	Signal
Scientific name	Panicum maximum	Pennisetum purpureum	Brachiaria mutica	Brachiaria decumbens
Category	Perennial grass	Perennial grass	Grass	Grass
Feed use	Grazing, cut and carry—fresh	Cut and carry fresh, hay or silage	Grazing, cut and carry—fresh	Grazing, cut and carry—fresh, hay
Edibility	Very palatable	Good eating quality in early stage, coarse with maturity	Palatable young stems and leaves	Good eating quality
Climate adaptation	Wet tropics and subtropics	Subhumid mid altitudes	Tropics, warmer subtropics	Humid tropics and warmer subtropics
Soils adaptation	Tolerant to acid soils	--	Wide soil range, good on acid soils	Wide soil range, good on acid soils
Drainage requirement	Not tolerant of water logging	Tolerates poor drainage, not water logging	Very tolerant of water logging	Not tolerant of water logging
Water requirement	Adapted to high rainfall but minimal drought tolerance	Can tolerate limited dry spells	Poor drought tolerance	Good drought tolerance, withstanding dry seasons of up to 4–5 months
Important characteristics	Wide adaptation from sea level to 2,500 m	Fast growing	--	Good resistance to grazing and cutting
Limitations to use	Frost sensitive, fertilizer dependent, intolerant of heavy grazing/ defoliation	Frost sensitive, fertilizer dependent	Frost sensitive, weed problems if ungrazed	Not tolerant of frost or flooding, susceptible to spittle bug
Field preparation	Well-prepared seed bed needed	Ploughed field, but would grow with zero tillage	Well-prepared seed bed, initial ploughing for stem cuttings	Will establish in poorly prepared soil although well-prepared seed bed better

Common name	Guinea	Napier	Para	Signal
Scientific name				
Establishment	Seed broadcast at 3–6 kg/ha	Stem cuttings 2–3 nodes at 50 cm spacing	Seeds broadcast 3–4 kg/ha, disc harrowing for stem cuttings also common	Broadcast at 2–4 kg/ha, can be propagated by root splits
Fertilizer	DAP at 100 kg/ha at establishment, N at 100 kg/ha or manure after each cut	Urea at 100 kg/ha, or manure after each cut	DAP at 100 kg/ha during establishment, N at 100 kg per ha after every cut	DAP at 100 kg/ha during establishment, N at 100 kg per ha after every cut, very responsive to N
Weeding	Twice after planting at monthly intervals during establishment	After establishment and after every cut	Twice after planting/monthly during establishment	Twice after planting/monthly during establishment, suppresses weeds effectively after establishment
Harvesting	Graze only after well established, do not graze or cut below 30 cm	Cut at 5 cm 3 times per year, or every 3 months if good growth	Cut before first flowering, graze when grass 20 cm tall and well established; 4–6-week intervals after	Cut before first flowering, 4–6-week intervals after, very frequent cuts give prostrate leaf growth—difficult to harvest
Expected yield Fresh or dry matter (DM)	14 t/ha per year DM	40 t/ha per year fresh	5–12 t/ha per year DM	Typical 10 t/ha per year, up to 30 t/ha per year under high soil fertility
Crude protein, digestibility	6–25% depending on age and N supply	9% protein content	14–20% crude protein	9 to 20% crude protein, value declines rapidly with aging

Source: Adapted from ILRI 2010 (various publications).

Appendix 4: Promising technologies to improve livestock feed intakes and nutrient uptakes

Interventions/ outcomes	Expected outcomes for feed/animals	Economic outcomes	Technology description	Equipment and other inputs required	Knowledge/skills to transfer
Chopping or grinding straw	Increased feed intake, reduction in amount of fodder fed	Feed cost reductions, transport cost reductions	Automated break-up of feed source	Electric-driven chopper/grinder	Use of chopper, forage options
Drying brewer's grains at breweries	Reduce bulk before transporting	Transport cost reductions	Drying, bagging, site relocation and centralization	Dryers, baggers, facilities (e.g. space at brewery)	Optimal drying conditions for storage
Maize and grass silage popularization	High value (dependent on parent crop), high DM and energy feed	Low-cost alternative to concentrates, particularly useful for dairy	Forage preservation in succulent condition using partial fermentation	Silage chopper, plastic bags for popularization, inoculants	Harvest timing, chopping lengths, plant compaction, oxygen exclusion
Hay preparation	Increased feed intake, reduction in amount of fodder fed, reduce bulk for transporting	Feed and transport cost reductions improve year-round feed availability	Improved knowledge on harvest timing etc. (hay making already exists in localities)	Dryers, potential for locally made drying tripods (e.g. from bamboo)	Forage planting and harvesting e.g., optimal forage maturity stage specific for hay
Treatment of crop residue	Increased value of feed, increased nutrient uptake	Supplement cost reductions	Treatment of shredded wheat/ barley straw with urea, molasses, salt, water etc.	Feed bloc makers, nutrients and supplements (e.g. urea)	Nutritive values of additives relative to animal nutrient requirements

Source: Adapted from Mogus 2011 and personal communication with ILRI scientists.