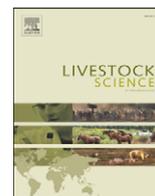




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journal homepage: www.elsevier.com/locate/livsciSustaining intensification of smallholder livestock systems in the tropics[☆]J.J. McDermott^{*}, S.J. Staal, H.A. Freeman, M. Herrero, J.A. Van de Steeg*International Livestock Research Institute, P.O. Box 30709, Nairobi, 00100, Kenya*

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ABSTRACT

Smallholder livestock keepers represent almost 20% of the world population and steward most of the agricultural land in the tropics. Observed and expected increases in future demand for livestock products in developing countries provide unique opportunities for improving livelihoods and linked to that, improving stewardship of the environment. This cannot be a passive process and needs to be supported by enabling policies and pro-poor investments in institutional capacities and technologies. Sustaining intensification of smallholder livestock systems must take into account both social and environmental welfare and be targeted to sectors and areas of most probable positive social welfare returns and where natural resource conditions allow for intensification. Smallholders are competitive in ruminant systems, particularly dairy, because of the availability of family labour and the ability of ruminants to exploit lower quality available roughage. Smallholders compete well in local markets which are important in agriculturally-based or transforming developing countries. However, as production and marketing systems evolve, support to smallholders to provide efficient input services, links to output markets and risk mitigation measures will be important if they are to provide higher value products. Innovative public support and links to the private sector will be required for the poor to adapt and benefit as systems evolve. Likewise targeting is critical to choosing which systems with livestock can be intensified. Some intensive river basin systems have little scope for intensification. More extensive rain-fed systems, particularly in Africa, could intensify with enabling policies and appropriate investments. In more fragile environments, de-intensification is required to avoid irreversible damage to ecosystems. Attention to both social and environmental sustainability are critical to understanding trade-offs and incentives and to bridging important gaps in the perspectives on livestock production between rich and poor countries and peoples.

Two specific examples in which important elements of sustainable intensification can be illustrated, smallholder dairy systems in East Africa and South Asia and small ruminant meat systems in Sub-Saharan Africa, are discussed.

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1. Introduction

Livestock systems in developing countries are highly varied, ranging from extensive pastoral systems dominated by smallholder producers and semi-subsistence production to large-scale commercially oriented industrial production

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systems. These systems are changing rapidly, particularly in Asia, Latin America, and densely populated areas of Africa. Several development trends and pathways for sustainable intensification can therefore evolve in developing-country livestock systems, depending on the magnitude and rate of change of key factors driving the demand for livestock products and the quality of the underlying resource base that supports livestock production.

Livestock production and marketing are essential to the livelihoods of more than 1 billion poor people in Africa and Asia, including smallholder livestock keepers. Yet, smallholder

livestock keepers are not homogeneous, their livestock assets vary considerably across regions and livestock systems. For example, a landless household in Bangladesh has an average of 1 tropical livestock unit (TLU) while a pastoral household in the Sahel of West Africa holds an average of 20 TLU (Otte and Chilonda, 2002). As essential as they are for food, income and health, these tropical livestock systems also damage some environments of the poor, particularly their water and land resources, and produce greenhouse gases partly responsible for global warming (Steinfeld et al., 2006).

The paper argues that an increase in public and private investments in smallholder livestock systems would help nearly one billion people use their livestock enterprises as pathways out of poverty. Such investments would help people with few alternative livelihoods meet the growing demand in developing countries for livestock products and do so in ways that are sustainable over the longer term.

This paper explores how these goals could be achieved across different livestock production and marketing systems in Asia and Africa.

2. What role for smallholders in a changing world?

Different factors are driving change in developing-country livestock systems over time (Herrero et al., 2009a, 2010; Moyo et al., 2007; Freeman et al., 2007; Steinfeld et al., 2006; MEA, 2005). These primary forces for change are shaping livestock development trends, trajectories of intensification, and the role of smallholders in diverse livestock systems. Rapid growth in the demand for livestock products – the ‘livestock revolution’ – is driven by rising incomes, urbanization, and preferences by the growing middle classes for a diet that includes milk, meat, eggs and other highly nutritious foods (Delgado et al., 1999). Demand for livestock products is thus skyrocketing in China, India and other fast-growing economies in Asia. These demand drivers are associated with increasing consumer concerns about food safety and a trend toward highly intensive livestock production systems, often in vertically integrated food chains. On the other hand, rapid

population growth and slow changes in the quality of the resource base due to land degradation or climate change is causing stagnation, loss of livelihood opportunities, and conflict over resources in livestock systems. This situation exists in many pastoral systems in the Sahel and the Horn of Africa and provides limited potential for sustainable intensification.

2.1. Livestock-sector demand in developing countries

The booming demand for livestock and livestock products is taking place almost exclusively in developing countries. Projections of food demand show per capita consumption growth rates for meat and milk differing greatly between developing and developed countries (Fig. 1).

To meet the growing demand, smallholders are playing different roles, largely depending on the stage of development of their countries – whether agriculture-based, transforming, or urbanized – a typology found in the *World Development Report 2008* (World Bank, 2007). Table 1 provides data on key livestock drivers for selected countries in these three types of developing countries. Livestock makes a significant contribution to economic activity, particularly in agriculture-based and transforming countries. Transforming countries such as China, Vietnam, and India that experienced the most rapid rates of GDP growth have recorded the greatest surge in demand for livestock products over the period 1990 to 2005.

The livestock sector plays a large role in agricultural GDP in all three country types, but the demand for livestock differs greatly among them. Demand for livestock products increases rapidly in societies as daily per capita income moves from US\$ 2 to US\$ 10 (ILRI, 2006). At income levels of US\$2 or less a day, households are pre-occupied with meeting their basic need for calories from the cheapest source. Under such poverty levels, food expenditure are made on relatively cheap sources of calories, such as cereals and roots and tubers, and the consumption of livestock products is low (Herrero et al., 2009a). As households cross the income threshold of US\$ 2 a day, demand for livestock products increases, particularly in

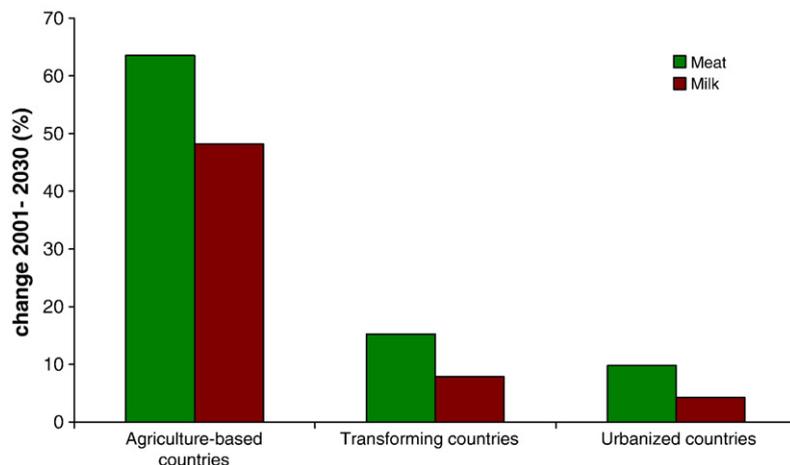


Fig. 1. Projected changes in demand for livestock products, 2001 – 2030, adapted from IAASTD (2007). Source: Adapted from IAASTD (2007).

Table 1

Income and population indicators in countries with different types of economies.

Sources: ^aFAOSTAT; ^bWorldBank Development Indicators.

	GDP per capita, PPP ^a		Contribution of agriculture to GDP (%) ^a		Contribution of livestock to agricultural GDP (%) ^a		GDP growth (annual change) (%) ^a				Urban population ^b		
	1990–1995	2000–2005	1990–1995	2000–2005	1990–1995	2000–2005	1990	1995	2000	2005	1990	2004	1990–2004
	Average	Average	Average	Average	Average	Average							
Agriculture-based countries													
Kenya	1345	1287	31	30	43	45	4.1	4.3	0.6	5.8	25	41	6.1
Mali	756	939	46	38	41	39	16.5	2.4	−3.2	6.1	24	33	5.1
Mozambique	405	578	38	26	20	15	1	3.3	1.9	6.2	21	37	6.6
Laos	1089	1580	59	49	17	15	6.7	7	5.8	7.1	15	21	4.7
Transforming countries													
China	1448	3159	22	14	27	25	3.8	10.9	8.4	10.4	28	40	3.6
Vietnam	1039	1789	33	23	17	18	5	9.5	6.8	8.4	20	26	3.4
Pakistan	1777	1970	26	23	49	54	4.5	5	4.3	7.7	31	34	3.3
India	1276	1864	29	21	27	31	5.6	7.6	5.4	9	26	29	2.5
Urbanized countries													
Argentina	9021	9578	6	9	46	37	−1.3	−2.8	−0.8	9.2	87	90	1.4
Brazil	7335	8046	8	7	42	44	−4.2	4.2	4.3	2.9	75	84	2.3
Peru	4681	5774	9	8	36	33	−5.1	8.6	3	6.7	69	74	2.2

urban areas. As incomes increase further, so does consumer preference for higher quality livestock products. On the other hand, where daily *per capita* income is lower than \$5, quantity has preference over quality.

These demand-side factors induce structural changes in livestock production, processing and distribution. Most smallholder producers sell their livestock products to low-income consumers via informal markets. Increasing urbanization and incomes, however, are increasing the length and complexity of livestock value chains and the quality and safety standards demanded in livestock markets, making it more difficult for smallholders to compete in these growing markets. Under these conditions, arrangements between primary producers, processors and distributors are necessarily becoming increasingly sophisticated. These structural changes in livestock value chains typically involve new actors such as private agribusiness firms thus provoking organizational and institutional innovations. Pro-active policies and investments can help ensure the inclusion rather than the exclusion of the poor who produce and sell on a small scale (Kaitibie et al., 2008).

2.2. Smallholder livestock systems in Africa and Asia

Herrero et al. (2009a, 2010) developed a typology of livestock systems that provides a measure of intensification potential. This typology integrates a system's natural resource potential, population density, and market access. The major livestock systems resulting from this classification are:

- Agro-pastoral and pastoral systems characterized by low population densities, low agro-ecological potential and weak linkages to markets. Crop production in these areas is marginal and livestock predominates as a source of livelihood.

- Extensive mixed crop–livestock systems characterized by rain-fed agriculture, medium population densities, moderate agro-ecological potential and weak linkages to market. Farming practices incorporate crop and livestock with limited use of purchased inputs.
- Intensive mixed crop–livestock systems characterized by high population densities, irrigation or high agro-ecological potential and good linkages to markets. Farming practices incorporate crops and livestock, but with intensive use of purchased inputs.
- Industrial systems characterized by large vertically integrated production units and 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.

In Africa and Asia, the ruminant component of mixed crop–livestock systems is the dominant system in terms of household livelihoods. In these systems, a staple crop such as maize in East and Southern Africa is closely integrated with cattle or small ruminants. In several countries in South East Asia, rice is integrated with pigs in mixed crop–livestock systems. However, in terms of area, pastoral systems predominate, particularly in Africa (Herrero et al., 2009a,b).

Smallholder livestock keepers dominate crop–livestock systems, with livestock playing an essential role in highly diversified livelihood strategies that typically combine crops and livestock with off-farm activities (Ellis and Freeman, 2004; Deshingkar et al., 2008). Livestock contribute about 50% of the income of poor households in crop–livestock systems in some agriculture-based states of India, (Deshingkar et al., 2008). Pastoral systems are less densely populated and for many households, livestock is often the largest non-land asset they own (World Bank, 2007). In pastoral areas of Kenya, livestock

production generates roughly half of rural household income, while in pastoral areas in Ethiopia, Niger and Burkina Faso, households earn over 80% of their incomes from livestock (Barrett et al., 2003; Nzuma and Baltenweck, 2008).

Most of the world's poor tropical livestock producers are in Sub-Saharan Africa and South Asia (Table 2). Large numbers of landless and other poor non-livestock keepers also depend on livestock for their livelihoods by providing feed, trading and transportation services. Despite the continued migration of rural people to cities, both regions still contain large rural populations and will continue to do so for some decades to come. In Africa, both urban and rural populations are growing. Across all regions with large numbers of smallholder farmers, rural land holdings are contracting in size, a trend contrary to that in the Americas over the last century, where farm sizes grew as rural populations fell (Fig. 2). Smallholder livestock production on mixed crop–livestock farms will thus remain dominant in Sub-Saharan Africa and South Asia for the foreseeable future (Jayne et al., 2003; ILRI, 2006). As developing-country economies grow and diversify over time, more rural people will migrate out of livestock production and other forms of agriculture and the remaining smallholder systems will consolidate, specialize and commercialize. Intensification of smallholder animal production over the short to medium terms should provide tens of millions of households with sufficient assets, skills and income to diversify out of livestock enterprises altogether. Demand factors, such as income growth, urbanization and changing consumer preferences, drive intensification in mixed crop–livestock systems where natural resources can be better managed. In contrast, population pressure and environmental factors are more important system drivers in agro-pastoral and pastoral systems, particularly where market access is weak. Mixed cropping households therefore face very different intensification challenges than pastoral households.

2.3. Can smallholders participate in meeting the increasing demand for livestock products in developing countries?

The importance of farm animals in household asset portfolios and the rapidly growing demand for livestock products in developing countries provide unique opportunities for using livestock as instruments for sustainable intensification and pathways out of poverty. The question is whether large numbers of smallholders will be able to meet the growing

demand for livestock products in developing countries, or will these products be provided by other categories of producers? The answer to this question will vary depending on the nature of demand in countries as well as on policy, investment levels and development actions. A better understanding that is derived from factual evidence is required of how livestock systems are evolving, the role of smallholder livestock keepers in rapidly changing livestock systems and the importance of demand, particularly from local, domestic and regional markets, in stimulating the intensification of livestock systems. Research within this systems and demand-led context will help to identify and evaluate targeted technological, policy, and institutional innovations that support sustainable intensification of livestock production for the benefit of poor people and their production environment.

In agriculturally-based economies, poor rural and urban people with low and slowly increasing incomes will provide much of the increasing demand for livestock products, largely from local informal and domestic markets, because livestock products are not widely traded over long distances (generally <10% of livestock products are traded across borders (Staal, 2001)). Smallholders are most competitive in such local markets. But, will these markets continue to provide growth opportunities for smallholders in the long run as income growth and urbanization increase consumer demand for food safety and the opportunity cost of time, particularly as more women join the work force? In urbanized countries, formal markets such as supermarkets are much more important and livestock food chains are increasingly vertically coordinated and integrated. Without pro-active policies and investments, smallholders will have much more difficulty in participating in these more complex and demanding value chains. Transforming countries will be intermediate to these, with big opportunities for smallholders in informal markets, but with challenges of engaging smallholders in more complex value chains for urban, higher-income consumers.

The collective concept of livestock has special characteristics that enhance its potential to reduce poverty (World Bank, 2007). Smallholder livestock keepers, however, need to be supported in order to be competitive as market forces cause these systems to become more intensive in response to market demands. In many contexts, smallholders can be competitive primary producers compared to larger local producers or foreign importers. The competitiveness of smallholders versus the potential for economies-of-scale, tends to differ by commodity and stage of production. In the case of ruminants at least, there is no strong evidence of economies-of-scale in production (Delgado et al., 2003). This is due to under-utilized family labour and the ability of ruminants to exploit low value roughage, including that gathered or grazed from public lands, even in relatively intensive mixed systems. This reliance of household labour and relatively low use of purchased input also explains the competitiveness of smallholders in informal and traditional markets for livestock products, particularly in labour intensive sectors such as dairy.

The following examples illustrate the point. (1) Based on economic efficiency, small farmers in India producing 20 L of milk a day were equally efficient to larger farmers producing over 150 L per day (Sharma et al., 2003). (2) In urbanized markets, consumer preferences for raw milk and wet markets for fresh meat provide competitive advantages for smallholder

Table 2

Number of people in poor livestock keeping households in Sub-Saharan Africa and South Asia (regional sub-totals and overall total in bold).

Region	Number of poor livestock keepers (millions)
Sub-Saharan Africa	319.9
Central Africa	29.8
Western Africa	132.7
East Africa	104.8
Southern Africa	52.5
South Asia	607.0
India	546.0
Bangladesh	61.0
Total	926.9

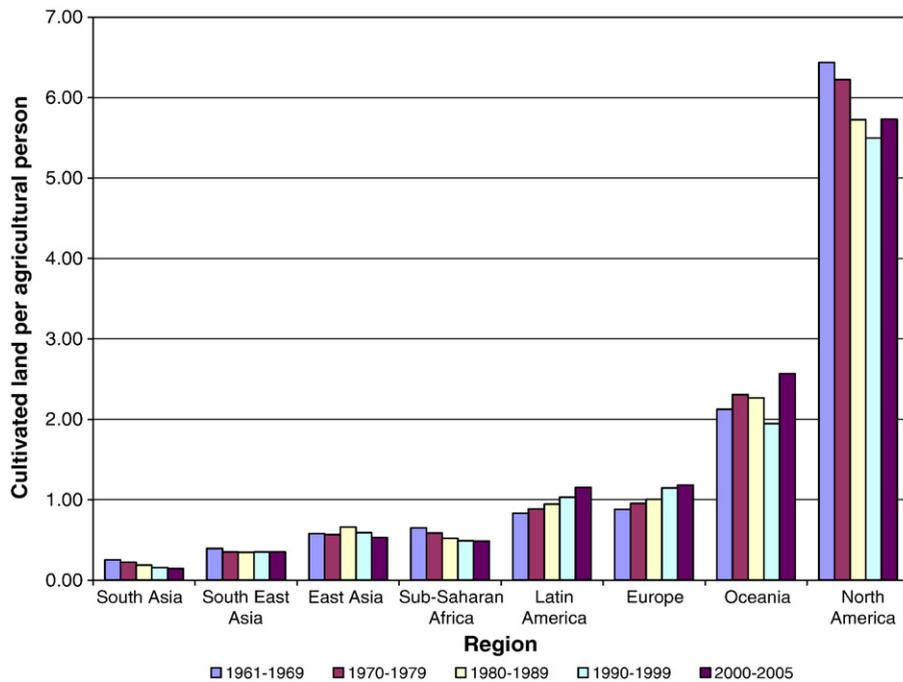


Fig. 2. Differences in agricultural land per capita in different regions of the world, adapted from FAOSTAT. Source: adapted from FAOSTAT (2009).

producers, because they tend to specialize in supplying these markets. In an urbanized country, such as Brazil, smallholder dairy provides 40% of milk produced (Staal, 2006). In urbanized countries, larger dairy farms may be less competitive as they rely on a greater use of less-reliable hired labour and on full-price purchased inputs.

The question will be whether these factors, that provide competitive advantages for smallholders in the short run, will persist in the long run with economic growth, availability of employment opportunities in other sectors and increasingly affluent urban consumers. Nevertheless, evidence suggests that fresh livestock products as well as fresh fruits and vegetables are the least likely food products to be purchased in supermarkets, reducing the pressure on the supermarket revolution on livestock producers (Tschirley, 2008). Such factors might slowdown, but probably not change the structural transformation processes that induce the growth of large retail markets particularly in urban areas.

To be competitive in future, smallholder livestock production, primarily on small mixed crop–livestock farms, will need to intensify and be able to provide higher value products. Major constraints faced by smallholders are the higher relative costs of quality inputs (improved animals and feed) and knowledge to produce more efficiently. The greater risk associated with the loss of an animal is a further constraint. Public investment has a role in overcoming the constraints through knowledge and technologies that deliver quality feed, animal health, breeding, technical advice and other services.

Smallholders can be supported to be competitive when vertically integrated livestock food chains develop. Economies-of-scale are more important for processing, distributing and

marketing of livestock products, particularly with enhanced standards for quality and safety are demanded. However, it is important that any investments in market development be planned carefully with serious thought given to the commercial viability and meaningful participation of poor people. This is particularly the case for countries investing in livestock exports. There are few success stories, such as meat exports from Namibia, compared with the many wasted investments in slaughtering and processing facilities that will never be effectively linked to economically viable market chains. Experiences in developing countries are that meeting export quality and safety standards are often not economical. Milk powder of export quality, for example, requires raw milk with bacterial quality that only on-farm cooling tanks can achieve, and which smallholders cannot afford. Exporting meat to the rich world is often seen as an important opportunity for poor countries. An analysis in Ethiopia, however, found that while systems could be economically developed for meeting the sanitary and phytosanitary requirements, by semi-processing and chilling of meat, the feed costs of raising animals to the high quality of finishing needed for export markets was prohibitive (Rich et al., 2008). Particularly in urbanizing and transforming developing countries, there will be opportunities for linking smallholder producers, input suppliers and market agents into vertically integrated production and marketing value chains through innovative institutional and contractual arrangements along the chain.

While a growing livestock sector can provide opportunities for the poor, there are deep concerns about the competitiveness and economic viability of poor livestock producers in a rapidly changing livestock sector. Improving incomes and providing employment to the poor who have limited livelihood options is

an important objective in many developing countries. Public policy and institutions can provide a supportive environment for dynamic smallholder-led growth that minimizes negative impacts on the environment. For example, analysis of pro-poor policies supporting informal milk markets in Kenya found that resulting market efficiencies led to annual benefits to the Kenyan economy of \$33 M per year, most of which went to poor producers and consumers (Kaitibie et al., 2008). Such interventions support broad-based rural growth and stronger rural–urban backward linkages (through increased demand for inputs, livestock services, and marketing), forward linkages (through links to dairy and meat processing plants) and consumption linkages (arising from rising livestock incomes) that provide scarce economic opportunities for rural areas.

3. Increasing production from smallholders – can it be sustainable?

Sustainability can be assessed in different dimensions. Our assessment of sustainable smallholder livestock systems focuses on two dimensions – the social and the environmental. The social dimension encompasses income, livelihood and equity issues for producers, service providers, employees, market agents and consumers. The environmental dimension considers the more efficient use of scarce land, water and nutrients and minimizing the production of greenhouse gases, environmental pollutants and disease risk. The paths to increasing sustainability for different systems can be considered in a two dimensional diagram (Fig. 3).

Across these two dimensions, there are stark differences in perspectives on the sustainability of livestock production. This demonstrates key trade-offs, but it can also be used to identify win-win options for improving livelihoods, while enhancing the sustainability of the resource base.

In developed countries where the socio-economic welfare and equity are high, over-consumption rather than under-

consumption of livestock products is more prevalent and the environmental dimension of livestock sustainability, prominent. Industrial livestock systems in these countries generate large concentrations of nutrient wastes. In situations where public policies are ineffective or regulatory institutions are weak, intensive livestock systems have a very bad image – associated with public problems of environmental pollution, public health, food safety and animal welfare and have visible and high input requirements. Contrasting outcomes for these intensive livestock systems are shown in the top quadrant of Fig. 3.

The negative impact of growing livestock numbers on climate change poses significant challenges for intensive livestock production. An estimate is that livestock contribute 18% to anthropogenic greenhouse gas emissions measured in CO₂ equivalents, globally (Steinfeld et al., 2006). In agriculture-based countries, with large ruminant livestock industries, livestock account for nearly 80% of all emissions from the agricultural sector (Steinfeld et al., 2006). However, in more industrialized nations, the share of livestock diminishes significantly (<40%) as other sources of greenhouse gas become proportionately more (EPA, 2006). However, in developed countries, total emissions are several times higher than in developing countries (Fig. 4) where rates of economic growth and resource consumption are relatively low. Even though inefficient livestock management and land use practices contribute to greenhouse gas emissions, poor people have a dramatically lower environmental impact than the rich. The overriding priority in these countries is economic growth and improved livelihoods for poor people. About two-thirds of poor people in developing countries – those living on less than \$2 a day – depend on agriculture and livestock for a significant part of their livelihoods. Thus, it is critical to assess the impact of livestock on climate change and the environment through a broader socio-economic and livelihood lens in order to identify sustainable interventions

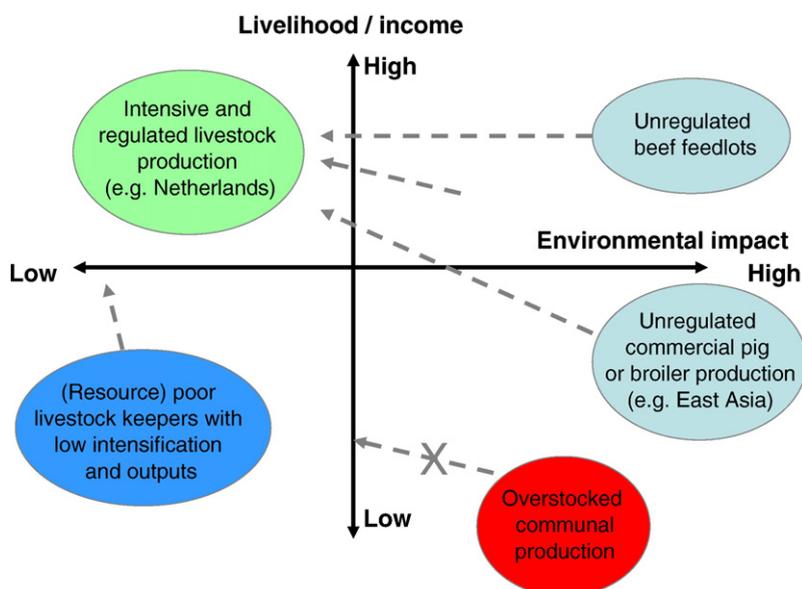


Fig. 3. Pathways of livestock evolution to increase the sustainability of livestock production in selected systems.

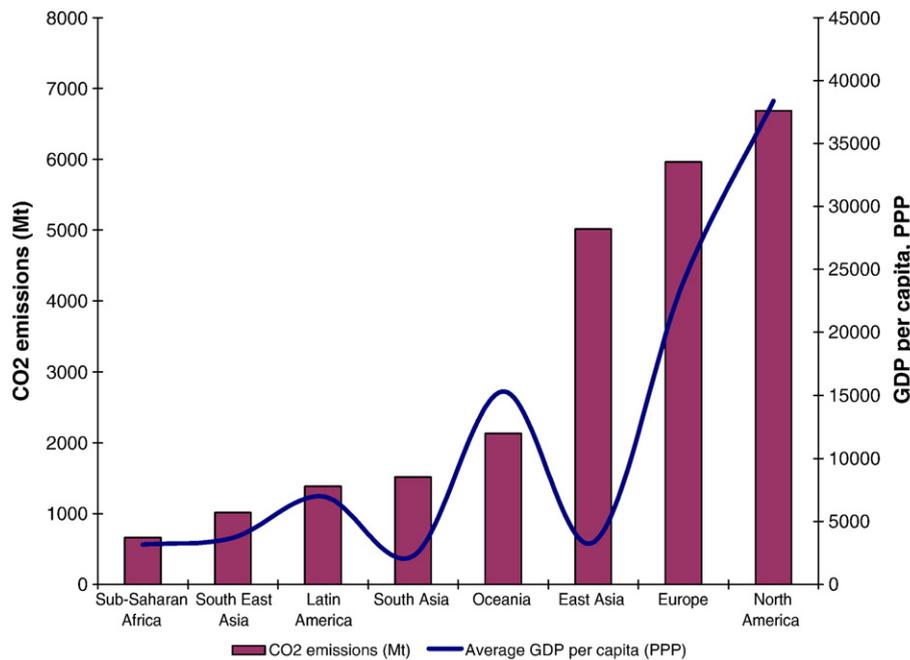


Fig. 4. CO₂ emissions and GDP per capita for different regions, adapted from World Bank Development Indicators. Source: adapted from World Bank Indicators (2009).

that provide real incentives for good stewardship of the environment. This is a perspective not appreciated in developed countries where basic livelihood needs are met and between 17 and 22% of kcal intake comes from livestock products. In Asia and Africa, only 6% of kcal intake comes from livestock products. Livestock are important in improving protein and micronutrient deficiencies for the poor (IAASTD, 2007; Herrero et al., 2009a,b).

Although on a *per capita* basis poor livestock keepers are not important contributors to environmental bads, their aggregate importance is high because of their population numbers, the increasing demands for livestock products and the large areas they occupy globally (Table 3). In this regard, mixed small-holder crop–livestock systems play a critical role, as they account for most livestock production in developing countries. Mixed production systems produce 68% of beef, 73% of milk, 54% of lamb, and significant amounts of poultry and eggs in the developing world (Herrero et al., 2009a, 2010). At the same time, the extensive tropical pastoral areas can play significant roles in providing integrated environmental solutions that benefit poor people. Manure from farm animal, for example,

Table 3

Farming systems in the developing world: surface area and population 2000–2030.

(Adapted from Herrero et al., 2009a).

Farming system	Area (10 ³ km ²)	Population 2000 (10 ³ people)	Population 2030 (10 ³ people)
(Agro-)pastoral	35.2	295.1	497.3
Mixed extensive	14	1099.2	1670
Mixed intensive	9.8	2674	3639.5
Other	16.9	480.3	682.3

provides organic matter that when properly managed can be a valuable resource underpinning intensification of land use in crop–livestock systems. Similarly, carbon sequestration from rangelands or through agro-forestry can provide opportunities to diversify incomes of poor people while contributing to reducing the potential impacts of climate change (Reid et al., 2004; Seré et al., 2008).

Growing resource scarcity, particularly water and land, imply that intensifying livestock production in mixed crop–livestock systems in a sustainable way will pose significant social and environmental challenges. Increases in production will need to be achieved without the major expansions in the use of land, water and other inputs that have driven past increases in agricultural production (World Bank, 2007).

Water is and will increasingly be one of the critical constraints. The demand for water for both agricultural and non-agricultural uses is rising, and water scarcity is becoming acute in much of the developing world, limiting the future expansion of irrigation (Comprehensive Assessment, 2007; World Bank, 2007). Approximately 1.2 billion people live in river basins with absolute water scarcity, 478 M live in basins where scarcity is fast approaching; and a further 1.5 billion suffer from inadequate access to water because of a lack of infrastructure or the human and financial capital to tap the available resources (Comprehensive Assessment, 2007). Today, each calorie of food produced takes approximately 1 L of water (Fig. 5; Comprehensive Assessment, 2007).

In assessing land and water use for future agricultural production, it has been estimated that highly productive irrigated areas, mostly in Asia, are approaching their productivity limits. While these areas currently feed a significant number of the poor, the largest gains for agricultural production

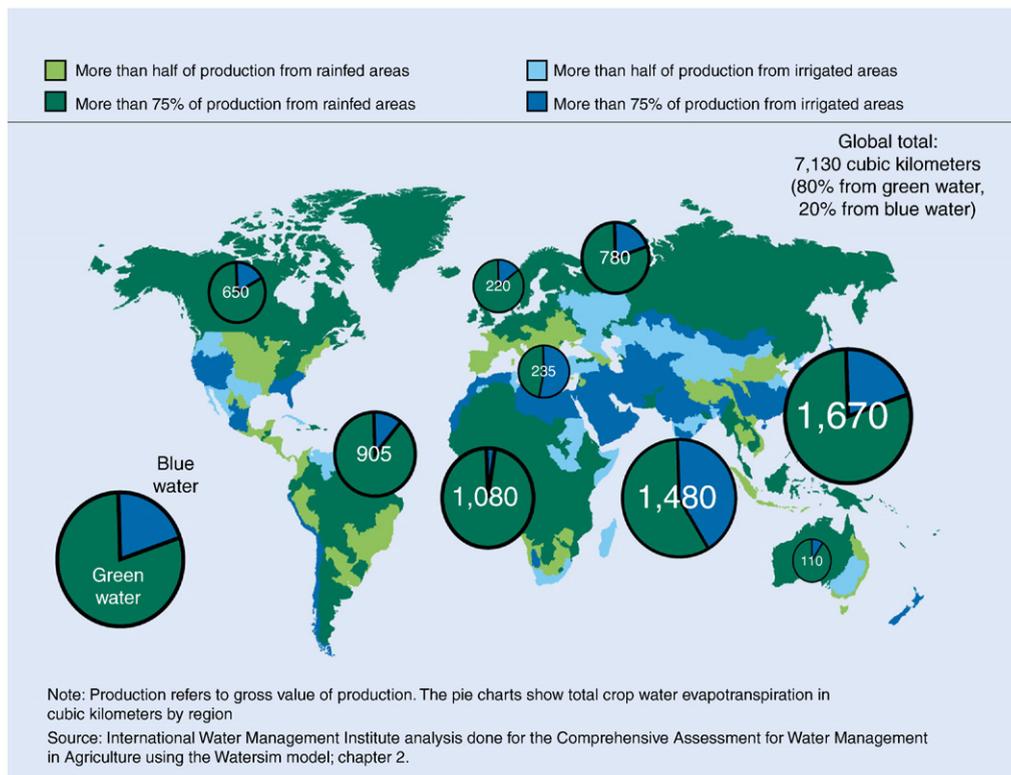


Fig. 5. Annual freshwater withdrawal by agriculture and GDP per capita for different regions (Comprehensive Assessment, 2007). Source: Comprehensive Assessment (2007).

are likely to come from improvements in the efficiency of water use and improved water management in rain-fed areas (Comprehensive Assessment, 2007). Economic growth and other structural changes in developing-country economies is also expected to increase future competition for water between crops, livestock and other non-agricultural uses. Agricultural production can be intensified in the more extensive mixed systems in developing countries. To achieve these gains, significant improvements in market access, service provision and reductions in transaction costs will be required. Without gains in water productivity, water resources devoted to agricultural production will likely increase by 70–90%. On top of this is the amount of water needed to produce fibres and biomass for energy. Water scarcity is becoming a key issue limiting development in mixed systems. Improved water management practices such as water harvesting and more efficient use of groundwater can help smallholder intensify livestock production in mixed crop–livestock systems.

Increasing water productivity of livestock systems also needs to be part of the solution. Significant improvements could be made in water productivity by improving feed management and sourcing, increasing diet quality, improving rangeland management, reducing land degradation through control of stocking rates, implementing water harvesting techniques and others (Peden et al., 2007).

Likewise, land availability is and will be a key constraint to the sustainable increases in livestock productivity.

Currently, mixed systems in the developing world occupy approximately a third of the global land area and support 80% of the global population (Table 3). Significant pressure on resources will occur as the global population increases to 9 billion by 2050 while the areas of mixed systems remain virtual the same. Increasing competition for food, feed and fuel will have significant impacts on natural resources and on equity.

In mixed systems, particularly in Sub-Saharan Africa, the depletion of soil nutrients is severe, with near universal negative soil–nutrient balances, year on year. In such nutrient-deficit situations, the nutrients from livestock excreta and urine in mixed systems play a critical role in improving soil nutrient balances and sustaining crop production. In intensive systems where feed resources are brought in from off-farm, livestock act as a nutrient funnel, channelling nutrients to small plots of land which can in turn support repeated cropping. In densely populated Western Kenya, on farms averaging only 0.65 ha in size, only farms with cattle were found to have positive soil–nutrient balances (Shepherd and Soule, 1998). The result is that somewhat paradoxically, as land holdings shrink, farmers may choose intensive livestock production as the only viable agricultural enterprise. Not coincidentally, poor soil nutrition is very often equated with poor human nutrition, particularly among rural children. Intensified smallholder livestock production can successfully address both – consumption of small amounts of milk and

meat improves child health, growth and cognitive development (Neumann et al., 2002).

Opportunities for intensification differ depending on the type of systems and their location, associated with differences in primary production potential, availability of inputs, infrastructure, markets, services and others (Herrero et al., 2010). For example, mixed intensive systems in fertile areas with suitable lengths of growing period and relatively low population densities abound in Central and South America. Sub-Saharan Africa, on the other hand has suitable land for increased intensification, but constraints such as lack of investment, markets and service provision prevent a better utilization of these resources. It is essential to acknowledge these structural differences as options and opportunities for sustainable growth in productivity and poverty reduction are largely dependent on them (Herrero et al., 2009a, 2010).

Important productivity gains could be made in the more extensive mixed rain-fed areas, as in these areas there is less population pressure on the land (Table 3, Herrero et al., 2009a, 2010). These mixed systems comprise large semi-arid areas of Sub-Saharan Africa, notably in Western and Southern Africa, areas far from population centres in the humid tropics of Latin America, and areas without irrigation in parts of South Asia (Herrero et al., 2009a). In these more extensive systems, with less pressure on the land, yield gaps of crops and livestock are still large (Freeman et al., 2008). Livestock feeds are a critical constraint in these drier systems. The major contribution to improving feed availability and quality will be through crop improvement programs. Multi-objective crop improvement programs can improve both human food and livestock feed and are often easily out-scaled through existing public and private crop breeding and seed systems. Given the greater risks and higher transaction costs in drier and more remote systems, there is a need for pro-poor policies and public investments to reduce transaction costs, manage incentives and improve risk management. Integration of production in these emerging intensive systems to supply agro-ecosystems services (feeds, food, etc.) to the more intensive systems should be promoted. One approach to this is that these systems could be 'providers' of agro-ecosystems services to more intensive systems (Freeman et al., 2008; Herrero et al., 2009a, 2010).

In contrast, mixed intensive systems in the developing world (i.e. irrigated systems of South East Asia) are under significant pressures. Resource constraints in some land-based mixed intensive systems are reaching a point where livestock production could decrease and where environmental degradation may have deleterious impacts on humans. Some systems may need to de-intensify or stop growing to ensure the sustainability of agro-ecosystems (Herrero et al., 2010). Initiatives to help communities develop viable ecosystem based enterprises for income generation and environmental resilience will provide real incentives for sustainable management of the environment. Developing sound, simple and equitable schemes for payments for ecosystems services as well as strategies, such as weather based insurance schemes, that help communities adapt to climate change provide real opportunities for livestock keepers to intensify production in sustainable ways. In some cases, de-intensification is required, before irreversible damage to ecosystem service functions takes place. Other, less fragile intensive systems can benefit from

options to improve efficiency such as more water efficient crop varieties and more suitable livestock systems, such as a shift to monogastric production when management is good and land availability is very limited (Herrero et al., 2009a, 2010).

There are still many large questions on the sustainability of smallholder livestock systems. Clearly political processes requiring appropriate policies and providing supportive conditions for the poor will be important. As we have argued, it is vital to consider both the social and environmental dimensions of sustainability in decision making. How interventions are sequenced is also critical. Frequently, supportive policies, enabling institutions and pro-poor market development are preconditions to enable technical innovations to have impact. Some examples of these will be discussed in the next section. Public policies and interventions, including participatory research and building consensus around agendas to support sustainable intensification require enhanced knowledge and evidence base for improved decision making and public investment. Given the massive numbers of people and land area of smallholder livestock systems in the tropics, the challenge of linking broad-based poverty alleviation in an environmentally sustainable way is a major challenge that requires action at community, national and global levels.

4. Opportunities for sustainable intensification of tropical smallholder livestock systems

This section will use two examples of successful intensification in tropical smallholder livestock systems – smallholder dairy in East Africa and South Asia and small ruminant systems in western and southern Africa – to identify lessons that can help meet current and anticipate future challenges to sustainable intensification of smallholder livestock systems. Each system will be briefly described, opportunities for sustainable livestock development will be identified and strategies proposed.

4.1. Smallholder dairy in East Africa and South Asia

East Africa and South Asia are two of the world's most important regions for smallholder dairy development. Dairy animals may be genetically improved indigenous cattle, cross-bred or exotic dairy cattle or dairy buffaloes (South Asia). Together, > 135 M households contribute to dairy production in these two regions (Table 4). Dairy production systems in East Africa vary considerably and range from grazing systems with indigenous or cross-bred cattle to more intensified mixed farming systems in the highlands that rely on stall-fed cross-bred or exotic cattle with feed including fodder (Napier grass, crop residues, and natural grass and weeds) and supplements brought to the animals. Average herd sizes vary from 1–5 cows in the most intensive systems and up to 10 in the extensive systems. A high percentage of the milk production is sold in intensified systems and manure is highly valued and used as fertilizer on crops. In South Asia, a large proportion of farming households and a considerable proportion of landless households keep dairy animals, generally in small herds with 2–5 adult females. Both cattle and buffaloes are popular with the latter being more numerous in the North and the West of the subcontinent. Feeding is based mainly on crop residues such as rice and wheat straw from private farmland and common

Table 4

Key production and marketing opportunities, pro-poor potential, supply constraints and priority interventions for selected livestock systems in the developing world.

Indicators	South Asia dairy	East Africa dairy	West Africa beef	West Africa small ruminants	Southern Africa small ruminant
<i>Growth and market opportunities</i>					
Domestic growth rate ¹	Bangladesh: – 0.6% India: 2.4%	2.8%	2.3%	1.1%	– 3.1%.
Import substitution ²	Bangladesh: 40.4% India: 0.1% Bangladesh potential lies in import substitution. India potential lies in strong domestic demand and in potential exports.	1.7%	7.7%	2.1%	16.1%.
		Potential lies in domestic demand for local products and in future potential exports, including regional trade.	Good opportunities for regional production. Imports substitution is possible in higher end markets if quality issues can be addressed.	Steady growth in regional demand is likely to increase with income growth under future economic development.	Negative growth rate may reflect economic turmoil (Zimbabwe) and rising prices. Good opportunities for import substitution.
<i>Pro-poor potential</i>					
Millions of poor ³	India: 124.3 M Bangladesh: 10.1 M	1.1 M	70 M	Local goats: 81.6 M Sheep: 21.3 M	Goat: 21.2 M Sheep: 7.1 M
Value of production ⁴	Bangladesh: \$200 M India: \$ 7088 M	\$ 4290 M	\$ 1119 M	\$ 970 M (goat & sheep, meat and milk)	Goat: \$ 132 M Sheep: \$ 262 M
Millions of poor ⁵	Bangladesh: 37 M India: 446 M Dairy production offers opportunities for many millions of poor. Because of low cost family labour and crop residues, smallholders will continue to dominate production for many years to come, but with increasing shift towards formal marketing.	68 M	130 M	130 M	40 M
		Because of low cost family labour and crop residues, smallholders will continue to dominate production for many years to come, but with some shift towards formal marketing.	Smallholders continue to dominate production of young feeder cattle aided by emerging stratification including feedlot enterprises. This region is responsive to market demands and may provide returns on intensification if effective input services are available.	Smallholders dominate production with increasing stratification through close-to-market feedlots. Producers in this region are responsive to market demands but mostly manage low input systems which are less amenable to intensification.	Smallholders dominate the production of goats, with increasing stratification (smallholders producing young animals that are sold to close-to-market feedlots). Smallholder production is very competitive, due to use of crop by-products, natural forage, and family labour.
<i>Supply constraints</i>					
Genetics	Lack of improved indigenous sires; poor AI for upgrading. Use of AI in buffalo's is limited due to technical constraints.	Lack of cost-effective way of adopting cross-bred cows. AI services not widely available, expensive and have low conception rates.	Lack of improved indigenous sires and proven cross breed. Investment in breeding infrastructure needed, but unclear result.	Lack of improved indigenous sires	Control of breeding is sometimes problematic. When achieved, lack of improved indigenous sires is a constraint, and systems to supply them.

Animal health	Not a major constraint relative to genetics and nutrition	A major constraint, especially East Coast fever and FMD.	Nutrition x disease complexities and FMD are constraints.	PPR a threat and high pre-weaning mortality	PPR, and pre-weaning mortality
Nutrition	Poor quality basal diet and low level supplementation. Low quality crop residues provide the large bulk of feed resources.	Poor quality basal diet and low level supplementation. Limited feed availability during the dry season, resulting in large seasonal fluctuation in milk production.	Under-nutrition of breeding females	Under-nutrition of breeding females.	Under-nutrition of breeding females In general, inadequate feed for females and young animals is a key barrier, and may be responsible for the large productivity gap.
Market/ institutional constraints	Poor access to formal output market and inadequate input services. Markets are largely informal and will likely remain so for decades. Legal and social barriers to slaughter of cattle reduce value of production. Cooperative development has only partially met the challenge.	Limited access to formal output market and poor input services, including genetics and feed (quality). As in South Asia, dairy markets in East Africa are largely informal, and will likely remain so for decades. Cooperative development has only partially met the challenge.	Very limited input services and inefficiencies in output marketing. In these extensive systems with poor infrastructure, access to services is minimal. Output marketing relies on itinerant traders and weekly markets, leading to high transactions costs.	Inefficient output marketing and absence of input services	Inefficient output markets, and poor access to services. Small ruminant producers typically rely on itinerant traders or weekly markets to sell their stock, and may often have poor bargaining power. Formal animal health and other services are often minimal to non-existent.
<i>Potential interventions</i>					
Potential productivity gains	For cross-bred cattle in mixed farms, 63% gain from low of 1200 kg to 2000 kg Buffalo are likely to be the target dairy species, due to a) ability to utilize low quality roughage and b) no ban on slaughter raises the value of meat. Feed efficiency will be key issue, due to the aggregate constraint of feed resources in a largely Arid/Semi-arid subcontinent.	For cross-bred cattle, milk production can be multiplied by 3, from low of 644 kg to 2657 kg Additional production may come from dryer areas, but this will require cross-breeds being produced in remote areas and sold to farmers in mixed systems. Strategies for improving feeding are a) improve quality/ quantity of roughage and b) increase access to low cost/high quality concentrate.	As observed on farms, gains of 50% or more are potentially achievable Interventions are: a) bulking and market information systems; b) animal health interventions to go along with CBPP, FMD vaccinations; c) reducing calf mortality New feedlot schemes particularly in meat deficit coastal areas may be possible.	Highest yields are seen on institutional farms in the semi-arid regions (>20 kg). Interventions are: a) organize marketing to meet seasonal demand (control breeding to meet seasonal demand), b) focus on prevention of PPR c) strategic feeding and d) reduce mortality	Productivity gaps of 250 to 300% (observed weaning weights in mixed systems) Interventions include strategic feeding, combined with targeted animal health interventions. Organizing marketing through farmer-managed associations (clusters or hubs) may help to overcome the transactions costs, as well as provide a vehicle for health/feed improvements.

Key: ¹% annual consumption growth rate in domestic market; ²% imports of domestic production; ³number of poor people (under \$1US per day) who keep the species/breed, in million; ⁴in US\$/year (million); ⁵number of poor people in the region under \$1US per day.

resource grazing. Unlike East Africa, fodder crops are rare outside of some irrigated areas. Concentrates are fed by only a few larger scale farmers. Milk is the main output although dung is applied to crops or made into cakes for fuel. In both regions the family is the main source of labour and in many cases women are responsible for managing the animals and milking. Wage labourers often play a role. In highland Kenya, for example, about half of all smallholder dairy farms employ a full-time labourer – the employment implications for the very poor are significant. In both regions, around 80% of the milk is marketed informally with the largest part of that proportion directly by farmers to consumers with no intermediaries. However, a substantial share passes through various forms of traders, vendors and cottage processors. The remainder is sold more formally through cooperatives or private processors and is growing in market share, but slowly, as demand for quality and convenience grows. The opportunities lie in strong local demand for milk, growing opportunities for exports from the few regions with potential to increase marketable surplus, in an era of increased milk prices.

4.2. Strategies for dairy development

The reliable supply of improved animal genetics is a major barrier to increased smallholder dairy production and sustainability across both South Asia and East Africa. Very few systems exist for the supply of either improved indigenous cattle breeds, or for artificial insemination (AI) to provide cross-bred cattle that will be needed to sustain dairy systems in often challenging climatic and disease environments. Existing AI services are not available everywhere, and where available, they usually offer semen from bulls that have not been appropriately selected, have high delivery charges and achieve low conception rates. Partly as a consequence, they are little used by farmers even where available. Genetic improvement and systems to develop, deliver and sustain that improvement are central to dairy development efforts in these regions. Evidence shows that genetic improvement, with accompanying changes in feed regimes, can lead to gains of 60% to 300% in milk productivity in cattle (Table 4).

Low quality crop residues provide the large bulk of feed resources, even in commercial systems, and concentrates are expensive and little used in both regions. Of concern is the limited availability of feed during the dry season, resulting in large seasonal fluctuations in milk production. Given the expected long-term reliance on crop residues, crop breeding for improvement in fodder quality (digestibility and palatability) of staple crops can increase available feed resources and be quickly scaled out through existing crop breeding and seed systems. As smallholders specialize, the use of planted fodder crops (Napier grass, herbaceous legumes, maize, and forage sorghum) will increase, but mostly limited to areas with available labour and reliable rainfall or irrigation. Increases in food prices are likely to lead to a crop supply response, increasing availability of feeds resources.

In East Africa and some areas of South Asia, animal health is a major issue, leading to mortalities in calves of 20% and 10% or more annually among cows. In East Africa, East Coast fever is an important risk, particularly in expanding dairy production for intensive to more extensive systems. Devel-

opment of a vaccine for ECF, now underway, will unlock the potential of large areas in East Africa currently under-utilized.

As in South Asia, dairy markets in East Africa are largely informal, and will likely remain so for decades. This limits the access of producers to formal markets, and while that continues, the high transactions costs in informal markets may pose barriers. Simply imposing a formal milk market model (required chilling and pasteurisation) is likely to succeed only in locations where formal milk demand is high (as has been the experience in the past). Upgrading the capacity, practices and standards among informal market players is likely to improve performance, lowering transactions costs and greatly improve market performance (Kaitibie et al., 2008). Evidence of employment and other pro-poor benefits and management of public health risks can be critical in influencing public policy for improving rather than outlawing informal milk markets.

Improved organization and management are needed to achieve these improvements. Organizational strategies must link input to output markets and other service delivery in a complementary fashion. One or more of the organizational mechanisms indicated above are likely to support the integration:

- In South Asia, the favoured organizational models have been a) farmer clusters linked to NGO development projects and cooperative chilling and processing schemes, or b) producer companies linked to private processors, a model now legally provided for.
- In East Africa, dairy development is being addressed through a) farmer-managed hubs linked to private and public service providers and processors having their collecting and chilling capacity, or b) self-help groups or cooperatives, linked to informal or formal distributors.

In either case, public investment in adaptive research, sustained organizations, and infrastructure will be required to deliver increased knowledge and capacity to small farmers, particularly in improved genetics and animal health.

5. Small ruminants in Sub-Saharan Africa

Small ruminants (sheep and goats) play an important role in household livelihoods across parts of Africa, particularly in drier, marginal agricultural areas, but also in humid forest zones (dwarf goats). Households may keep up to 10 animals, with 2–3 being common. Many small ruminants are raised with almost no cash input, kept mainly as an “insurance” or “emergency cash” resource and are often owned and managed by women. In some drier regions there is an increasing market orientation, especially for sheep, which in many parts have high effective demand around religious festivals, when prices are at a premium. Within grazing areas, management is minimal and the natural resources are subject to continuous grazing often linked to land degradation. Bush encroachment is widespread, reducing crop/livestock productivity and the carrying capacity of rangeland. Where there is market orientation, small ruminants are typically fed on crop residues, cereal stovers supplemented with legume (cowpea or groundnut) hay and various combinations of bran from the household processing of grain. As systems intensify, there is less opportunity for free

grazing and small ruminants are increasingly confined within the home compound. In peri-urban areas, fattening operations keep small ruminants enclosed and fed on concentrates and fresh fodder for finishing and sale. Small ruminants are not generally kept for milk in most areas, although it varies by region. Chronically poor nutrition and poor husbandry methods result in low reproduction rates, high mortality rates and low off-take. Markets and processing for small stock are less developed than for cattle. Goats are mainly slaughtered or sold locally or to traders, contributing significantly to local food security either through meat provision or cash from sales.

As in the case of dairy, many millions of rural households keep small ruminants (approximately 130 M people across western and southern Africa), and goats are particularly important for the poor. Smallholders dominate the primary production of goats with largely informal links to close-to-market feedlots for finishing. For the poor, small ruminant ownership allows the building of assets that are inflation proof, and they can be raised with minimal cash inputs through locally available feed materials and family labour. For these reasons, smallholders are very competitive relatively to large-scale producers. In southern Africa, the significant number of migrant workers increases the importance of goats as assets in the hands of women.

5.1. Strategies for small ruminant development

Gains in the short term can be achieved primarily from improving both feed and animal health management, to reduce mortalities of young animals and to increase weight gain. These improvements lead to more rapid herd and animal growth, both central to profitability. High pre-weaning mortality is a significant problem for herd growth and thus profitability, and PPR (peste de petit ruminant) is a threat in many areas. Pre-weaning mortality is associated with under-nutrition of breeding females. In general, inadequate feed for females and young animals is a key barrier, and may be responsible for the large observed productivity gap of 300% in some areas (Table 4). Although weaning weight is only one indicator of productivity, the large observed gaps point to significant opportunities to increase productivity. This will involve strategic feeding, combined with targeted animal health interventions.

Improved breeding is more difficult to manage in small ruminant systems and even when achieved, the lack of improved indigenous stock is a constraint. Experimentation with new options for small ruminant breeding that can build on local systems, practices and infrastructure is needed. Improving breeding systems will usually be led by demand-pull and thus developing marketing systems will usually be an essential pre-requisite. Currently, small ruminant producers typically rely on itinerant traders or weekly markets to sell their stock and may often have poor bargaining power, leading to low prices. Formal animal health and other services are often minimal to non-existent. Some form of farmer organizations (clusters or hubs) may help to achieve great market power and establish stronger vertical links to larger and more lucrative urban markets. As they evolve, farmer hubs should link marketing with the supply of knowledge

and inputs. There are few successful models at present but this should be an active area of investment given the pro-poor potential for small ruminants.

These two examples (smallholder dairy and small ruminant systems) illustrate key principles for pro-poor sustainable intensification or ruminant systems in Sub-Saharan Africa and South Asia. First, demand from local, domestic, and regional markets is a key factor stimulating smallholder-led intensification. Second, the sequencing of development investments and interventions is critical, with market demand-pull and an enabling policy and regulatory environment essential pre-requisites for subsequent technological innovations and institutional arrangements for delivery of input, services, and products to markets. Third, the diversity of smallholder production and marketing situations suggests the need for a clearer understanding of incentives for public and private sector delivery systems (or combinations), particularly in increasingly liberalized domestic markets. The private sector has the greatest incentive to supply inputs and services to smallholders where market concentration is high and market risks are low. Outside these situations, input and services are better delivered through public-private partnerships, including NGOs or the public sector. Fourth, there are no silver bullets. Experimentation and testing of different models in different situations, when complemented with results based monitoring and evaluation, provide opportunities to identify best practices and learn what works, what does not work, and why. These insights are keys in scaling up interventions that enhance sustainable intensification in livestock systems. With further intensification of production and market chains, more complex solutions will need to evolve, to retain markets and to sustain production under increasing natural resource constraints. These system changes suggest the need to strengthen the capacity in foresight to be able to identify and anticipate demand and future challenges to smallholder intensification. The opportunities and threats for sustainable intensification are best understood in a systems context. Such an understanding can help guide the balance of technological, policy, and institutional interventions that enhance competitiveness and sustainable intensification of smallholder livestock systems.

6. Conclusions

Three quarters of poor people in developing countries live in rural areas (World Bank, 2007). Smallholder livestock keepers represent around 20% of the world population and farm most of the agricultural land in the tropics. Projected increases in future demand for livestock in developing countries provide unique opportunities to use sustainable intensification of livestock systems as an instrument for reducing poverty and improving stewardship of the environment. But the future is uncertain and difficult to predict. There are even greater uncertainties about the role of smallholder livestock producers in future livestock development scenarios because of rapid socio-economic transformations globally and in developing countries.

Efforts to support sustainable intensification will vary by production systems and the specific factors driving changes. Research needs to be responsive to what is changing to

maximize its contribution to sustaining intensification of smallholder livestock systems. Future scenarios of sustainable livestock systems can be used to explore important uncertainties and assess the impact of different technologies, policies, and institutions on livestock systems and poor people. Monitoring indicators of key drivers over time as well as their impacts enhance the capacity of research and development organizations to respond effectively in a rapidly changing context.

Growing demand for livestock products, particularly from local, domestic, and regional markets will continue to be the main driver of livestock system intensification in developing countries. Policies and investments that lift millions of poverty over the \$2 a day threshold will lead to significant growth in demand for livestock products in Asia and Africa for many years to come. Decisions about sustainability must take into account both socio-economic and environmental dimensions and different perspectives on these two dimensions need to be bridged to achieve global consensus on sustainability priorities. Smallholders can play an important role in the needed sustainable intensification if investments are targeted and implemented in areas of most probable positive returns, policies and investments are pro-poor and emphasis is given to empowerment and developing the capacities of the poor to participate more fully.

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