Animal (2013), **7:s1**, pp 3–18 © The Animal Consortium 2012
doi:10.1017/S1751731112001954

animal

The roles of livestock in developing countries

M. Herrero†, D. Grace, J. Njuki, N. Johnson, D. Enahoro, S. Silvestri and M. C. Rufino

International Livestock Research Institute, PO Box 30709, Nairobi, Kenya

(Received 2 December 2011; Accepted 7 September 2012; First published online 5 November 2012)

Livestock play a significant role in rural livelihoods and the economies of developing countries. They are providers of income and employment for producers and others working in, sometimes complex, value chains. They are a crucial asset and safety net for the poor, especially for women and pastoralist groups, and they provide an important source of nourishment for billions of rural and urban households. These socio-economic roles and others are increasing in importance as the sector grows because of increasing human populations, incomes and urbanisation rates. To provide these benefits, the sector uses a significant amount of land, water, biomass and other resources and emits a considerable quantity of greenhouse gases. There is concern on how to manage the sector's growth, so that these benefits can be attained at a lower environmental cost. Livestock and environment interactions in developing countries can be both positive and negative. On the one hand, manures from ruminant systems can be a valuable source of nutrients for smallholder crops, whereas in more industrial systems, or where there are large concentrations of animals, they can pollute water sources. On the other hand, ruminant systems in developing countries can be considered relatively resource-use inefficient. Because of the high yield gaps in most of these production systems, increasing the efficiency of the livestock sector through sustainable intensification practices presents a real opportunity where research and development can contribute to provide more sustainable solutions. In order to achieve this, it is necessary that production systems become market-orientated, better regulated in cases, and socially acceptable so that the right mix of incentives exists for the systems to intensify. Managing the required intensification and the shifts to new value chains is also essential to avoid a potential increase in zoonotic, food-borne and other diseases. New diversification options and improved safety nets will also be essential when intensification is not the primary avenue for developing the livestock sector. These processes will need to be supported by agile and effective public and private institutions.

Keywords: livestock, developing world, environment, poverty reduction, food security, livelihoods

Implications

Recognising the different roles played by livestock in the developing and the developed world is essential to understand the impact of livestock on livelihoods, economic development and the environment. The importance of this paper lies in providing a balanced account of the roles of livestock in developing countries. This kind of information is necessary to dissect the key issues in the often, ill-informed or generalised discussion on the current and future roles of livestock. Only by understanding the nuances in these roles will we be able to design more sustainable solutions for the sector.

Introduction

We are at a moment in time where our actions could be decisive for the resilience of the world food system, the environment and a billion poor people in the developing world, let alone for the fate of our planet. The society has realised that there are significant pressures on the world's food and ecological systems, where the alterations of global biogeochemical cycles could be irreversible and where new drivers, such as climate change, are likely to exert additional pressures for sustainably feeding 9 billion people in the future. At the same time, and especially in the developing world, the demand for livestock products is increasing, thus adding additional pressures on the world natural resources. Not surprisingly, the world is asking a big question: what should we do about livestock? There is an urgency to reduce the environmental footprint of livestock production while the world evaluates the choices for sustainably feeding the human population in the future.

This question requires a sophisticated and disaggregated answer. The sector is large. There are 17 billion animals in the world eating, excreting and using substantial amounts of natural resources, mostly in the developing world, where

† E-mail: m.herrero@cgiar.org

https://doi.org/10.1017/S1751731112001954 Published online by Cambridge University Press

most of the growth of the sector will occur. The roles of livestock in the developing world are many, spanning from the social to the economic, to the environmental. At the same time, they can be positive (i.e. income) or negative (i.e. pollution). These roles can shift depending on location. For example, livestock can be polluters in one place, whereas in another they provide vital nutrients for supporting crop production. The picture is complex. Whether for its positive or negative roles, livestock are in the spotlight. It is essential to dissect the discussion on the roles of livestock, as the economic development of different countries, their structure of production, the demand for livestock products, the competition with other sectors and others shape these roles, making broad generalisations about the livestock sector useless (and dangerous) for informing the current global debates on food security and the environment. It is essential to deliver nuanced, scientifically informed messages about livestock's roles in relation to food systems, livelihoods and their economic and environmental performance.

This paper reviews the positive and negative roles of livestock in the developing world. It also discusses key factors that are likely to determine the future contribution of the sector to food security, environmental protection and economic growth. The paper proposes key actions for improving different aspects of livestock systems so that the positive roles outweigh the negatives.

Livestock and its socio-economic roles in developing countries

Livestock production, economics and trade

Livestock production in the developing world occurs in a wide range of heterogeneous production systems. These can range from pastoral/grassland-based systems, which occupy most of the land area and have low human population densities, through mixed crop-livestock systems, usually in areas suitable both for arable and livestock production and where the bulk of rural human population lives, and intensive systems usually in peri-urban/urban areas. Landless systems are also often found in urban areas. All these systems in developing countries produced about 50% of the beef, 41% of the milk, 72% of the lamb, 59% of the pork and 53% of the poultry, globally (Herrero *et al.*, 2009). These shares are likely to increase, as most future growth in livestock production is projected to occur in the developing world (Bruinsma, 2003; Rosegrant *et al*,. 2009). Most meat and milk in the developing world comes from mixed systems (Seré and Steinfeld, 1996; Steinfeld *et al.*, 2006; Herrero *et al.*, 2009). These systems play a very important role in global food security, as they also produce close to 50% of the global cereal output (Herrero *et al.*, 2009 and 2010). However, the highest rates of increase in animal production observed in the last decades, and forecasted into the future, are in the intensive pig and poultry sectors of the developing world (Delgado *et al.*, 1999; Bruinsma, 2003; Steinfeld *et al.*, 2006).

Livestock production in the developing world is also an important economic activity. Livestock products are high-value products, especially when compared with crops. For example, the average global price of a tonne of red meat is more than 10 times higher than the price of soya bean, whereas that of milk is 70% higher (data from FAOSTAT, 2011). This makes milk and meat to rank as some of the agricultural commodities with the highest gross value of production (VOP) in the developing world (FAOSTAT, 2011). In the last decade, livestock have represented between 17% and 47% of the total agricultural VOP in developing country regions (range defined by South East (SE) Asia and Central America, respectively; FAOSTAT, 2011). Over the last 40 years, the value of livestock production has seen an average 2.7% growth per year in sub-Saharan Africa (SSA), 3.4% in Central America and 4.1% in SE Asia. These indicators of growth compare favourably with, for example, a mean annual growth in VOP of 1.2% in North America over the same period (FAOSTAT, 2011). These growth rates are largely a reflection of increased production in the developing world.

Table 1 *Number of livestock keepers living below US$2 per day*

Region/sub-region	Number of poor livestock keepers ('000)
Sub-Saharan Africa	319 908
Central Africa	29 815
Western Africa	132 742
East Africa	104 816
Southern Africa	52 534
South Asia	606 967
India	546 012
Bangladesh	60 955
Total	926 875

Sources: Staal *et al.*, 2009 (updated from Thornton *et al.*, 2002).

Trade is an important dimension in the economics of livestock. Local consumption dominates livestock product demand, and international trade is relatively small. However, international trade has increased in recent years as a result of trade liberalisation and lack of competitiveness and low technological change in some regions (Table 1; FAO (Food and Agricultural Organization), 2009). Dairy and eggs dominate trade, but meat exports are important for a handful of countries (i.e. Brazil, Thailand; FAO, 2009). Most trade of livestock products occurs within a country, with movements of animal products, inputs and services being very dynamic because of increased internal connectivity, transport networks, improved value chains and the increasing need to supply the growing urban populations.

Livestock and livelihoods in developing countries

Nearly 1 billion people living on $<$2 dollars a day in South Asia and SSA keep livestock (Table 2). More than 80% of poor Africans keep livestock, and between 40% and 66% of poor people in India and Bangladesh keep livestock (FAO, 2009).

Livestock play multiple roles in supporting livelihoods. One of the most important is as a source of household income. According to nationally representative data from across the developing world, 68% of households earn

https://doi.org/10.1017/S1751731112001954 Published online by Cambridge University Press

Table 2 *Global trade in livestock products*

	World exports		Share of total production (%)	
Product	1980	2006	1980	2006
Meat	9.6	32.1	7.0	11.7
Pig	2.6	10.4	4.9	9.8
Poultry	1.5	11.1	5.9	13.0
Bovine	4.3	9.2	9.1	14.2
Ovine	0.8	1.1	10.6	7.7
Dairy	42.8	90.2	8.7	12.7
Eggs	0.8	1.5	3.1	2.2

FAO = Food and Agricultural Organization.
Source: FAO (2009).

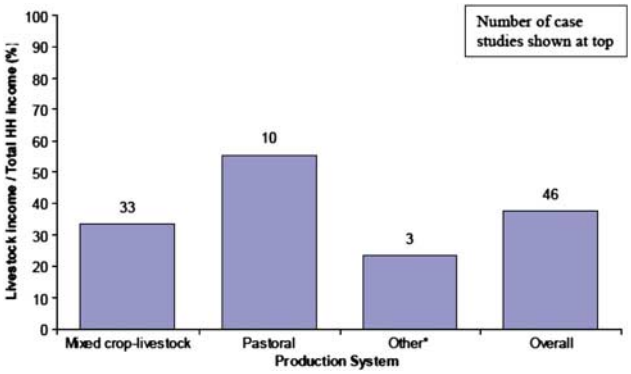


Figure 1 Average income derived from livestock in different production systems. Data from 92 case studies from the developing world. *Source:* Staal *et al.* (2009).

income from livestock (Davis *et al.*, 2007). In their study, consisting mostly of mixed crop-livestock systems in 15 countries, livestock's share of rural household income ranged from 1.6% to 33.8% depending on the livestock-keeping objectives (traction, assets or production), the level of cropping, off-farm income and monetary transfers. The average share of livestock income was lower than that of crops, 12% *v.* 30%; however, it grew much faster than that of crops. Although the share of income from cropping remained stable or even declined, the share of income from livestock grew by 75% in Ghana between 1992 and 1998, by 110% in Vietnam between 1992 and 1998 and by 290% in Panama between 1997 and 2003 (Davis *et al.*, 2007). Staal *et al.* (2009) analysed 92 case studies from the developing world (Figure 1) and found that livestock contributed, on average, 33% of the income in mixed crop-livestock systems, with higher incomes being associated with dairy and poultry production. They also reported average livestock incomes from pastoral production of 55% of total income. In a set of comparative studies with Maasai pastoralists, Burnsilver (2009), Nkedianye *et al.* (2009) and Thompson *et al.* (2009) found livestock incomes ranging from 37% to 85% of total income. These depended on the level of diversification and market access of the studied groups. Bernues and Herrero (2008) found a similar range of incomes (37% to 88%) from livestock in systems with different degrees of crop-livestock integration and diversification in low-land Bolivia (the more diverse and integrated with crops, the lower the share of the total income; the more specialised towards dairy, the higher the share).

Although livestock ownership is often seen as a sign of wealth – household typically move up the 'livestock ladder' from poultry to goats or sheep, to cattle/buffalo (Dercon and Krishnan, 1996; Ellis and Freeman, 2004; Kristjanson *et al.*, 2005; Deshingkar *et al.*, 2008) – livestock's share of income was highest in the poorest income quintile, which shows that they are important to the poor as well (Davis *et al.*, 2007).

The growth in demand for milk and meat, mainly driven by urban consumers in developing countries, has been increasing in the last few decades and is projected to double by 2050 (Delgado *et al.*, 1999; Rosegrant *et al.*, 2009). This rising demand for milk, meat, fish and eggs has generated jobs all along the livestock value chain, from input sales through animal production, trading and processing to retail sales.

Trading and processing jobs in the livestock sector are especially high in the informal sectors of countries in Asia and Africa, where most meat, milk, eggs and fish are sold (Grace *et al.*, 2008) and where most of the people selling and buying livestock foods are themselves poor (Omore *et al.*, 2001; Kaitibie *et al.*, 2008). Street food is a large part of the informal sector in most developing countries – the largest in South Africa (Perry and Grace, 2009) – and therefore a major source of income and employment for the poor. Animal source foods are among the most commonly sold street foods (Perry and Grace, 2009), and it is poor women who do most of the work preparing and selling these foods. It is estimated that up to 1.3 billion people globally are employed in different livestock product value chains globally (Herrero *et al.*, 2009).

Livestock are often one of the main assets that rural households possess. Access to, control over and ownership of assets are critical aspects of well-being (Sherraden, 1991; Carter and Barrett, 2006). Assets are stores of wealth that can be sold to finance investments such as school fees or in time of need such as an illness or drought. Assets can act as collateral and facilitate access to credit and financial services, as well as increase social status. In their study of 'voices of the poor', Narayan *et al.* (2000) found that 'the poor rarely speak of income, but focus instead on managing assets – physical, human, social and environmental – as a way to cope with their vulnerability'.

Accumulation of livestock assets is commonly followed by a shift to more non-farm income in comparison with farm-related income (Reardon, 1997; Barrett *et al.*, 2001; Ellis and Freeman, 2004). For example, in a livelihoods analysis of four African countries by Ellis and Freeman (2004), the highest income quartile of the rural poor was found to have the highest livestock holdings, as well as the highest percentage of total income from non-farm sources. These authors conclude that 'livestock is a substitutable asset than can be sold in order to invest in land or small businesses, and vice versa, non-farm income can be used to build up herds'.

Across the developing world, people keep livestock to earn income, increase their crop production (animals provide

https://doi.org/10.1017/S1751731112001954 Published online by Cambridge University Press

manure for fertilising crop fields and traction for ploughing and transporting goods to markets), store wealth and to feed their families. In the absence of banks and insurance policies, livestock serve as 'piggy banks', a way for people to save and store money and manage risk. Despite their multiple benefits, livestock are also associated with negative impacts on health (though food safety or zoonotic disease) and on the environment. Helping household to increase the benefits and minimise the risks associated with livestock can make an important contribution to improving livelihoods and reducing poverty.

Importance of livestock for women

Almost two-thirds of the world's billion poor livestock keepers are rural women (Staal *et al.*, 2009), and in the recent past research has focused on the role of livestock for women, as well as the role of women in livestock production (Bravo-Baumann, 2000; Njuki *et al.*, 2004; Herath, 2007; Deshingkar *et al.*, 2008; Flintan, 2008). The multiple roles that livestock play in livelihoods of the poor make generalising about women's roles in, and economic contributions to, livestock development problematic, and prioritising livestock research and interventions for women's development challenging (Niamir-Fuller, 1994; Rangnekar, 1998; Livestock in Development (LID), 2004; Aklilu *et al.*, 2008). However, there are a few key aspects that are important and for which there is evidence for the role of livestock and the role of women in livestock production including (i) livestock as an asset for women, (ii) roles of women in livestock production, (iii) roles of women in livestock marketing and (vi) role of livestock for food security and nutrition.

Livestock as an asset for women

Research on intra-household dynamics has shown that it is not only the total amount of household assets that determines developmental outcomes, but also who in the household controls the assets. Livestock are an important asset for women because it is often easier for many women in developing countries to acquire livestock assets, whether through inheritance, markets or collective action processes, than it is for them to purchase land or other physical assets or to control other financial assets (Rubin *et al.*, 2010). Livestock assets are, however, generally more equitably distributed between men and women than are other assets like land (Flintan, 2008).

Evidence from many different developing countries and covering many different small-scale livestock and agricultural production systems and livestock species reveals that poor women can and do own livestock. A common perception is that women are more likely to own small stock, such as chickens, sheep and goats, than larger animals, such as cattle, water buffaloes and camels. Although often the case, studies show that the type of species owned by women varies by region and culture and can be dynamic. In India, Heffernan *et al.* (2003) found that, despite a common perception that only men own bullocks, they were of particular interest among landless women, who rented them to farmers. In pastoral areas of Ethiopia, a study documented women purchasing bulls (Rubin *et al.*, 2010), whereas in mixed crop-livestock systems men and women both own cattle, goats and sheep, although men own more (Yisehak, 2008).

Men and women are also likely to differ in the types of breeds they own within a given species, with men more likely to have improved animals than women in dairy areas of Kenya (East Africa Dairy Development (EADD), 2008). Although a higher percentage of female-headed households than male-headed households own local cattle, the reverse was observed for (higher-yielding, genetically improved) exotic cattle, with 63% of male-headed households owning exotic cattle compared with 49% of female-headed households. These results are consistent with those from Rwanda, where 45% of male-headed households owned exotic cattle compared with 32% of female-headed households (EADD, 2008).

Men and women may also differ in the types of rights they have to livestock. For example, in many cases women control cattle milk when it is used for home consumption; however, they cannot sell it and keep the income (Valdivia, 2001). Guèye (2000), in a review of backyard poultry in Africa, states that women generally own and care for poultry; however, they can seldom take sole decision over the use of the birds or eggs (consumption, selling, exchange, etc.). McPeak and Doss (2006) found that, among mobile pastoralists in northern Kenya, women had the right to sell milk; however, men were responsible for the overall herd and had the right to decide where the household would camp. Yet in other societies, for example, among the Nandi (Oboler, 1996), the women may have a say in sales decisions even though they do not 'own' the animals.

Women's roles in livestock production and their access to technologies and inputs

Men and women often manage different types of animals and are responsible for different aspects of animal care. Women and men also typically have different objectives for keeping animals, different authorities and responsibilities regarding animal management, and different abilities to access and use new information and improved technologies. Although there is great variability across systems and socio-economic contexts, women generally play a major role in managing and caring for animals, even when they are not the owners. Flintan (2008) documents participation of women in every aspect of livestock management in different pastoral systems around the world. In intensive Asian livestock systems, more than three-quarters of livestock-related tasks are the responsibility of women (Niamir-Fuller, 1994). In Nigeria, Ayoade *et al.* (2009) report that women feed and manage vulnerable animals (calves, small ruminants and sick, injured and pregnant animals), clean barns, milk cows and make butter and cheese, but are not involved in livestock marketing or managing livestock diseases. However, in Ethiopia, women clean cowsheds, milk cows, look after calves and sick animals, cut the grass and supervise the feeding and grazing of cows, make dung cakes, butter and

https://doi.org/10.1017/S1751731112001954 Published online by Cambridge University Press

cheese, and sell these products once or twice a week. Men, on the other hand, feed the oxen and take the animals for veterinary treatment when the need arises (Yisehak, 2008). Njuki (2001), in a study in central and eastern Kenya, found that women were more engaged in feeding of cattle, whereas men were more involved in watering and disease management. The total time allocation to dairy-related work did not, however, differ significantly between men and women.

Despite the role of women in livestock production, women have lower access to technologies and inputs than men. There are gender disparities in access to extension services, information and training throughout the developing world. A study in the Taurus Mountain villages in Turkey found that most women farmers had little access to information about animal production through public extension services (Budaka *et al*., 2005). Similar findings have been documented in Cameroon, Ghana and Madagascar (Salman *et al*., 1999), in Pakistan (Teufel *et al*., 1998) and in The Gambia (Jaitner *et al*., 2001). The reasons given for this lack of access to extension services by women included women's long workdays, which precluded them from engaging with, or searching out, extension officers, a neglect of women's needs and circumstances when targeting extension work, and widespread female illiteracy.

Technology change also affects men and women differently. Many interventions aimed at intensifying livestock production, such as shifting from grazing to stall-feeding or by keeping potentially higher-yielding, but also more demanding, breeds, increase the workload of women and girls, because the intensification lies in their traditional tasks (Okali and Sumberg, 1985; Mullins *et al*., 1996; Wangui, 2008).

Women's participation in livestock markets

Women play important roles at different stages of livestock value chains, as producers, traders and as consumers. Among the Fulani societies in Ferlo, Senegal, milk production is entirely controlled by women, who have sole control also over the sale of any surplus and ini-dairies are often run by women. A study of evolving pastoral markets in northeastern Somalia (Nori, 2008) documents the crucial role that women play in the commoditisation of pastoral camel milk. In northern Kenya, Coppock *et al*. (2006) note that self-initiated groups convened and managed by women have managed to access livestock markets. Women also serve an important role as processors and retailers. In most African countries, most street-food processors and vendors are women (Canet and N'Diaye, 1996). In addition to being one of the few income-generating activities open to poor women, the street-food sector is of great importance to the economy. This, however, poses a risk for women from zoonotic diseases. For example, in Zimbabwe, cooked meats posed the greatest health risk of all food sold on the street (Grace, 2007) and a study in Harare found that 81% of the food vendors were women (Graffham *et al*., 2005).

Evidence from East Africa shows that where and which milk is sold can determine whether or not women manage the milk income. Women have greater control over the evening milk than the morning milk and manage more income from milk sold at local markets and to neighbours and mobile traders than they do from milk sold to collection centres or chilling plants (EADD, 2008). Where a strong market value for milk and/or dairy products is established, women's roles in dairying can be enhanced and their labour refocused on marketing rather than production. Commercialisation can, however, lead to an erosion of women's control of livestock and livestock products.

Livestock, women and food security

Livestock contributes to food security in several ways, namely, (i) contributing to direct access to animal source foods; (ii) providing cash income from sale of livestock and livestock products, which can in turn be used to purchase food especially during times of food deficit; (iii) livestock ownership can contribute to increasing aggregate cereal supply as a result of improved productivity from use of manure and traction; and (iv) increasing livestock production can lead to lower prices of livestock products and, therefore, increased access to such products by the poor, especially poor urban consumers. Given women's traditional responsibility for household food security, their level of control over decisions about whether to sell or consume the family's animal products, as well as over how to use any income obtained from the sale of animal foods, could greatly determine the nutritional well-being of household members.

The role of livestock in enhancing and endangering human health

Direct and indirect links between livestock and human health

In developing countries, human health is inextricably linked to the livestock, which underpin the livelihoods of almost a billion people (see preceding sections). Livestock have an essential role in contributing to good health through providing animal source food, manure and draft power for plant source food, as well as income to buy food and health care. At the same time, livestock can lead to poor health if animal source foods contribute to poor diet and through providing a reservoir for diseases infectious to people (zoonoses). The relationship between livestock, human nutrition and human health are complex, with multiple synergistic and antagonistic links, some of which are detailed in Figure 2. For example, poor livestock keepers worldwide face daily trade-offs between selling their (relatively expensive) milk, meat and eggs to increase their household income and consuming the same (high-quality) foods to increase their household nutrition. Because animal source foods are so dense in nutrients, including micronutrients that help prevent 'hidden hunger', decisions in these matters have potentially large implications for the nutritional and economic health of households. Livestock contributes to food security and nutrition in various ways.

Livestock and nutrition

In poor countries, livestock and fish make significant contributions to diets. In East Africa, for example, livestock

https://doi.org/10.1017/S1751731112001954 Published online by Cambridge University Press

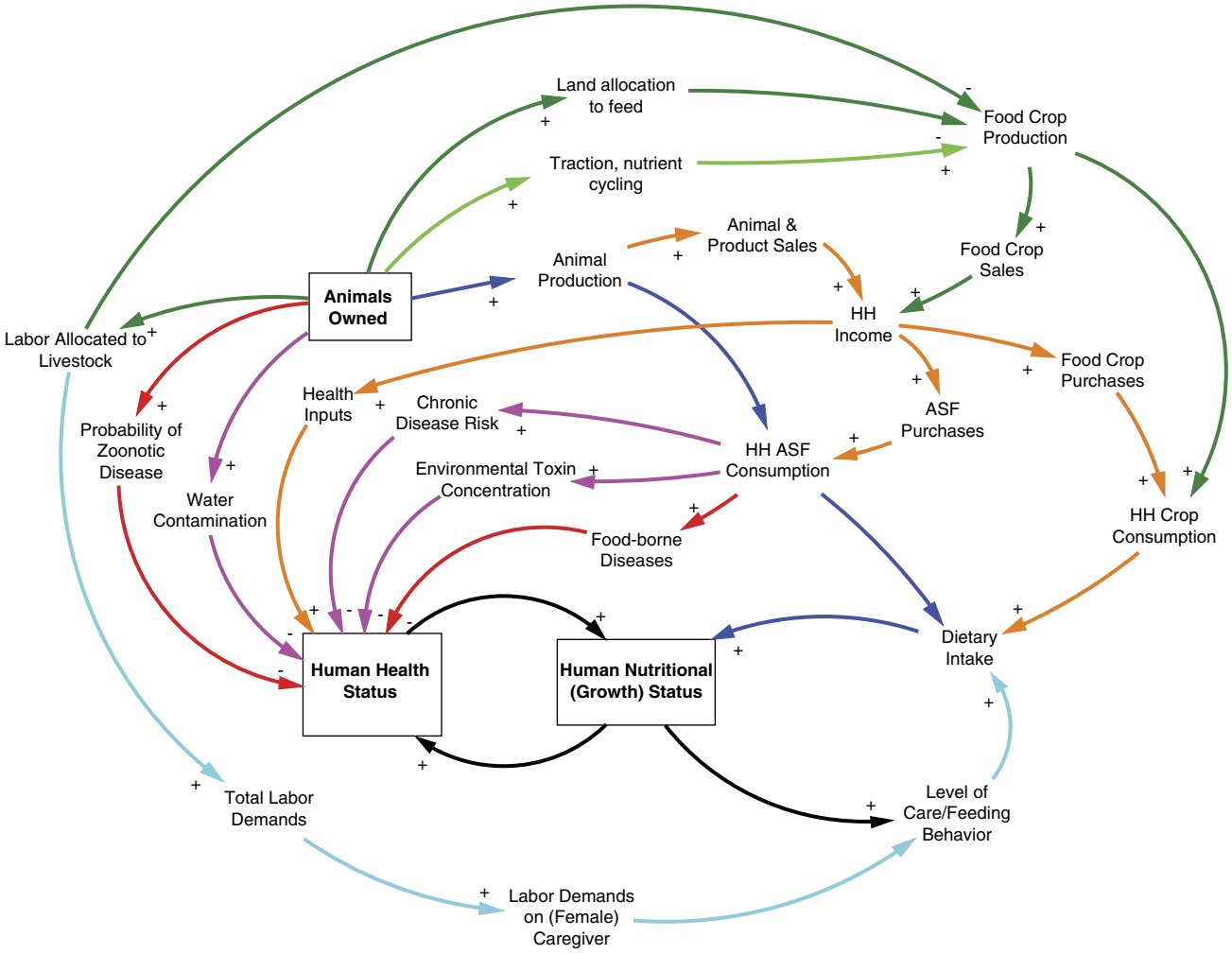


Figure 2 An example of the complex interaction between humans, livestock and diseases. *Source:* Randolph *et al.* (2007).

provide on average 11% of energy and 26% of protein in poor people's diets (FAOSTAT, 2011). Fish, meanwhile, account for at least half the animal protein intake for the 400 million poorest people in Africa and South Asia (FAO, 2009). For some vulnerable groups, such as the world's 180 million pastoralists, the contribution of livestock products to diet is much higher; for example, among Nuer agro-pastoralists in Sudan half of the total energy intake of children aged <5 years comes from milk (Fielding *et al.*, 2000).

Although livestock and fish clearly make important contributions to overall food security, there is an even more important role of animal source foods in achieving nutrition, as opposed to food, security. Animal source foods are dense and palatable sources of energy and high-quality protein, important for vulnerable groups, such as infants, children, pregnant and nursing women and people living with human immunodeficiency virus with high nutritional needs. They also provide a variety of essential micronutrients, some of which, such as vitamin A, vitamin B12, riboflavin, calcium, iron, zinc and various essential fatty acids, are difficult to obtain in adequate amounts from plant-based foods alone (Murphy and Allen, 2003). Animal source foods provide multiple micronutrients simultaneously, which can be important in diets that are lacking in more than one nutrient: for example, vitamin A and riboflavin are both needed for iron mobilisation and haemoglobin synthesis, and supplementation with iron alone may not successfully treat anaemia if these other nutrients are deficient (Allen, 2002). Micronutrients in animal source foods are also often more readily absorbed and bioavailable than those in plant-based foods (Murphy and Allen, 2003).

Consumption of even small amounts of animal source foods has been shown to contribute substantially to ensuring dietary adequacy and preventing undernutrition and nutritional deficiencies (Neumann *et al.*, 2003). Extensive longitudinal studies in Egypt, Kenya and Mexico (Neumann *et al.*, 2003) have shown strong associations between intake of animal source foods and better growth, cognitive function and physical activity of children, better pregnancy outcomes and reduced morbidity from illness. Consumption of adequate amounts of micronutrients, such as those that can be found in animal source foods, is associated with more competent immune systems and better immune responses (Keusch and Farthing, 1986). Low levels of consumption of

https://doi.org/10.1017/S1751731112001954 Published online by Cambridge University Press

animal source foods by the poor are due to limited supply in some regions, such as SSA, as well as income constraints. It has been estimated that to effectively combat undernutrition 20 g of animal protein per person per day is needed, which can be achieved by an annual consumption of 33 kg lean meat, 230 kg milk or 45 kg fish (FAO, 2009).

In rich countries, consumption of animal source food has been linked to a number of high health burden chronic diseases including obesity, cardiovascular disease and cancer (McMichael *et al.*, 2007). Many developing countries are also facing a 'double burden of malnutrition', that is, the persistence of undernutrition along with the rapid rise of overnutrition and associated diseases. In South Africa, for example, over a quarter of rural children are stunted, whereas nearly 60% of women are overweight or obese (Toriola and Goon, 2012). Similar problems are also observed in developing countries with large, expanding middle classes (i.e. India, China, Brazil).

Livestock and infectious disease

In poor countries, infectious disease still accounts for around 40% of the health burden in terms of years lost through sickness and death (World Health Organization (WHO), 2008). Livestock directly contribute to this through the food-borne diseases transmitted through animal source foods, the zoonoses transmissible between livestock and people, and human diseases emerging from livestock. A recent estimate suggests that 12% of the infectious disease burden in least developed countries is due to zoonoses, and the majority of this is transmitted to people from livestock hosts through consumption of animal source foods, vectors or direct contact (Grace *et al.*, 2012). More indirectly, keeping of livestock affects agro-ecosystems in ways that influence their ability to provide health-provisioning services. This may be positive or negative. In some circumstances, livestock act as a buffer, for example, between trypanosomosis-carrying tsetse or malaria-carrying mosquitoes and people; in this case, livestock act as alternative hosts, effectively protecting people. In other cases, livestock are an amplifying host, for example pigs harbouring and multiplying Japanese encephalitis and thus increasing the risk it poses to people.

Food that nourishes can also contain biological and chemical hazards that sicken and kill. Food-borne disease is the world's most common illness and is most commonly manifested as gastrointestinal disease. Diarrhoea is one of the top three infectious diseases in most developing countries, killing an estimated 1.4 million children a year (Black *et al.*, 2010). The great majority of cases ($>$90%) are caused by bacteria and viruses not chemicals, although the latter are often of more concern to the public (De Boer *et al.*, 2005). In countries where good data exist, zoonotic pathogens are among the most important causes of food-borne disease (Thorns, 2000; Schlundt *et al.*, 2004). Animal source food is the most risky of food commodities (Lynch *et al.*, 2006), not surprising as meat and milk provide excellent mediums for microbial growth. Less is known about the aetiology of food-borne disease in developing countries; on the one hand, less animal source food is consumed, decreasing risk, but on the other hand surveys show far higher level of hazards in the animal source foods marketed. Food-borne diseases has been recently estimated to cost the United States $152 billion a year and Nigeria $3 billion (Scharff, 2010; Okike *et al.*, 2010).

Most (61% of all) human diseases are zoonotic (i.e. transmissible between animals and humans), including many of the most important causes of sickness and death. Endemic zoonoses that prevail in poor countries are among the most neglected diseases. To give just one example, echinococcosis is responsible for 1 million lost DALYs in addition to human-associated economic losses (including medical costs, wage losses) estimated at US$1.9 billion and livestock losses of US$2.1 billion (Maudlin *et al.*, 2009). Sleeping sickness, rabies, leishmaniasis, cysticercosis, brucellosis and leptospirosis are other zoonoses of similar importance, which also have livestock reservoirs.

Zoonoses (diseases transmissible between animals and man) and diseases recently emerged from animals (mostly human immunodeficiency virus (HIV)-acquired immunodeficiency syndrome) make up 25% of the infectious disease burden in the least developed countries (Gilbert *et al.*, 2010). Many other important human diseases, such as HIV, measles and smallpox, were originally diseases of animals but jumped species when people changed ways of farming and keeping animals. In the first epidemiological transition, unprecedented levels of globalisation, urbanisation, animal production and environmental degradation are driving new epidemics of infectious diseases, both familiar and novel. Currently, one new disease is emerging every four months, and 75% of these originate in animals (Jones *et al.*, 2008).

Other important problems (whose indisputably important contribution to overall health needs to be better assessed) include: fungal toxins (mycotoxins) in animal source foods; use of water contaminated with animal waste for agriculture; misuse of agricultural chemicals and antibiotics in livestock resulting in direct toxicity and contributing to resistance to antibiotics for treating human infection; and the health impacts of alteration of ecosystems as the result of livestock-keeping. These impacts may be local or global. An example of the former is the small dams constructed for livestock watering in semi-arid areas with water-associated diseases such as schistosomiasis, whereas an example of the latter is the changing distribution of diseases as a result of the global warming to which livestock emissions contribute.

Identifying at-risk populations

The greatest burden of livestock-associated disease falls on poor producers, poor consumers and others involved in food value chain. The first population of critical concern are the vulnerable and marginalised that bear much of the burden of malnutrition and neglected tropical zoonoses. Although many of the poorest countries in SSA fit in this category, it also applies to less-favoured groups in better-off developing countries (e.g. tribal people in India). They are frequently politically and socially disempowered with little access to medical services. Undernutrition is widespread among this

https://doi.org/10.1017/S1751731112001954 Published online by Cambridge University Press

population and is implicated in the deaths of a third of all children under five (Black *et al.*, 2008); an estimated 195 million children are too short for their age (stunted) and 129 million children are underweight. High-burden zoonotic diseases (sleeping sickness, cysticercosis, zoonotic tuberculosis) are at home in many of these populations. Diseases controlled in other places (e.g. rabies, brucellosis, hydatid disease) persist. There is often competition over declining resources, which may lead to intensified interaction between people, livestock and wildlife (e.g. around water sources in pastoral areas) and increased transmission of disease: in the world, 180 million pastoralists are at high risk.

The other population of concern are people living in rapidly intensifying and/or changing agriculture and food systems. These include the urbanising and rapidly developing systems of Latin America and SE Asia, but also areas of South Asia (e.g. the Karachi buffalo colony with more than 300 000 animals) and Africa (e.g. the bush meat value chain associated with opening up of the rainforests by road building). These systems are characterised by growing populations and standards of living, high demand for livestock products, relatively good market access but low levels of regulation. Retail transitions are important in some areas (e.g. Latin America, South Africa), in others preference for wet markets and traditional eating habits (e.g. consumption of wildlife) persist strongly (e.g. South Asia). This drives highly dynamic peri-urban production systems, as well as lengthening food supply chains. Malnutrition is less of a problem but problem, nonetheless; however, food- and water-borne diseases and environmental hazards are more important. Because these systems are highly dynamic, have high densities of genetically homogeneous livestock and high contact rates between people, livestock and wildlife, these systems are considered crucibles for the emergence of new diseases.

Livestock and the environment

The impacts of livestock on the environment have received considerable attention as the publication of the Livestock's Long Shadow study (Steinfeld *et al.*, 2006). This study helped draw attention to the magnitude and scale of livestock's impact on land use, greenhouse gas (GHG) emissions and pollution among others, and it created a thrust for the sector's stakeholders to develop research agendas geared towards generating better data for the environmental assessment of global livestock systems, and to develop solutions for mitigating environmental livestock problems, and policy agendas more conducive to a greening of the sector by promoting regulation, increases in efficiency and others. Numerous publications exist on this subject (Steinfeld *et al.*, 2006; FAO, 2009 and 2010; Herrero *et al.*, 2009; PBL, 2010; Pelletier and Tyedmers, 2010; Thornton, 2010; Thornton and Herrero, 2010; Bouwman *et al.*, 2011). Readers are referred to these for a more in-depth account of livestock's role in environmental regulation. What follows is a summary of the main livestock–environment interactions.

Livestock as users of land and water

Livestock systems are one of the main users of land. Steinfeld *et al.* (2006) estimated that livestock utilise 3.4 billion ha for grazing and 0.5 million ha of cropland for the production of feeds (33% of arable land), globally. Of the grazing areas, 2.3 million ha (67%) are in the developing world. Expansion of pastureland at the expense of natural habitats in the developing world has been in the order of 330 million ha in the last 40 years (FAO, 2009). This phenomenon has occurred predominantly in Latin America, and is projected to increase by a further 100 to 120 million ha by 2050 under current practices (Smith *et al.*, 2010). Cropland area in the same period expanded by 190 million ha and is expected to increase at a faster rate than rangelands to supply additional feed for monogastric production and more intensive ruminant production (Smith *et al.*, 2010), which will require an additional 450 million tonnes of grain to meet demand for animal products by 2050 (Rosegrant *et al.*, 2009).

Land use is closely linked to water cycles. Not surprisingly, 90% of the water used by livestock is through the impacts of grazing and the production of feed. The fraction of drinking water accounts for $<$10% of the total (Peden *et al.*, 2007). Recent research (Lannerstad *et al.*, 2012) suggests that, globally, the production of feed for the livestock sector appropriates 5315 km^3/year of evapotranspiration (ET; 9% of global evapotranspiration). The authors found that feed production from croplands uses 37% of the water for crop production, and the biomass consumed by livestock from grazing lands appropriates 32% of the total ET from grazing lands. The rest of the ET supports a range of key ecosystems services, which seems to be a key role that rangelands are playing globally. Enhancing this role through improved rangeland management could be of essential importance for enhancing global green water cycles (Rockström *et al.*, 2007). At the global level, the aggregated virtual water content (VWC) of livestock products has an average value of 5.63 m^3/1000 kcal. In contrast, VWC of vegetal products from croplands is estimated to be only 0.66 m^3/1000 kcal (Lannerstad *et al.*, 2012). Producing livestock products used on average nine times the amount of water that it took to produce calories from crop-based products. In their study, total VWC for individual products ranged from 1.50 m^3/1000 kcal for pig meat up to 35.24 m^3/1000 kcal for meat from dairy sheep & goats, with the range reflecting vast differences in intensity of production (feeds, agro-ecology, species, type of production systems and others). Green water represented 97% of the water used by livestock.

Livestock as emitters of GHGs

Livestock are an important contributor to global GHG emissions. Current estimates range from 8.5% to 18% of global anthropogenic GHG (O'Mara, 2011), with the range reflecting methodological differences (inventories *v.* life cycle assessment), attribution of emissions to land use (Herrero *et al.*, 2011; O'Mara, 2011) and uncertainty in parameter values (FAO, 2010). According to Steinfeld *et al.* (2006), methane from enteric fermentation, nitrous oxide from manure management and carbon dioxide from land use

https://doi.org/10.1017/S1751731112001954 Published online by Cambridge University Press

Table 3 *Contribution of greenhouse gas emissions from livestock*

	Estimated emissions[1]		Estimated contribution by species[2]			
Step in animal food chain	(Gigatonnes)	(% Of total livestock sector emissions)	Cattle and buffaloes	Pigs	Poultry	Small ruminants
Land use and land-use change	2.50	36	■ ■ ■	■	■	ns
Feed production[3]	0.40	7	■	■ ■	■ ■	ns
Animal production[4]	1.90	25	■ ■ ■ ■	■	■	■ ■
Manure management	2.20	31	■ ■	■ ■ ■	ns	ns
Processing and transport	0.03	1	■	■	■ ■	ns

FAO = Food and Agricultural Organization; ns = not significant.
[1]Estimated quantity of emissions expressed as CO_2 equivalent.
[2]■ = lowest to ■ ■ ■ ■ = highest.
[3]Excludes changes in soil and plant carbon stocks.
[4]Includes enteric methane, machinery and buildings.
As presented in FAO (2009). Adapted from Steinfeld *et al.*, 2006.

contribute 25%, 31% and 36% to the emissions of the livestock sector, respectively (Table 3). Livestock in the developing world contributes 50% to 65% of the total emissions from livestock in the world. Emission intensities also vary and these are mainly related to the species (monogastrics more efficient than ruminants), products (milk, white meats and eggs more GHG efficient than red meat) and the productivity of the animals (the higher the productivity the lower the emissions per unit of product, FAO, 2010). These aspects are largely dependent on feed type, quantity, quality and provenance and the manure management system implemented. There is large heterogeneity in emission intensities in the developing world. However, in general terms, the following order usually prevails: industrial systems are less GHG intensive, and these are followed by mixed crop-livestock systems and by grazing systems. Emission intensities of systems in temperate tropical highlands are usually lower than in drier areas. Nevertheless, livestock systems in general terms generate significantly more emissions per kilocalorie when compared with crops. However, the mitigation potential in the livestock sector is very large (1.74 Gt CO_2-eq per year, Smith *et al.*, 2007), with land-use management practices (carbon sequestration in rangelands, land sparing impacts of reduced animal numbers/production intensification) representing over 80% of this potential (Smith *et al.*, 2007). Most of the mitigation potential (70%) lies in the developing world (Smith *et al.*, 2007, see Henderson *et al.*, 2011 for a discussion on the topic).

Livestock as nutrient recyclers

Livestock play an important role in accelerating ecosystems' nutrient cycles. Bouwman *et al.* (2011) in a historical analysis of nutrient cycles show that it was the introduction of synthetic fertilisers that allowed the explosive increase in livestock production. Agriculture based only on the recycling of organic resources and supported on N fixing legumes could not have supported the current global production and consumption of animal protein. The widespread use of fertilisers has helped to intensify not only agricultural production, but also the rate of nutrient cycling, with accumulation of nutrients in certain environments creating threats for human health and nature (Sutton *et al.*, 2011).

Livestock has a very different role in the nutrient cycles in the developed-industrialised world and in the poor developing world. Although in large parts of Africa and East and SE Asia, agricultural production and nutrient cycles are closely related to local-scale recycling of organic residues (including animal manures), in Western Europe and North America crops are fully sustained on synthetic fertilisers and livestock production on the import of feeds produced sometimes thousands of miles away. In much of the industrialised world, the link between livestock and the land has been broken, with animals separated spatially from the places where their feed is produced (Naylor *et al.*, 2005).

Meeting the increasing demand of animal protein in the developing world requires managing nutrient cycles more efficiently. Expansion of agricultural land has lead to marginal increases of livestock production in parts of the developing world because the production systems remain low input and often the natural resources are poor or are degraded to a state that cannot support large outputs per unit of land. This, together with low investment in agriculture, makes places such as SSA to have experienced very little technological change in ruminant production in the last 40 years (FAOSTAT, 2011). In places with large human population density where most suitable land is already taken, increasing livestock production will compete with the production of food crops and will bring associated environmental costs. More intensive livestock production (e.g. dairy, fattening systems, monogastrics) may achieve higher technical efficiency. However, the concentration of animal wastes around urban centres raises serious concerns for water pollution and for GHG emissions, which may increase significantly in places of large livestock density (Gerber *et al.*, 2005).

Costs and benefits of cycling nutrients through livestock

Livestock wastes – considered a serious problem in the developed world – are a critical agricultural resource in large parts of Africa, where soils are inherently poor (Petersen *et al.*, 2007; Rufino *et al.*, 2007). Liu *et al.* (2010) estimated

https://doi.org/10.1017/S1751731112001954 Published online by Cambridge University Press

that manure contributes between 12% and 24% of the nitrogen input in nitrogen cycles in cropland in the developing world. Recycling of animal manures is practiced in most mixed crop-livestock systems, although efficiencies are rarely close to those of the developed world (Rufino *et al*., 2006). Synthetic fertilisers are unaffordable for most small-scale farmers, who depend on the (poor) fertility of their soils to produce food crops, or on livestock to concentrate nutrients from the relatively large grazing lands.

Intensifying livestock production requires using additional nutrients to produce feeds. Nitrogen fixing legumes play a very important role in the developed world dairy industry, with soya beans produced in South America and the United States being fed as protein supplements in Europe. Research in the developing world has tried to implement this model of using legumes produced on farm on a local scale in, for example, African mixed systems with some success (Sumberg, 2002), but not enough to supply the future demand for feeds.

Producing grain legumes or fodder legumes requires in certain soils the addition of P fertilisers, and there are GHG emissions associated with their production. Dual-purpose legumes such as cowpea may be used as food and feeds, and its production justified to contribute to income and nutrition (Singh *et al*., 2003). However, the production of feeds, including legumes, results in emissions to the environment (e.g. Chikowo *et al*., 2004; Baggs *et al*., 2006) that must be accounted for by the livestock sector. Designing technologies for intensification requires in the developing world addressing the trade-off poverty reduction and environmental impact.

Nutrients, livestock manure, soils and poverty

Poverty has often been associated with poor soil fertility (Sanchez, 2002), and problems of fertility are often not solved by just adding fertilisers, requiring sensible use of organic resources (Chivenge *et al*., 2011). In many farming systems, the production of food crops is directly or indirectly related to livestock production. Direct relationship arises from the need for animal manures to increase effectiveness of fertilisers applied to cropland (Vanlauwe and Giller, 2006). Indirect relationship arises from the competition for biomass to restore degraded agricultural soils, or to feed growing livestock populations (Rufino *et al*., 2011).

Although animal manure can be a very effective soil amendment, in systems where the land support livestock production its availability at the farm level is often very limited. This implies that designing technologies for soil fertility restoration only around the use of animal manure is unrealistic. Again, nutrients, including carbon, must be included in the trade-offs analysis. Increasing food security will require a sensible use of the natural resources, and in many places a clear strategy to store C and reduce emissions from livestock production.

Manure management and emissions

The size of the GHG emissions from manure depends mainly on collection and storage management. Across continents, the fate of manure excreted in housing facilities differ (Table 4). In Europe, strong environmental regulations led to recycling of large proportion of the excreted manure, partly in grassland and cropland and partly for biogas production (Oenema *et al*., 2007). In Africa, in the extensive rangeland-based systems manure is not managed, whereas in the mixed systems most manure is not returned to grazing land. In intensive livestock systems, composted manure may be applied to fodder crops, but the large majority is applied to food and high-value crops (e.g. coffee, tea, tobacco).

In highly populated areas of Asia, most manure is destined to different and competing uses such as organic fertiliser, feed for fish ponds, biogas production and biofuel (i.e. burnt for cooking). In the mixed intensive systems of North America, manure is not yet fully recycled. There are places where manure is indirectly discharged into water bodies (Centner, 2011), or accumulated in constructed wetlands (Knight *et al*., 2000). Use of manure for biogas production is increasingly gaining attention, but it is not yet globally widespread (Cuellar and Webber, 2008).

In Latin America, recycling of manure is not widely practised (León-Velarde and Quiroz, 2004). This can be explained by: (i) access to cheap fertiliser is more widespread than in Africa and Asia, (ii) soils are inherently more fertile than in the other continents and (iii) expansion of agricultural land is still used to counteract poor soil fertility. Exceptions are urban and peri-urban areas (e.g. southern Brazil) where recycling of wastes into agricultural land, treatment of slurries and biogas production have been the result of the environmental concerns and the disconnection between livestock and the land than from the demand of the organic resources as soil amendments (Kunz *et al*., 2009).

Table 4 *Ranges of NCE in mixed systems of the developed and developing world*

	NCE through livestock	NCE for manure collection	NCE for manure storage	NCE for cropping	NCE for mixed systems
Developed world					
Europe[1]	0.55 to 0.95	0.50 to 0.90		0.40 to 0.60	0.11 to 0.51
USA[2]	0.65 to 0.85	0.10 to 1.00	0.50 to 0.80	0.20 to 0.50	0.01 to 0.34
Developing world					
Africa[2]	0.46 to 1.00	0.05 to 0.95	0.37 to 0.87	0.10 to 0.47	0.01 to 0.39

NCE = N cycling efficiencies.
The numbers show the fraction of N recovered and cycled in the next step.
Sources: [1]Oenema (2006); [2]Gourley *et al.* (2011), Powell *et al.* (2010); [3]Rufino *et al.* (2006).

https://doi.org/10.1017/S1751731112001954 Published online by Cambridge University Press

Table 5 *Linking ecosystem services and disservices from livestock with opportunities from payment for environmental schemes*

	Ecosystem services		
Production systems	Climate regulation	Biodiversity conservation	Water conservation and hydrological services
Pastoral or grazing systems	Access to PES can be driven by restoration of degraded lands and implementation of sustainable grazing land management, which presents also the great potential for stocking carbon. On optimally grazed lands, carbon accrual is greater than in ungrazed or overgrazed (Conant and Paustian, 2002). Also greater livestock density reduces biomass removal by fires	Positive biodiversity effects are achievable by: reducing stocking density; protecting migration corridors; maintaining the seasonal dispersal areas; refraining from poaching wildlife and reporting poaching by others; protecting natural vegetation on land and avoiding fencing or sub-dividing land; restricted grazing	PES schemes for water for livestock are in general designed to target the reduction of land-use change caused, for example, by extensive cattle grazing in forest (forest degradation diminishes water quality and quantity and increases risks associated with landslides and flooding)
Mixed crop-livestock systems	Access to PES schemes can be driven by: adoption of improved feed supplement that can lead to emissions reduction; adoption of improved pastures with high density trees and fodder banks that reduce land degradation; switching to organic fertilizer to increase capacity of stocking carbon; integrated livestock and manure management	Positive biodiversity impacts achievable by: reducing stocking densities; application of sustainable management practices to reduce environmental degradation and protecting natural vegetation on land; trees planting and sustainable soil management (zero grazing and fodder and manure production)	PES schemes are in general designed to target the reduction of land-use change caused, for example, by extensive cattle ranching in the upper part of a catchment (cloud forest may be threatened and a downstream dam may run the risk of siltation reducing his useful lifespan). Participants can be paid to not cut trees or clear forest on enrolled land. In more intensive livestock systems, participants may be paid to limit livestock contamination (mainly determined by nutrients loading)

PES = payment for environmental services.
Adapted from Silvestri *et al.* (2012).

Livestock and payment for environmental services (PES)

The previous section explored the impacts of livestock on the environment. The negative environmental impact of the livestock sector could increase with the forecasted increase of demands for animal proteins in the developing world (FAO, 2007; Tarawali *et al.*, 2011). As a result, there is increasing interest in incentive systems to promote more environmentally responsible livestock rearing practices. One of these options is the PES as an alternative instrument to enhance the delivery of environmental services, mitigate the disservices and promote income-diversification options for poor livestock keepers.

To date, most PES projects have focused on one or more of the following services: climate regulation, water conservation and hydrological services, maintenance of landscape beauty, and conservation and management of biodiversity or a 'bundle' of the previous services (Landell-Mills and Porras, 2002; Wunder, 2005). Despite the fact that livestock is widely distributed in virtually all agro-ecosystems of the developing world, there are few examples of PES targeting livestock keepers.

To what extent do PESs target livestock inclusive agricultural production systems in developing countries? What are potential and limitations for their implementation? Table 5 shows the opportunities for pastoral/grazing systems and for mixed crop-livestock systems to access to PES schemes: climate regulation, biodiversity conservation and water conservation and hydrological services. Opportunities in PES schemes for livestock inclusive agricultural systems are mainly driven by carbon market.

The implementation of PES schemes for livestock production systems can be favoured by the growing potential of the carbon market, the emerging efforts for the inclusion of PES in national policy frameworks, the increasing catalysing policy support of PES networks, research institutes together with the growing private sector participation and farmers' involvement. In particular, PES schemes can be an incentive for the application of agricultural practices that can lead to GHG mitigation and an incentive for the implementation of sustainable land management practices that can reduce the pressure on the environment and help conserving biodiversity and protecting wildlife and ensure an equitable use and share of natural resources. Especially in the context of the developing world where future trends foresee an intensification of livestock sector, PES schemes may contribute in facilitating agricultural transitions (Silvestri *et al.*, 2012).

On the one hand, PES can benefit the poor directly, through the provision of increased cash flow and as a means

https://doi.org/10.1017/S1751731112001954 Published online by Cambridge University Press

of promoting household income diversification, and indirectly through social and cultural benefits (Grieg-Gran *et al.*, 2005; Pagiola *et al.*, 2005 and 2008; Turpie *et al.*, 2008). On the other hand, barriers such as (1) high transaction and investment costs, (2) weak cooperative institutions among poor providers, (3) low awareness, education and technical capacity and (4) not well-defined property rights can all limit the participation and PES benefits among poor providers.

For most PES programmes that involve crop and livestock producers, the income generated from the environmental benefit will only be a small share of household income, compared with the profits from farm production (FAO, 2007). In Africa, where close to half of the pastoralists earn less than US$1/day it is estimated that even modest improvements in natural resource management in the drylands may yield gains of 0.5 t C/ha per year,[1] which translates into US$50/year that can bring about a 14% increase in income for the pastoralist (Reid *et al.*, 2004). Benefits from participation in carbon PES schemes might also be associated with increases in production creating a double benefit (Steinfeld *et al.*, 2006). However, carbon markets will not automatically generate benefits for farmers and pastoralists without a proper institutional arrangement to support the participation of poor households.

Concluding remarks

The analyses presented here have demonstrated the complex balancing act of weighing the roles that livestock play in the developing world. On the one hand, we acknowledge that livestock is an important contributor to the economies of developing nations, to the incomes and livelihoods of millions of poor and vulnerable producers and consumers, and it is an important source of nourishment. On the other side of the equation, the sector has been criticised for its inefficiencies and environmental performance: large user of land and water, notorious GHG emitter, a reservoir of disease, source of nutrients at times, polluter at others and the list could continue.

Against this dichotomy, there is a sector that could improve its environmental performance significantly by sustainably intensifying, applying regulations and incentives to manage environmental loads and disease risks, diversifying income sources through payments for environmental services (as a reward for being the global stewards of large patches of land), and in cases by becoming more market-orientated to generate the pull-factors needed for increasing productivity. On top of this, value chain development, food safety standards and others could be catalysts to hence the role that livestock play in food systems globally (McDermott *et al.*, 2010).

There are several factors that could play a significant role in shaping the roles of livestock in the developing world in the coming decades. Some of them are:

The debate on whether or not to eat meat: This debate translates into poor food choices *v.* the food choices of the poor. The debate on human diets is dominated by the concerns of the developed world on the negative health impacts of livestock product overconsumption. This also applies for large parts of the middle classes of the developing world, who overconsume animal products and are obese, diabetic and suffer from heart disease. Evidence shows that these sectors of society should reduce the consumption of animal products as a health measure. However, the debate needs to increase in sophistication so that the poor and undernourished are not the victims of generalisations that may translate into policies or reduced support for the livestock sector in parts of the world where the multiple benefits of livestock outweigh the problems it causes. This does not mean that we should take as given the projected trajectories of animal consumption proposed by the so-called 'livestock revolution'. They are not inevitable. Part of our responsibility is to challenge these future trajectories, and ensure that we identify levels of consumption and nutritional diversity for different parts of the world that will achieve the best compromise between a healthy diet that includes livestock products (or not), economic growth, livelihoods and livestock's impacts on the environment. No mean feat, but certainly a crucial area of research.

Efficient and market-orientated smallholders v. *large-scale consolidated farms as engines for feeding the world*: Large parts of the food systems of the developing world have as a starting point the smallholder mixed crop-livestock farmer or the vulnerable pastoralist. Some of these systems produce a significant amount of food, mostly for local consumption, have significant, exploitable, yield gaps in crops and livestock, and in many cases they have low opportunity costs of labour. If livestock is to be used as an engine for poverty reduction, it is essential that these producers become market-orientated. Hence, investment in developing efficient value chains (including market development, service provision, adequate institutional support, etc.) should be high in the development agenda, to create incentives for smallholders to integrate in the market economy, formal or informal. Advocates of large-scale farming argue in favour of the higher efficiencies of resource use often found in these systems and how simple it is to disseminate technology and effect technological change. True, when the market economy is working. If common sense prevailed, the answer to this question should lead to the coexistence of a thriving environmentally responsible, diversified, commercial smallholder sector that helps feed the world and lifts people out of poverty, together with a large-scale efficient livestock sector that efficiently produces food while generating enough employment for rural people. The balance between these ways of farming is likely to be different in different regions of the world, but understanding where the balance should lie for achieving socially and environmentally goals is still the question that merits significant research. This is still an open question because we lack comprehensive information on the impacts of different farming avenues and their future evolutionary pathways on water cycles, biodiversity, social aspects (nutrition, incomes, employment), coping with

[1] Considering carbon valued at US$10/tonne.

https://doi.org/10.1017/S1751731112001954 Published online by Cambridge University Press

production risks (i.e. climate variability and change, commodity prices) and others.

Competitiveness of the smallholder sector: The degree of competitiveness of smallholders against imports from countries that can produce vast amounts of animal products, at lower production costs, will be a crucial factor to determine the success of many men and women livestock farmers in the developing world, especially as the volume of traded livestock products increases because of trade liberalisation. Formal and informal markets will need to ensure the supply of cheaper, locally produced, safe livestock products to adequately compete. This implies a significant reduction in transaction costs for the provision of inputs, increased resource use efficiencies, and very responsive, innovative and supporting institutions for the livestock sector in developing countries (FAO, 2009).

The success of paying for environmental services: PES schemes as an income diversification strategy for mitigating climate change or for protecting important regional or global goods that regulate essential biogeochemical cycles have received a lot of attention recently. However, not many successful examples exist with smallholder livestock producers or pastoralists. Proofs of concept that test how these schemes could operate in very fragmented systems, with multiple users of the land or in communal pastoral areas, are necessary. Research on fair, equitable and robust monitoring and evaluation frameworks and mechanisms for effecting payments schemes that work under these conditions is necessary. The promise of PES schemes as a means to deliver the income diversification for the poor, and natural resource protection necessary to produce food while protecting the world's ecosystems, is yet to be seen on a large scale.

The ability of the sector to adapt to climate change and to mitigate green house gas emissions: Climate change is likely to cause severe impacts on livestock systems and on poor vulnerable producers. The capacity and speed of adaptation of smallholders will play an important role in defining the contribution of livestock to livelihoods under climate change. At the same time, in a low carbon economy, it will be essential that the sector mitigate GHG effectively in relation to other sectors. Demonstrating that these options are real with tangible examples is essential to generate the evidence for increasing the investments in climate change adaptation and mitigation for the livestock sector. This becomes more imperative as the global food system prepares to become part of the climate change negotiations.

Institutional and market mechanisms for reaching smallholders: The reality is that livestock production in the developing world is largely fragmented and disorganised. Underinvestment in extension systems and other support services has rendered poor producers disenfranchised to access key support systems necessary for increasing productivity and efficiency, or in cases important safety nets for reducing vulnerability (i.e. to drought/famines). The poorer farmers are unlikely to be able to respond sustainably to the increased demands for animal products without increased public investment in innovation and support platforms, as these are essential to foster the technological change required to increase productivity and link them to markets (McDermott *et al*., 2010). More advanced farmers or larger farmers in the developing world are likely to rely on the private sector for these support services. It is essential that the roles of women in production and trading of livestock products and in controlling livestock assets be taken into consideration when designing these institutional mechanisms.

Trade-offs and investments: The multiple social roles of livestock in the developing world may lead to compromise solutions that prevent the attainment of maximum environmental efficiencies, such as lowering GHG intensities. Balancing these roles and articulating them well is essential, as in the face of stern public opinion in favour of protecting global environmental goods, instead of local livelihoods, could create an investment climate that promotes more intensive, and environmentally efficient systems in the future, to the detriment of the poor smallholder farmer.

On the other hand, there are other aspects that will play an important role in shaping livestock production in the developing world, such as animal welfare and ethics and the magnitude of intensification in livestock production systems, technological surprises and access to them, and agricultural policies and the economic environment in the developed world. It is also essential that the informal and formal retail sectors gain the consumers trust as safe providers of livestock products for urban and rural consumers.

Balancing the multiple roles of livestock in the developing world and contrasting them with those in the developed world is not simple. The disaggregated evidence by region, species, production system, value chain, etc. needs to be generated. Messages need to be well distilled, backed by scientific evidence and well articulate to avoid making generalisations that more often than not, confuse the picture and ill-inform policy. Livestock's roles are simply not the same everywhere. The roles, whether good or bad, need to be accepted by the scientific community. Research agendas need to use the livestock bads as opportunities for improvement, while continuing to foster the positive aspects. These are essential ingredients for society to make better-informed choices about the future roles of livestock in sustainable food production, economic growth and poverty alleviation.

Acknowledgements

This paper is an ILRI output reported under the following CGIAR Research Programmes: CRP3.7 – Livestock and Fish and CRP7 – Climate Change, Agriculture and Food Security.

References

Allen LH 2002. Iron supplements: scientific issues concerning efficacy and implications for research and programs. Journal of Nutrition 132, 813S–819S.

Aklilu HA, Almekinders CJM, Udo HMJ and Van der Zijpp AJ 2008. Village poultry consumption and marketing in relation to gender, religious festivals and market access. Tropical Animal Health and Production 39, 165–177.

Ayoade JA, Ibrahim HI and Ibrahim HY 2009. Analysis of women involvement in livestock production in Lafia area of Nasarawa State, Nigeria. Livestock Research for Rural Development 21, article #220.

https://doi.org/10.1017/S1751731112001954 Published online by Cambridge University Press

Baggs EM, Chebii J and Ndufa J 2006. A short-term investigation of trace gas emissions following tillage and no-tillage of agroforestry residues in western Kenya. Soil and Tillage Research 90, 69–76.

Barrett CB, Reardon T and Webb P 2001. Nonfarm income diversification and household livelihood strategies in rural Africa: concepts, dynamics, and policy implications. Food Policy 26, 315–331.

Bernues A and Herrero M 2008. Farm intensification and drivers of technology adoption in mixed crop-dairy systems in Santa Cruz, Bolivia. Spanish Journal of Agricultural Research 6, 279–293.

Black R, Allen L, Bhutta Z, Caufield L, de Onis M, Ezzati M, Mathers C and Rivera J 2008. Maternal and child undernutrition: global and regional exposures and health consequences. The Lancet 371, 243–260.

Black R, Cousens S, Johnson H, Lawn J, Ruden I, Bassani D, Jha P, Campbell H, Walker C, Cibulsklis R, Eisele T, Liu L and Mathers C 2010. Global, regional, and national causes of child mortality in 2008: a systematic analysis. The Lancet 375, 1969–1987.

Bouwman AF, Klein Goldewijk K, Van der Hoek KW, Beusen AHW, Van Vuuren DP, Willems J, Rufino MC and Stehfest E 2011. Exploring global changes in nitrogen and phosphorus cycles in agriculture induced by livestock production for the period 1900-2050. Proceedings of the National Academy of Sciences, doi/10.1073/pnas.1012878108.

Bravo-Baumann H 2000. Gender and livestock: capitalisation of experiences on livestock projects and gender. Working Document. Swiss Agency for Development and Cooperation, Bern. http://www.fao.org/wairdocs/LEAD/X6106E/x6106e00.HTM

Bruinsma J 2003. World agriculture: towards 2015/2030 – an FAO perspective. Earthscan Publications, London, UK.

Budaka DB, Darca N and Kantar M 2005. Women farmers and extension services in small ruminant production in mountain areas of Turkey. Journal of Arid Environments 62, 507–515.

Burnsilver S 2009. Pathways of continuity and change: Maasai livelihoods in Amboseli, Kajiado district, Kenya. In Staying Maasai: livelihoods, conservation and Human Development in East African Rangelands (ed. K Homewood, P Trench, P Kristjanson, M Radeny), pp. 161–207. Studies in Human Ecology and Adaptation, Springer Press, Germany.

Canet C and N'Diaye C 1996. L'alimentation de rue en Afrique. Alimentation, nutrition et agriculture 17/18:4-13. FAO, Rome.

Carter MR and Barrett CB 2006. The economics of poverty traps and persistent poverty: an asset-based approach. Journal of Development Studies 42, 179–199.

Centner TJ 2011. Addressing water contamination from concentrated animal feeding operations. Land Use Policy, doi:10.1016/j.physletb.2003.10.071.

Chikowo R, Mapfumo P, Nyamugafata P and Giller KE 2004. Mineral N dynamics, leaching and nitrous oxide losses under maize following two-year improved fallows on a sandy loam soil in Zimbabwe. Plant and Soil 259, 315–330.

Chivenge P, Vanlauwe B and Six J 2011. Does the combined application of organic and mineral nutrient sources influence maize productivity? A meta-analysis. Plant Soil, doi:10.1007/s11104-010-0626-5.

Conant RT and Paustian K 2002. Potential soil carbon sequestration in overgrazed grassland ecosystems. Global Biogeochemical Cycles 16, 1143–1152.

Coppock D L, Desta S, Wako A, Aden I, Gebru G, Tezera S and Tadecha C 2006. Collective action by women's groups to combat drought and poverty in northern Kenya. Pastoral Risk Management Project Research Brief 06-01. Global Livestock Collaborative Research Support Program, University of California – Davis, Davis, CA, USA. www.glcrsp.ucdavis.edu).

Cuellar AD and Webber ME 2008. Cow power: the energy and emissions benefits of converting manure to biogas. Environmental Research Letters 3, 034002 (8pp).

Davis B, Winters P, Carletto G, Covarrubias K, Quinones E, Zezza A, Stamoulis K, Bonomi G and DiGiuseppe S 2007. Rural income generating activities: a cross-country comparison. ESA Working Paper 07-16. FAO, Rome.

De Boer W, Folman LB, Summerbell RC and Boddy L 2005. Living in a fungal world: impact of fungi on soil bacterial niche development. FEMS Microbiology Ecology 29, 795–811.

Delgado C, Rosegrant M, Steinfeld H, Ehui S and Courbois C 1999. Livestock to 2020: the next food revolution. Food, Agriculture and the Environment Discussion Paper 28. IFPRI/FAO/ILRI, Washington, DC, USA.

Dercon S and Krishnan T 1996. Income portfolio in rural Ethiopia and Tanzania: choices and constraints. The Journal of Development Studies 32, 850–875.

Deshingkar P, Farrington J, Rao L, Sharma SAP, Freeman A and Reddy J 2008. Livestock and poverty reduction in India: findings from the ODI Livelihoods Options Project. Discussion Paper No. 8. Targeting and Innovation. ILRI (International Livestock Research Institute), Nairobi, Kenya.

East Africa Dairy Development (EADD) 2008. Gender, dairy production and marketing, East Africa Dairy Development Project. Baseline Report No. 6 (Flintan). EADD/ILRI, Nairobi, Kenya.

Ellis F and Freeman HA 2004. Rural livelihoods and poverty reduction strategies in four African countries. The Journal of Development Studies 40, 1–30.

FAO 2007. State of Food and Agriculture Report: paying farmers for environmental services. Food Agricultural Organisation, United Nations. http://www.fao.org/docrep/010/a1200e/a1200e00.htm

FAO (Food and Agriculture Organization) 2009. The State of Food and Agriculture. Livestock in the balance. Food and Agriculture Organization of the United Nations, Rome, Italy.

FAO 2010. Greenhouse gas emissions from the dairy sector. A life cycle assessment. Food and Agriculture Organization of the United Nations, Rome, Italy FAO 2009.

FAOSTAT 2011. FAOSTAT database. FAO, Rome, Italy

Fielding W, Gullick C, Coutts P and Sharp B 2000. An introduction to the food economy research in Southern Sudan, 1994–2000. WFP and SC UK, Nairobi, Kenya.

Flintan F 2008. Women's Empowerment in Pastoral Societies. WISP, GEF, IUCN, UNDP.

Gerber P, Chilonda P, Franceschini G and Menzi H 2005. Geographical determinants and environmental implications of livestock production intensification in Asia. Bioresource Technology 96, 263–276.

Gilbert J, Lapar ML, Unger F and Grace D 2010. The most important zoonosis in the world. Paper presented at Ecohealth Conference, August 18–20, London.

Gourley CJP, Aarons SR and Powell JM 2011. Nitrogen use efficiency and manure management practices in contrasting dairy production systems. Agriculture, Ecosystems & Environment, doi:10.1016/j.agee.2011.05.011.

Grace D 2007. Women's reliance on livestock in developing-country cities. ILRI Working Paper. International Livestock Research Institute, Nairobi, Kenya.

Grace D, Randolph T, Olawoye J, Dipelou M and Kang'ethe E 2008. Participatory risk assessment: a new approach for safer food in vulnerable African communities. Development in Practice 18, 611–618.

Grace D, Mutua F, Ochungo P, Kruska R, Jones K, Brierley L, Lapar L, Said M, Herrero M, Pham Duc P, Nguyen BT, Akuku I and Ogutu F 2012. Mapping of poverty and likely zoonoses hotspots: report to the Department for International Development. ILRI report International Livestock Research Institute, Nairobi, Kenya.

Graffham A, Zulu R and Chibanda D 2005. Improving the safety of street vended foods in Southern Africa. Final Report, CPHP Project R8272. In Engendering Agricultural Research. IFPRI Discussion Paper 00973. International Food Policy Research Institute, Washington, DC.

Grieg-Gran M, Porras I and Wunder S 2005. How can market mechanisms for forest environmental services help the poor? Preliminary lessons from Latin America. IIED.

Guèye EF 2000. The role of family poultry in poverty alleviation, food security and the promotion of gender equality in rural Africa. Outlook on Agriculture 29, 129–136.

Heffernan C, Misturelli F and Pilling D 2003. Livestock and the poor: findings from Kenya, India and Bolivia. Animal Health Programme. Department for International Development, London.

Henderson B, Gerber P and Opyo C 2011. Climate change and livestock, challenges and options. CAB Reviews: Perspectives in Agriculture, Veterinary Science, Nutrition and Natural Resources 6, No. 16, 11p.

Herath S 2007. Women in livestock development in Asia. Journal of Commonwealth Veterinary Association 24, 29–37.

Herrero M, Thornton PK, Gerber P and Reid RS 2009. Livestock, livelihoods and the environment: understanding the trade-offs. Current Opinion in Environmental Sustainability 1, 111–120.

Herrero M, Thornton PK, Havlík P and Rufino M 2011. Livestock and greenhouse gas emissions: mitigation options and trade-offs. In Climate change mitigation and agriculture (ed. E Wollenberg, A Nihart, ML Tapio-Bistrom and C Seeberg-Elverfeldt) Earthscan, London, UK (in press).

Herrero M, Thornton PK, Notenbaert AM, Wood S, Msangi S, Freeman HA, Bossio D, Dixon J, Peters M, van de Steeg J, Lynam J, Parthasarathy Rao P, Macmillan S, Gerard B, McDermott J, Seré C and Rosegrant M 2010. Smart investments in sustainable food production: revisiting mixed crop-livestock systems. Science 327, 822–825.

https://doi.org/10.1017/S1751731112001954 Published online by Cambridge University Press

Jaitner J, Sowe J, Secka-Njie E and Dempfle L 2001. Ownership pattern and management practices of small ruminants in The Gambia – implications for a breeding programme. Small Ruminant Research 40, 101–108.

Jones KE, Patel N, Levy MA, Storeygard A, Balk D, Gittleman JL and Daszak P 2008. Global trends in human emerging infectious diseases. Nature 451, 990–993.

Kaitibie S, Omore A, Rick K, Salasya B, Hooton N, Mwero D and Kristjanson P 2008. Influence pathways and economic impacts of policy change in the Kenyan dairy sector, ILRI Research Report No. 15. ILRI, Nairobi, Kenya, 40p.

Keusch GT and Farthing MJG 1986. Nutrition and infection. Annual Review of Nutrition 6, 131–154.

Knight RL, Payne VWE Jr, Borer RE, Clarke RA Jr and Pries JH 2000. Constructed wetlands for livestock wastewater management. Ecological Engineering 15, 41–55.

Kristjanson P, Krishna A, Radeny M, Kuan J, Quilca G and Sanchez-Urrelo A 2005. Dynamic Poverty Processes and the Role of Livestock in Peru. FAO/Pro-Poor Livestock Policy Initiative Working Paper.

Kristjanson P, Waters-Bayer A, Johnson N, Tipilda A, Jemimah N, Batenwreck I, Grace D and MacMillan S 2010. Livestock and women's livelihoods: a review of the recent evidence. Discussion Paper 20. ILRI, Addis Ababa, Ethiopia.

Kunz A, Miele M and Steinmetz RLR 2009. Advanced swine manure treatment and utilization in Brazil. Bioresource Technology 100, 5485–5489, doi:10.1016/j.biortech.2008.10.039.

Landell-Mills N and Porras I 2002. Silver bullet or fools' gold? A global review of markets for forest environmental services and their impact on the poor. IIED, London.

Lannerstad M, Heinke J, Herrero M and Havlik P. Livestock production systems – green, green, blue consumptive water use. In Water and livestock: Interactions, trade-offs and opportunities symposium, World Water Week in Stockholm 2012, Water and food security, 26 August 2012. Stockholm, Sweden.

León-Velarde CU and Quiroz R 2004. The development of livestock production systems in the Andean region: implications for smallholder producers. In Animal production and animal science worldwide: A Review on Developments and Research in Livestock Systems, World Association of Animal Production, Book of the Year 2003 (ed. A Rosati, A Tewolde, C Mosconi), pp. 233–240. Wageningen Academic Publishers, The Netherlands.

LID (Livestock in Development) 2004 . Livestock services and the poor. Veterinary Epidemiology and Economics Research Unit. Department of Agriculture, University of Reading, Reading.

Liu J, You L, Amini M, Obersteiner M, Herrero M, Zehnder AJB and Yang H 2010. A high resolution assessment of nitrogen flows in cropland. Proceedings of the National Academy of Sciences 107, 835–840.

Lynch M, Painter J, Woodruff R and Braden C 2006. Surveillance for foodborne-disease outbreaks – United States, 1998–2002. MMWR – Morbidity & Mortality Weekly Reports 55, 1–42.

Maudlin I, Eisler MC and Welburn SC 2009. Neglected and endemic zoonoses. Philosophical Transactions of the Royal Society B: Biological Sciences 364, 2777–2787.

McDermott JJ, Staal S, Freeman HA, Herrero M and van de Steeg J 2010. Sustaining intensification of smallholder systems in the tropics. Livestock Science 130, 95–109, doi:10.1016/j.livsci.2010.02.014.

McMichael AJ, Powles JW, Butler CD and Uauy R 2007. Food, livestock production, energy, climate change, and health. The Lancet 370, 1253–1263.

McPeak J and Doss C 2006. Are household production decisions cooperative? Evidence on migration and milk sales from northern Kenya. American Journal of Agricultural Economics 88, 525–541.

Mullins GL, Wahome P, Tsangari A and Maarse L 1996. Impacts of intensive dairy production on smallholder farm women in Coastal Kenya. Human Ecology 24, 231–253.

Murphy SP and Allen LH 2003. Nutritional importance of animal source foods. Journal of Nutrition 133, 3932S–3935S.

Narayan D, Patel R, Schafft K, Rademacher A and Koch-Schulte S 2000. Voices of the Poor. Can Anyone Hear Us? Voices from 46 Countries. The World Bank, Washington, DC.

Naylor R, Steinfeld H, Falcon W, Galloway J, Smil V, Bradford E, Alder J and Mooney H 2005. Losing the links between livestock and land. Science 310, 1621–1622.

Neumann CG, Bwibo NO, Murphy SP, Sigman M, Whaley S, Allen LH, Guthrie D, Weiss RE and Demment M 2003. Animal source foods improve dietary quality, micronutrient status, growth and cognitive function in Kenyan school children: background, study design and baseline findings. Journal of Nutrition 133, 3941S–3949S.

Niamir-Fuller M 1994. Women livestock managers in the Third World: focus on technical issues related to gender roles in livestock production. Staff Working Paper 18. IFAD, Rome.

Njuki JM 2001. Gender roles in agroforesty: a socio-economic analysis of Embu and Kirinyaga Districts, Kenya. PhD thesis, Sokoine University of Agriculture, Tanzania.

Njuki J, Kihiyo M, O'ktingati A and Place F 2004. Male versus female labour in an agroforestry system in the Central Highlands of Kenya: correcting the misconception. International Journal of Agricultural Resources, Governance and Ecology 3, 154–170.

Nkedianye D, Kristjanson P, Radeny M and Herrero M 2009. Chapter 4. Assessing returns to land and changing livelihood strategies in Kitengela. In Staying Maasai: livelihoods, conservation and human development in East African Rangelands (ed. K Homewood, P Trench, P Kristjanson, M Radeny), pp. 115–139. Studies in Human Ecology and Adaptation, Springer Press, Germany.

Nori M 2008. Milking drylands: gender networks, pastoral markets and food security in stateless Somalia. Thesis, Wageningen University, Wageningen, NL. <http://library.wur.nl/WebQuery/wda/lang/1929205>

Oboler RS 1996. Whose cows are they, anyway? Ideology and behaviour in Nandi cattle "ownership" and control. Human Ecology 24, 255–272.

Oenema O 2006. Nitrogen budgets and losses in livestock systems. International Congress Series 1293, 262–271.

Oenema O, Oudendag D and Velthof GL 2007. Nutrient losses from manure management in the European Union. Livestock Science 112, 261–272.

Okali C and Sumberg JE 1985. Sheep and goats, men and women: household relations and small ruminant development in south-west Nigeria. Agricultural Systems 18, 39–59.

Okike A, Grace D and Hussni M 2010. Assessment of risks to human health associated with meat in Nigeria. Integrated Animal & Human Health Management Project, Unpublished report.

O'Mara FP 2011. The significance of livestock as a contributor to global greenhouse gas emissions today and in the near future. Animal Feed Science and Technology 166, 7–15.

Omore A, Cheng'ole MJ, Fakhrul ISM, Nurah G, Khan MI, Staal SJ and Dugdill BT 2001. Employment generation through small-scale dairy marketing and processing: experiences from Kenya, Bangladesh and Ghana, ILRI (http: www.fao.org/ag/againfo/resources/en/pubs_aprod.html#1).

Omore A, Arimi S, Kangethe E, McDermott J, Staal S, Ouma E, Odhiambo J, Mwangi A, Aboge G, Koroti E and Koech R 2001. Assessing and managing milk-borne health risks for the benefit of consumers in Kenya. SDP research report. International Livestock Research Institute, Nairobi, Kenya.

Pagiola S, Arcenas A and Platais G 2005. Can payments for environmental services help reduce poverty? An exploration of the issues and the evidence to date from Latin America, World Development. Elsevier 33, 237–253.

Pagiola S, Rios AR and Arcenas A 2008. Can the poor participate in payments for environmental services? Lessons from the Silvopastoral Project in Nicaragua, Environment and Development Economics. Cambridge University Press 13, 299–325.

PBL 2010. The Protein Puzzle: the consumption and production of meat, dairy and fish in the European Union. Netherlands Environmental Agency, Bilthoven, The Netherlands.

Peden D, Tadesse G, Misra AK, Awad Amed F, Astatke A, Ayalneh W, Herrero M, Kiwuwa G, Kumsa T, Mati B, Mpairwe D, Wassenaar T and Yimegnuhal A 2007. Chapter 13: Livestock and water for human development. In Water for food, water for life: comprehensive assessment of water management in agriculture (ed. D Molden), pp. 485–514. Oxford University Press, Oxford, UK.

Pelletier N and Tyedmers P 2010. Forecasting potential global environmental costs of livestock production 2000–2050. Proceedings of the National Academy of Sciences of the USA 107, pp. 18371–18374.

Perry B and Grace D 2009. The impacts of livestock diseases and their control on growth and development processes that are pro-poor. Philosophical Transactions of the Royal Society B: Biological Sciences 364, 2643–2655.

Petersen SO, Sommer SG, Béline F, Burton C, Dach J, Dourmad JY, Leip A, Misselbrook T, Nicholson F, Poulsen HD, Provolo G, Sørensen P, Vinnerås B, Weiske A, Bernal MP, Böhm R, Juhász C and Mihelic R 2007. Recycling of livestock manure in a whole-farm perspective. Livestock Science 112, 180–191.

Powell JM, Gourley CJP, Rotz CA and Weaver DM 2010. Nitrogen use efficiency: a measurable performance indicator for dairy farms. Environmental Science and Policy 13, 217–228.

https://doi.org/10.1017/S1751731112001954 Published online by Cambridge University Press

Randolph TF, Schelling E, Grace D, Nicholson CF, Leroy JL, Cole DC, Demment MW, Omore A, Zinsstag J and Ruel M 2007. Role of livestock in human nutrition and health for poverty reduction in developing countries. Journal of Animal Science 85, 2788–2800.

Rangnekar S 1998. Women in livestock production in developing countries. International Conference on Sustainable Animal Production, 24–27 November, Hisar, India.

Reardon T 1997. Using evidence of household income diversification to inform study of the rural nonfarm labor market in Africa. World Development 25, 735–748.

Reid RS, Thornton PK, McCrabb GJ, Kruska RL, Atieno F and Jones PG 2004. Is it possible to mitigate greenhouse gas emissions in pastoral ecosystems of the tropics? Environment, Development and Sustainability 6, 91–109.

Rockström J, Lannerstad M and Falkenmark M 2007. Assessing the water challenge of a new green revolution in developing countries. Proceedings of the National Academy of Sciences 104, 6253–6260.

Rosegrant MW, Fernandez M, Sinha A, Alder J, Ahammad H, de Fraiture C, Eickhout B, Fonseca J, Huang J, Koyama O, Omezzine AM, Pingali P, Ramirez R, Ringler C, Robinson S, Thornton P, van Vuuren D, Yana-Shapiro H, Ebi K, Kruska R, Munjal P, Narrod C, Ray S, Sulser T, Tamagno C, van Oorschot M and Zhu T 2009. Looking into the future for agriculture and AKST (Agricultural Knowledge Science and Technology). In Agriculture at a crossroads (ed. BD McIntyre, HR Herren, J Wakhungu, RT Watson), pp. 307–376. Island Press, Washington, DC.

Rubin D, Tezera S and Caldwell L 2010. A calf, a house, a business of one's own: Microcredit, asset accumulation, and economic empowerment in GL CRSP projects in Ethiopia and Ghana, Global Livestock Collaborative Research Support Program.

Rufino MC, Rowe EC, Delve RJ and Giller KE 2006. Nitrogen cycling efficiencies through resource-poor African crop-livestock systems: a review. Agricultural Ecosystems and Environment 112, 261–282.

Rufino MC, Tittonell P, van Wijk MT, Castellanos-Navarrete A, Delve RJ, de Ridder N and Giller KE 2007. Manure as a key resource within smallholder farming systems: analysing farm-scale nutrient cycling efficiencies with the NUANCES framework. Livestock Science 112, 273–287.

Rufino MC, Dury J, Tittonell P, van Wijk MT, Herrero M, Zingore S, Mapfumo P and Giller KE 2011. Competing use of organic resources, village-level interactions between farm types and climate variability in a communal area of NE Zimbabwe. Agricultural Systems 104, 175–190.

Salman MD, Morley PS and Ruch-Gallie R (eds) 1999. International Society for Veterinary Epidemiology and Economics, Nairobi (Kenya). Proceedings of the 9th Symposium of the International Society for Veterinary Epidemiology and Economics. Paper 333, Nairobi, Kenya.

Sanchez PA 2002. Soil fertility and hunger in Africa. Science 295, 2019–2020.

Scharff RL 2010. Health-related costs from foodborne illness in the United States. The Produce Safety Project at Georgetown University, Washington, DC.

Schlundt J, Toyofuku H, Jansen J and Herbst SA 2004. Emerging food-borne zoonoses. Annual Review of Information Science and Technology 23, 513–533.

Seré C and Steinfeld H 1996. World livestock production systems: current status, issues and trends. FAO Animal Production and Health Paper 127, Rome, Italy.

Sherraden M 1991. Assets and the poor: a new American welfare policy. ME Sharpe, Armonk, NY.

Silvestri S, Osano P, De Leeuw J, Herrero M, Ericksen P, Kariuki J, Njuki J, Notenbaert A and Bedelian C 2012. Assessing the potential of payment for environmental services in livestock-inclusive agricultural production systems in developing countries. ILRI research report, International Livestock Research Institute, Nairobi, Kenya.

Singh BB, Ajeigbe HA, Tarawali SA, Fernandez-Rivera S and Musa A 2003. Improving the production and utilization of cowpea as food and fodder. Field Crops Research 84, 169–177.

Smith P, Gregory PJ, van Vuuren D, Obersteiner M, Havlík P, Rounsevell M, Woods J, Stehfest E and Bellarby J 2010. Competition for land. Philosophical Transactions of the Royal Society B 365, 2941–2957.

Smith P, Martino D, Cai Z, Gwary D, Janzen H, Kumar P, McCarl B, Ogle S, O'Mara F, Rice C, Scholes B and Sirotenko O 2007. Agriculture. In Climate change 2007: mitigation. Contribution of Working Group III to the Fourth Assessment Report of 24 the Intergovernmental Panel on Climate Change (ed. B Metz, OR Davidson, PR Bosch, R Dave and RL Meyer), pp. 497–540. Cambridge University Press.

Staal S, Poole J, Baltenweck I, Mwacharo J, Notenbaert A, Randolph T, Thorpe W, Nzuma J and Herrero M 2009. Strategic investment in livestock development as a vehicle for rural livelihoods. Bill and Melinda Gates Foundation – ILRI Knowledge Generation Project Report. International Livestock Research Institute, Nairobi, Kenya, 78pp.

Steinfeld H, Gerber P, Wassenaar T, Castel V, Rosales M and de Haas C 2006. Livestock's long shadow. Environmental issues and options. LEAD-FAO, Food and Agriculture Organization, Rome, Italy, 390pp.

Sumberg J 2002. The logic of fodder legumes in Africa. Food Policy 27, 285–300.

Sutton MA, Oenema O, Erisman JW, Leip A, Van Grinsven H and Winiwarter W 2011. Too much of a good thing. Nature 472, 159–161.

Tarawali S, Herrero M, Descheemaeker K, Grings E and Blümmel M 2011. Pathways for sustainable development of mixed crop livestock systems: taking a livestock and pro-poor approach. Livestock Science 139, 11–21.

Teufel N, Kuettner K and Gall C 1998. Contribution of goat husbandry to household income in the Punjab (Pakistan): a review. Small Ruminant Research 28, 101–107.

Thompson DM, Serneels S, Ole Kaelo D and Chevenix Trench P 2009. Maasail mara – land privatization and wildlife decline: can conservation pay its way? In Staying Maasai: livelihoods, conservation and Human Development in East African Rangelands. Studies in Human Ecology and Adaptation (ed. K Homewood, P Trench, P Kristjanson, M Radeny), pp. 77–114. Springer Press, Germany.

Thorns CJ 2000. Bacterial food-borne zoonoses. Revenue scientifique et technique Office international des epizooties 19, 226–239.

Thornton PK 2010. Livestock production: recent trends, future prospects. Philosophical Transactions of the Royal Society B 365, 2853–2867.

Thornton PK and Herrero M 2010. The inter-linkages between rapid growth in livestock production, climate change, and the impacts on water resources, land use, and deforestation. Background paper for the 2010 World Development Report. Policy Research Working Paper 5178. The World Bank, Washington, US, 82pp.

Thornton PK, Kruska RL, Henninger N, Kristjanson PM, Reid RS, Atieno F, Odero A and Ndegwa T 2002. Mapping poverty and livestock in the developing world. International Livestock Research Institute, Nairobi, Kenya, 124pp.

Toriola AL and Goon DT 2012. Overweight, obesity and underweight in rural black South African children. South African Journal of Clinical Nutrition 25, 57–61.

Turpie JK, Marais C and Blignaut JN 2008. The working for water programme: evolution of a payments for ecosystem services mechanism that addresses both poverty and ecosystem service delivery in South Africa. Ecological Economics 65, 788–798.

Valdivia C 2001. Gender, livestock assets, resource management, and food security: lessons from the SR-CRSP. Agriculture and Human Values 18, 27–39.

Vanlauwe B and Giller KE 2006. Popular myths around soil fertility management in sub-Saharan Africa. Agriculture, Ecosystems and Environment 116, 34–46.

Wangui EE 2008. Development interventions, changing livelihoods, and the making of female Maasai pastoralists. Agriculture and Human Values 25, 365–378.

World Health Organization (WHO) 2008. The World Health Report 2008 – primary health care: now more than ever.

Wunder S 2005. Payment for environmental services: some nuts and bolts. CIFOR Occasional paper no. 42, Bogor, Indonesia.

Yisehak K 2008. Gender responsibility in smallholder mixed crop–livestock production systems of Jimma zone, South West Ethiopia. Livestock Research for Rural Development 20. Retrieved January 14, 2010, from http://www.lrrd.org/lrrd20/1/yise20011.htm

https://doi.org/10.1017/S1751731112001954 Published online by Cambridge University Press