Feeding the World in 2050: trade-offs, synergies and tough choices for the livestock sector

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Abstract. Feeding the World in 2050 is a major challenge at the forefront of the global development agenda. The importance of agriculture in addressing this challenge has re-emerged in recent years as food security issues are considered in a more holistic manner. The role of livestock as part of the solution is, however, often not considered. This article presents a brief overview of the global food security challenge, and considers the increased focus on holistic food systems. It contends that animal agriculture is relevant to this complex, multifaceted and dynamic global challenge. However, if livestock-based solutions are to become a reality a number of partial truths and trade-offs often associated with livestock and food need to be addressed. The role of livestock systems in future food security is considered in relation to different potential development trajectories of the sector, highlighting opportunities to ensure that livestock's contribution to global food security is a positive one that also addresses concerns of environment, equity and human health.

Keywords: Agriculture, food security, livestock, food systems, misperceptions, trade-offs.

Introduction

By 2050 most of the world's population 10 billion or so inhabitants will be living in towns and cities. Feeding these people will require a 70 - 100% increase in the amount of food produced today (Burney *et al.* 2010). Not only will the quantity of food that is needed increase, but requirements for quality will be more exacting, driven by both consumers and regulators. People who live in the rapidly emerging economies, and even those in countries currently categorized as poor, will demand better and more varied diets that contain far more meat, milk and eggs – the animal-source foods - than today. And increasingly food will be purchased in supermarkets, pre-packed and processed.

Against a background of growing water scarcity, rising energy prices, the best land already being in production and impacts of climate change which are often detrimental, producing sufficient quantity and quality of food for nearly 10 billion people represents a huge challenge.

It is estimated that by 2050 at least an additional one billion tonnes more cereals (IAASTD 2009), one billion tonnes of dairy and 460 million tonnes of meat (FAO 2011a) will be needed annually (based on consumption estimates). With the drivers of increased population, urbanization and higher incomes, value of and demand for animal-source products will increase faster than other agricultural sectors (Herrero *et al.* 2013a). Much of this increased production will have to come from the same land base which is currently producing food of both animal and plant origin.

How will the world be fed? Where and by whom will its food be produced and at what cost to the environment, public health and animal welfare? Who will benefit from the global food system and who will lose out? How will agricultural and food systems adapt to meet these changes and challenges? The answer to these important questions will depend largely on the policy and institutional frameworks that nations, regions and the global community develop and the incentives and barriers these create.

All too often livestock is ignored in the global agriculture and food debate: the focus of attention for agriculture is invariably crops and food usually means staples, mostly cereals. Even when nutrition is considered, an area where the animal-source foods have a real comparative advantage, livestock rarely gets a mention.

This paper therefore sets out to position livestock as a key part of the solution to feeding the world in 2050: a source of nutrient-dense animal-source foods that can support normal physical and mental development and good health; an income stream that enables the world's billion poorest people to buy staple foods and other household essentials; and a means of underpinning soil health and fertility and increased yields, thereby enabling more sustainable and profitable crop production. In doing so, it acknowledges that livestock production has the potential to do harm to the environment as the sector is a significant source of greenhouse gases and can be detrimental to human health. However, on the positive there are real opportunities to mitigate such negative impacts as livestock systems transition in the coming decades.

It will argue that the meat, milk and eggs, and other goods and services that livestock provide, can and must be produced in ways that are less damaging to the environment and with reduced risk to public health, whilst also supporting sustainable livelihoods for hundreds of millions of the world's poorest citizens who currently have few other options – at least while they transit to new occupations and livelihoods as economies grow, mature and diversify. In the process it will address some of the common misconceptions that surround livestock and which

all too often cloud the debate.

Feeding the world – what are the challenges?

With less than two years remaining to the 2015 deadline for the attainment of the Millennium Development Goals (MDGs), the international community is closely scrutinizing the progress made. Goal number one refers to the eradication of poverty and hunger, recognizing that these two dimensions are inextricably linked: the poor spend the majority of their income on food.

The 2013 hunger report (Bread for the World Institute 2012) recently proposed a bold new goal, a successor to the MDGs - to eliminate poverty and hunger by 2040. It further recognised that the highest numbers of people living on less than $US 1.25 a day are in middle income (not poor) countries. Food prices matter and every country will need different solutions.

The Global Hunger Index (Deutsche Welthungerhilfe e.V., International Food Policy Research Institute and Concern Worldwide 2012) is one measure of progress towards the target of eradicating poverty and hunger. The index combines three equally weighted indicators: the proportion of the population with insufficient calorific intake, the proportion of children under 5 years of age who are underweight and the mortality rate of under-fives. Globally, although the index has fallen steadily since 1990, the overall score for the world is categorized as 'serious'.

The two poorest regions of the world are South Asia and sub-Saharan Africa. The hunger index for South Asia fell markedly between 1990 and 1996 but since then has failed to maintain this rate of improvement. In sub-Saharan Africa, improvements since 2000 mean that by 2012 the index score fell below that for South Asia. Of the top 10 countries which have made the most improvement in the index since 1990, none are in South Asia and only one, Ghana, in sub-Saharan Africa; of the six countries whose scores have deteriorated most over this period no less than five are in Africa and one other, the Democratic Republic of the Congo, only misses the list due to shortage of data.

It is a shocking indictment of the global food system that, in the 21st century, the majority of the world's population have sub-optimal diets: at least a billion going to bed hungry; two billion are vulnerable to food insecurity; a billion have diets which do not meet all their nutritional requirements; and another billion suffer the effects of over-consumption (Smith *et al*. 2012).

The shift to 'food systems'

Alongside increased attention to how the world will feed itself in the coming decades, there have been two other shifts in emphasis. Firstly, from quantity at all costs, to sustainable quantities at acceptable quality. It is no longer regarded by many as being acceptable to consider production of 'enough' food in isolation; food must be produced in ways that are environmentally, socially and economically sustainable. The second is that defeating hunger by providing enough energy is not enough; balanced, wholesome nutrition must also be part of the solution.

So, in addition to addressing the overall hunger index, the Global Hunger Index 2012 report stresses that food supply must include the sustainable and responsible use of natural resources, food distribution and access, balanced nutrition and access and management of natural resources (Deutsche Welthungerhilfe e. V., International Food Policy Research Institute and Concern Worldwide 2012). It considers that addressing these aspects demands policy steps to include responsible management of natural resources, scaling up of technical approaches and addressing the drivers of natural resource scarcity.

The High Level Task Force on global food security, established by the UN in 2008[1] as a response to the food price crisis that year, has a similarly broad goal and recognizes the importance of functional links between policy and actions for food, land, water and energy security, environmental sustainability, adaptation to and mitigation of climate change and ecosystem services.

A number of studies also recognize that food security in the future needs to include managing risk and ensuring reduced vulnerability to the major food systems of the world. Especially in developing economies, food is produced in systems that are often fragile: for example, increased hunger since 1990 in Burundi, Comoros, and Côte d'Ivoire can be attributed to prolonged conflict and political instability, while the devastating earthquake of 2010 pushed Haiti back into the 'extremely alarming' category.

The poor spend a disproportionate amount of their income on food. This means they are especially vulnerable both through limited access and food prices spikes. The Montpelier Panel stresses the need for agricultural growth (especially in Africa) to be underpinned by resilient markets, agriculture and people (The Montpelier Panel 2012).

Agriculture back on the agenda

Since 2008, when the fragility of national food systems and their susceptibility to the vagaries of trade and price fluctuations came to the fore, the role of agriculture, including the underpinning research and development efforts, has returned to the agenda as a crucial component of food security at global, regional and national levels.

A recent FAO report (FAO 2012a) emphasizes the importance of agricultural investment for growth, reduction in poverty and hunger, and the promotion of environmental sustainability. Countries recognized as the poorest and hungriest are also those with the least agricultural investment. Governments have a crucial role in providing a conducive investment climate and helping farming communities, especially women, in governing large-scale investments and investing in public goods and services that generate high returns. A recent report from the World Economic Forum stresses the importance of agriculture as a driver for food security, environmental sustainability and economic opportunities (World Economic Forum 2013).

One of the more recent trends in the global quest for food security is land acquisitions involving significant private and foreign investments. Rulli *et al.* (2013) report that some 46 million hectares of land (and the associated water) has been allocated in this way, with 90% of this

[1] http://www.un.org/en/issues/food/taskforce/

distributed over just 24 countries. Efforts are underway to promote more positive development opportunities through such processes. Cotula *et al.* (2009) point out that such acquisitions are often based on the misperception that land is abundant and 'unused', and tend to overlook the complexities of land ownership and rights. In relation to the livestock sector, in many cases land that is apparently 'unused' may actually constitute critical dry seasonal grazing resources or migration routes crucial for the management and ecological integrity of pastoralists, their animals and the natural resources of which they are stewards.

Smallholder agriculture – what role?

The role of agriculture in addressing future food needs is unquestioned. What is more contentious is how and in what time frame agricultural systems will evolve in relation to this. Today, a considerable amount of food is produced by smallholders: 500 million smallholders supporting more than 2 billion people (Conway 2012). This begs the question of whether, or for how long, this can continue.

The roles of smallholders in providing future food, especially those who raise livestock, are complex, multi-dimensional and at times controversial. Hazell *et al.* (2007) and Wiggins *et al.* (2010) evaluated the pros and cons of smallholder development, recognizing the combinations of policy, market and institutional innovations that are demanded to make these enterprises viable in the future.

One dimension where there is broad agreement is that as agricultural systems transition, one of the crucial though hitherto marginalized elements will be to address the role of women, in particular their access to information and inputs (FAO 2011b). Conway (2012) suggests that while the world's one billion hungry can be fed, 24 conditions are needed if that is to happen: one of them is more funding for mixed livestock systems.

In south Asia more than 80% of farms are less than 2 hectares; in sub-Saharan Africa smallholders contribute more than 80% of livestock production; and globally farms with a few ruminants, such as two cattle and half-a-dozen sheep or goats (*i.e.* 2 tropical livestock units (TLU)) and 2 hectares of land contribute 50-75% of the total livestock production. South Asia and sub-Saharan Africa have 45% and 25%, respectively, of the world's 725 million poor livestock keepers (FAO 2012b).

Smallholder and extensive livestock keepers produce in fundamentally different ways from large scale industrial farmers. Industrial systems almost always rely on food that could potentially be eaten by people – mostly grains. Smallholder and extensive systems relay mostly on food that is not available to people (grass, fodder, residues and wastes).

Feeding the world – are livestock part of the solution?

Whilst livestock commodities and systems are rarely mentioned in the context of addressing food security, livestock are, and must be, part of the solution to global food security: significant amounts of the world's food supply, both crop and livestock products, comes from systems in which livestock are important. Livestock products play a critical role in nutrition and human health. Amongst agricultural commodities, livestock products are among the highest by value and fastest growing in terms of demand. However, the potentially negative impacts of livestock on human health and the environment must also be addressed along with equity issues as the sector grows.

By 2050 it is projected that per capita consumption of meat and milk in developing countries will have increased by more than 57% and 77%, respectively, and total consumption of meat and milk in these regions will have increased by 2.4 and 2.6 fold (FAO 2011a). Yet even with this rate of increase, consumption levels of meat and milk will still be less than half those found in developed countries.

More than 60% of all human diseases are shared by animals and for new and emerging diseases the number is as high as 75%. Diseases can pass from animals to people in many ways but one of the most common is through livestock products. Not only can animal source foods transmit pathogens present in the animal, they are often a vehicle for transmitting pathogens present in the environment or shed by people. Animal source foods are excellent sources of nutrition for people: unsurprisingly, they are also better at supporting growth of pathogens than staple crops (Grace, 2012).

Trajectories of livestock systems

The context for livestock development is rapidly evolving, driven by the continued rising demand for livestock products, particularly in Asia, and a greater recognition that the on-going transformation needs to be nuanced in relation to the roles of smallholders, their diverse economic situateions and the different livestock commodities they produce.

Higher demand means that the private sector in developing countries has become much more dynamic, creating new types of opportunities for smallholder livestock production and marketing systems, and means for market development. Accompanying these, however, are rapid structural changes in scale and quality of livestock commodity production, marketing and consumption. As with all aspects of food production, there is a need to consider the diversity of livestock production systems and scale in developing country food systems and how they can evolve to improve food security while reducing poverty in a way that is environmentally sound and has positive human health outcomes.

In order to better position research and development efforts to encompass the diversity of livestock systems, three potential livestock growth scenarios have been identified recently which better capture the dynamics of the sector than the conventional pastoral, mixed crop livestock and industrial categorisation. These emerged from a High-Level Consultation for a Global Livestock Agenda to 2020 co-convened by the International Livestock Research Institute (ILRI) and the World Bank[2] and were developed further in ILRI's strategy 2013-2022 (ILRI 2013). These trajectories also resonate with the categorization of livestock systems used in a recent FAO study of the role of livestock in food security (FAO 2011a): livestock

[2] http://mahider.ilri.org/handle/10568/16716

dependent societies, small-scale mixed farmers and city populations. The three trajectories are detailed below.

Strong growth systems

These address the need to develop sustainable food systems that deliver key animal-source nutrients to the poor while facilitating a structural transition in the livestock sector of developing countries. This will entail a transition from most smallholders keeping livestock in low-productive systems to eventually fewer households raising more productive animals in more efficient, intensive and market-linked systems. These mostly mixed smallholder systems already provide significant livestock and crop products in the developing world and are likely to grow the most in aggregate. In some instances, strong growth will occur in rangeland systems where appropriate market connections and productivity increases can be facilitated. In many parts of Africa and Asia the transition is happening slowly, with smallholder marketing systems still largely informal, although there are pockets of more rapid change in higher potential systems with good market access.

It is these rapidly changing scenarios where there are real opportunities to apply approaches such as sustainable intensification (Pretty *et al*. 2011) which describes seven key components to sustainable intensification summarised as *"…producing more output from the same area of land while reducing the negative environmental impacts and at the same time increasing contributions to natural capital and the flow of environmental services"*.

Fragile growth systems

Rapid, market-focused growth will, however, not be the trajectory for all poor livestock keepers. In areas where growth in productivity is severely limited by remoteness, harsh climates or environments, or by poor institutions, infrastructure and market access, the emphasis will need to be on enhancing the important role livestock play in increasing the resilience of people and communities to variability in weather, markets or resource demands. Livestock-based livelihoods will continue to be important to feed families and communities, supported by protection of assets and conservation of natural resources. Payment for ecosystem services is also likely to become increasingly important although so far these schemes are still rare (Silvestri *et al*. 2012).

High growth with externalities

Where dynamic markets and increasingly skilled human resources are already driving strong growth in livestock production, fast-changing small-scale livestock systems might damage the environment and expose their communities to increased public health risks. Furthermore, in these scenarios participation of the poorest livestock keepers and other value chain actors is limited. This demands an understanding and anticipation of all possible negative impacts of small-scale livestock intensification. Incentives, technologies, strategies and product and organizational innovations that mitigate health and environment risks while supporting the poorest people to comply with increasingly stringent livestock market standards are important approaches.

Livestock partial truths explored

Given the importance of livestock systems for food security, as well as their potential to impact on poverty, livelihoods, health and nutrition, and the environment, the relatively little attention paid to the sector is puzzling. This might, perhaps, be related to a number of misperceptions. Although true in some circumstances, none of them is globally true and there are invariably various trade-offs, synergies and tough choices that need to be to be addressed in developing livestock-based solutions to the global food security challenge. These often differ according to the most likely livestock growth trajectory. Below a series of livestock partial truths are explored and opportunities to address these in relation to different livestock trajectories are suggested.

Livestock contribute to food security both directly and indirectly, and play a crucial role in the livelihoods of almost one billion of the World's poorest people. At the same time, animal production, marketing and consumption can have negative implications for human health, on the environment and climate change. Understanding and making appropriate choices amongst trade offs is essential if the positive attributes are to be realized whilst the negative ones are minimized. In this context, a number of perceptions about the livestock sector are explored in relation to food security, animal source foods and human health, how and where food is produced and the environment

Food security

Food security is about staple cereals – animal-source foods are a luxury

It is true that the direct contribution made by livestock products to world food supply may appear modest: globally, 17% of the energy and 33% of the protein come from livestock commodities (FAO 2009). But the contribution of livestock to the world's food is often under appreciated. Mixed crop livestock systems, however, contribute significantly both to the global supply of animal products and also supply almost half of global cereal: in the developing world these systems supply 41% of maize, 74% of millet, 66% of sorghum and 86% of rice (Herrero *et al*. 2009). Developing countries now produce 50% of the world's beef, 41% of milk, 72% of lamb, 59% of pork and 53% of poultry (FAO 2011a).

In these mixed systems, livestock also play an important role in the production of crops. Livestock provide manure, a valuable soil nutrient, traction for land preparation and transport, and also generate income that can be used to purchase seeds of improved varieties, fertilizer, labour and other inputs. Manure provides 12% of the nitrogen used for crop production globally rising to 23% in mixed crop livestock systems (Liu *et al*. 2010). In many of these systems livestock consume and use crop by-products as major feed resources (Blummel 2010). Livestock therefore have and will continue to have a major role in food security, especially for the poor in developing countries, and approaches such as sustainable intensification continue to play an important role (Pretty *et al*. 2011). In addition it has been estimate that 1.3 million people are

employed in livestock value chains globally (Herrero *et al* 2013a); the incomes they gain therefore make a major contribution to their food security.

Livestock compete with human food

It is often argued that livestock consume feedstuffs that people could benefit from directly, such as grains and legumes, and thus, impact negatively on the total amount of food available. It is true that today, about half the world's annual production of grain is fed to animals, especially monogastrics (IAASTD 2009), and 77 million tons of plant protein are fed to livestock to produce 58 million tons of animal protein (Steinfeld *et al*. 2006). Feed crops occupy an estimated half a billion hectares of land; including grazing land, livestock accounts for four-fifths of all agricultural land (Steinfeld *et al*. 2010). Extrapolating from current trends, by 2050 an additional 1 billion tonnes of grain will be needed for the world, about 40% of which will be required for livestock feed, mostly pigs and chickens (IAASTD 2009).

But it is often not realised that raising fewer livestock and consuming less animal products is unlikely to mean more grain is available for human consumption: for the billion undernourished people in the world, releasing grain by not feeding to animals would not make it available for their consumption: fundamental challenges would remain related to affordability and access to food (FAO 2011a). Msangi and Rosegrant (2011) explored the implications of 'healthier diets' with less meat in developed countries on improving nutrition in developing countries: they found little, if any positive results. And importantly, it is not the livestock of the poor who competed for their food, it is the livestock of the rich.

For livestock systems based on grazing, which constitute 40% of the earth's surface and support some 120 million people (FAO 2011a; FAO 2012b), livestock are not consuming food that could be directly consumed by people; rather they are converting materials humans cannot eat into milk, meat and eggs that they can. Herrero *et al.* (2009) estimate that 7% of the milk and 37% of global beef and lamb production is from such systems. FAO (2011a) estimates are that such grassland based systems provide 12% of the milk and 9% of the meat annually. Differences are most likely due to the system boundaries used for such estimations. In some of these systems there is potential for strong growth if appropriate market arrangements coupled with productivity increases can be aligned. But for other regions, these will be systems with fragile growth prospects where a focus on safety nets, insurance function of assets and environmental stewardship must come to the fore.

Overall in the mixed crop-livestock systems, livestock mostly do not compete directly with people for food and mainly convert inedible materials into milk and meat. The major feed resource for animals in these systems (notably ruminants) is crop residues – as much as 70% of animal diets being composed of such materials which are essentially a by product of food production and therefore not in competition with human food (Blümmel 2010). However, increasingly trade-offs between crop residue and biomass use for animal feed, soil fertility and biofuels are being highlighted as important issues to consider as crop-livestock systems evolve (Valbuena *et al.* 2012): a major challenge for the future is to address the looming biomass shortage and how livestock systems may be intensified in sustainable ways (Duncan *et al*. 2013). Especially in those systems that have the potential for strong growth, there are significant opportunities to improve animal productivity without introducing high grain based diets (Tarawali *et al.* 2011) thereby achieving win-win efficiency and green-house gas mitigation.

Animal source foods and human health

Poor people do not care what they eat

It is true that poor consumers are sensitive to price, but contrary to common belief, developing country consumers who shop in informal markets do care about quality attributes of food; they are even willing to pay a 5-15% premium for safer foods (Jabbar *et al*. 2010). Studies in Ethiopia have shown that, while the poorer sectors of society have less concern than the rich, they take food safety seriously.

Food scares, whether bird flu in poultry or horsemeat in burgers, offer natural experiments in which peoples' attitudes towards food safety and quality can be tested. Even in poor countries, dramatic changes in consumption patterns have also been observed in response to food scares. ILRI's work in Vietnam showed that when 'blue ear' (porcine reproductive and respiratory syndrome virus) made the news, the vast majority of consumers stopped eating pork, shifted to chicken or went to outlets perceived as safer (ILRI 2010). Assessments conducted in the context of Rift Valley fever outbreaks in Kenya showed consumers demanding to see butchers certificates and a drop in demand for ruminant meat as consumers switched to poultry (ILRI 2007).

All three growth scenarios require solutions to the challenges of food borne diseases and zoonoses, especially in the higher growth scenarios. The use of risk based approaches and complex institutional arrangements will be important in addressing such challenges (Randolph *et al*. 2007).

Animal-source foods are bad for your health

It is true that over a billion people suffer from the effects of over-consumption, including of animal-source foods, increasing their risk of non-communicable diseases such as cancers, cardiovascular disease and diabetes (McMichael *et al*. 2007). Understandably animal-source foods are often considered a threat to health. But it is often not appreciated how important animal source foods can be for the several billion who are undernourished, for whom consumption of too little animal-source food may have even worse consequences.

Children are particularly vulnerable to nutritional deficiencies during the first 1000 days from conception and chronic under nutrition of young girls means that 'a vicious cycle of under nutrition repeats itself, generation after generation' (UNICEF 2008).

Several forms of malnutrition (protein-energy malnutrition, iron-deficiency anaemia and vitamin A deficiency) can be prevented if sufficient animal-source foods are included in the diet. Even small amounts of these

foods can result in better cognitive development, growth and physical activity of children (Neumann *et al*. 2002; Sadler *et al*. 2012). Animal-source foods are a concentrated source of energy, protein and various essential micro-nutrients, including those absent or scarce in plant-based foods. They also match well with human dietary requirements (Young and Pellett 1994; Allen 2005). It has been estimated that to combat effectively under nutrition, 20 g of animal protein per person per day is needed – the equivalent of an annual per capita consumption of 33 kg lean meat, 230 kg milk or 45 kg fish (FAO 2009).

As people get wealthier, an important question to address is how much animal-source food should they eat? This is the subject of considerable debate, both from the perspective of the quantity as well as the practicalities of limiting the increased consumption of milk, meat and eggs: as people become less poor, the first manifestation is often an increase in consumption of animal-source foods. A range of figures has been proposed, ranging from 58 to 90 g of meat per person per day (McMichael *et al.* 2007; FAO 2011a; Westhoek *et al*. 2011). Livestock products themselves are not major contributors to the increasing burden of obesity in poor countries; but they are often fried or otherwise processed in ways that make them unhealthy choices (Ziraba *et al.* 2009).

As livestock systems evolve in strong and high growth scenarios, paying attention to an appropriate level of animal consumption will be a challenge. Meanwhile for fragile growth scenarios, ensuring that enough animal-source food is available and accessible will remain the challenge.

How food is produced

Large industrial livestock farms are the only answer

Smallholder livestock farms are often inefficient, producing at low levels and often with a high level of greenhouse gas emissions per unit of product (FAO 2010). Capper *et al.* (2009) assessed dairy production in the US and noted that, compared to 1944, in 2007 just 21% of the animals, 23% of the feedstuffs, 35% of the water and only 10% of the land were being used to produce one billion kilograms of milk. This period was characterised by significant increases in average herd and farm size, a phenomenon not yet observed to any great extent in developing countries, where it may be anticipated that a similar trajectory is likely over coming decades.

More than 70% of the dairy products in India, the world's largest dairy producer, come from small-scale production enterprises and considerable amounts of live-stock products are sold in informal markets (Costales *et al.* 2010). While smallholders may continue to be competitive in the dairy sector, for pig and poultry a more rapid switch to industrial systems is likely (Tarawali *et al*. 2011).

Disease management and biosecurity are also consider-ed poor in smallholder systems. Hence, many recommend that future livestock farming must be based on large-scale industrial systems. Not all agree however. Industrialization of livestock systems may facilitate disease transmission, for example through high density populations and the challenge of managing large volumes of waste, and promote the use of anti-microbials and thus emergence of antibiotic resistance. It may also lead to reduced levels of genetic diversity which may promote evolution of patho-gens and reduce options for an uncertain future (Jones *et al.* 2013).

Livestock and the environment

Livestock are responsible for climate change

There is no doubt that livestock production contributes to greenhouse gas emissions. How much has been a matter of some debate; estimates range between 8 to 51% of total greenhouse gas emissions emanating from the sector (Herrero *et al*.2011a) although most estimates fall in the range of 12-18%. Within agriculture as a whole, it is the livestock sector where the greatest opportunities for mitigating the greenhouse gas emissions occur, both today and in the future. Herrero *et al.* (2013b) estimate that up to half of the global greenhouse gas mitigation potential of agriculture, forests and land use combined is in the livestock sector. Thornton and Herrero (2010) estimated that the mitigation potential from feeding improvements alone in tropical systems was around 7% of the global mitigation potential of agriculture.

Milk production in sub-Saharan Africa produces more than twice the emissions per unit of production at the farm gate than the global average (FAO 2010) and similar inefficiencies are reported for beef (Capper 2011). In the US dairy sector, a four-fold increase in the efficiency of production, attributed to better feeding, breeding and animal health, took place over a six decade period (Capper *et al.* 2009). There are real opportunities in many mixed systems for similar efficiency gains even without moving fully to industrial style production systems (McDermott *et al*. 2010; Tarawali *et al*. 2011; FAO 2011a; 2012b) especially for ruminant production in agrarian economies. There are also opportunities to improve efficiencies in all livestock production systems, given the wide range in the current values (de Vries and de Boer 2009). Developing country livestock systems, especially those on a strong growth trajectory, also present significant greenhouse gas mitigation potential and opportunities for carbon offsets. For fragile growth trajectories, carbon sequestration from rangelands and the associated co-benefits can be explored (see below).

Livestock systems are significantly impacted by climate change and sound adaptation strategies are required. This is especially critical in the grassland systems which are often undergoing fragile growth and where some of the world's poorest people rely entirely on livestock for their livelihoods. Recent crises in the Horn of Africa and Sahel bear witness to this and have resulted in major humanitarian and food security disasters. In many such cases, livestock are the only asset remaining on which to rebuild and attention needs to be paid to insuring the asset and mitigating loss. Innovative arrangements, such as weather-index based livestock insurance schemes, which are triggered by remotely sensed thresholds, are showing considerable promise in this regard (Carter and Janzen 2011).

Water scarcity is a result of livestock production

Until recently, livestock and water were considered almost exclusively from the perspective of the impact of livestock

on water pollution (Steinfeld *et al*. 2006). Yet almost one-third of total agricultural water is used by the livestock sector: 840 m^3 annually in grasslands and 1340 m^3 growing feeds; direct consumption for drinking is relatively insignificant in comparison representing 10% of total usage (Herrero *et al.* 2013a).

For mixed crop livestock systems that are on a strong growth trajectory there are significant opportunities to increase productivity of milk and meat per unit of water used through feed, water and animal management strategies (Peden *et al.* 2007). If such approaches are combined they could improve livestock water productivity at least three-fold (Descheemaeker *et al.* 2010a, b). For rangelands there are opportunities to improve water productivity by 45% through better rangeland management practices (Rockstrom *et al.* 2007).

Water use estimates for livestock production has been a hotly contested issue: highly diverse estimates of up to 4.6m^3 (Singh et al. 2004) and a global average of 0.77 m^3 water per litre of milk produced (Chapagain and Hoekstra 2003) and a range of 10 to 100 m^3 water per kg of beef (Descheemaeker *et al*. 2009) suggest there is significant potential for improvement.

Livestock production causes land degradation

Headlines often tell a grim story of land degradation due to livestock: extensive cattle raising in the Amazon accounts for at least 65% of the deforestation and up to 600,000 hectares per annum are reported to be cleared for crop production to produce feed for pigs, poultry and intensive dairy (Herrero *et al.*2011b). However, with rangelands occupying 40% of the Earth's surface, these resources, largely managed by livestock dependent people, are a potentially huge carbon sink similar in magnitude to forests.

Carbon sequestration through rangelands, which is optimum under conditions of moderate livestock grazing (Conant and Paustain 2002), has the potential to sequester up to 8.6 million tonnes of carbon per year in Africa (compared to 1.9 with light grazing and 6.1 with heavy grazing). Supporting such schemes and implementing them in practice, however, is an area that requires new research and development efforts to address the complexities of institutional and certification mechanisms, benefit sharing and co-benefits (Silvestri *et al*. 2012; World Bank 2012). This is an area which could have significant dividend for livestock systems undergoing fragile growth scenarios.

Conclusion

With the global population approaching 10 billion by 2050, the world is understandably concerned about how it will feed itself in the future. Increasingly, the solution to this challenge is being considered in relation to holistic 'food systems', in which producing food is considered in relation to environmental, health and sometimes also equity issues.

Responding to rising food demand and uncertainty of supply and prices in recent years put agriculture firmly back on the development agenda. But it is only very recently that smallholder agriculture has been recognized as part of the food security equation.

The role of livestock is seldom articulated in relation to global food issues, and yet it presents opportunities for important contributions to solutions that relate to food security and sustainable livelihoods, as well as health and environmental dimensions.

Livestock are undoubtedly part of the solutions to feeding the world in 2050, but this will require a nuanced approach that takes cognizance of the different development trajectories of the livestock sector and encompasses solutions that combine a range of biophysical, institutional, market, infrastructure, and policy issues.

In all these situations, better information about the true impacts of livestock and a balanced assessment of the benefits and dis-benefits of the sector will enable the livestock sector's role in global food security to be more appreciated, valued and addressed.

The complexities of the livestock sector, the varied trade-offs and balances demand that research and development efforts to address food security must consider both biophysical and institutional solutions in relation to the potential transition of today's diverse livestock sector.

References

Allen LH (2005) Multiple micronutrients in pregnancy and lactation: An overview. *American Journal of Clinical Nutrition* **81,** 1206S–1212S.

Blümmel M (Ed.) (2010) Special issue on food feed crops. *Animal Nutrition and Feed Technology* **10S**.

Bread for the World Institute (2012) Within reach: Global development goals. 2013 Hunger Report. (Bread for the World, Washington DC)

Burney JA, Davis SJ, Lobell DB (2010) Greenhouse Gas Mitigation by Agricultural Intensification. *Proceedings of the National Academy of Sciences* **107**, 12052–12057.

Capper JL (2011) Replacing rose-tinted spectacles with a high-powered microscope: The historical versus modern carbon footprint of animal agriculture. *Animal Frontiers* **1,** 26–32.

Capper JL, Cady RA, Bauman DE (2009) The environmental impact of dairy production: 1944 compared with 2007. *Journal of Animal Science* **87**, 2160-2167.

Carter MR, Janzen SA (2012) Coping with Drought: Assessing the Impacts of Livestock Insurance in Kenya. I4 Basis Brief no. 14. USAID.

Chapagain A, Hoekstra A (2003) Virtual water trade: a quantification of virtual water flows between nations in relation to international trade of livestock and livestock products. In 'Virtual Water Trade. Proceedings of the International Expert Meeting on Virtual Water Trade' Value of Water Research Report Series 12. (Ed AY Hoekstra.). Delft, The Netherlands

Conant RT, Paustian K (2002) Potential soil carbon sequestration in overgrazed 17 grassland ecosystems. *Global Biogeochemical Cycles* **16**, 1143-1152.

Conway G (2012) One billion hungry: Can we feed the World? (Comstock Publishing Associates UK)

Costales AC, Pica-Ciamarra U, Otte J (2010) Social consequences for mixed crop-livestock production systems in developing countries. In 'Livestock in a changing landscape: Drivers, consequences, and responses'. (Eds H Steinfeld, H Mooney, F Schneider and L Neville) pp. 249-267. (Island Press, Washington, DC)

Cotula L, Vermeulen S, Leonard R, Keeley J (2009) Land grab or development opportunity? Agricultural investment and international land deals in Africa Enabling poor rural people to overcome poverty. FAO, IIED and IFAD.

Descheemaeker K, Amede T, Haileselassie A (2009) Livestock and Water Interactions in Mixed Crop livestock Farming

Systems of sub-Saharan Africa: Interventions for Improved Productivity. Working Paper 133. (International Water Management Institute (IWMI), Colombo, Sri Lanka)

Descheemaeker K, Amede T, Haileslassie A (2010a) Improving water productivity in mixed crop livestock farming systems of sub-Saharan Africa. *Agricultural Water Management* **97**, 579-586.

Descheemaeker K, Amede T, Haileselassie A, Bossio D (2010b) Analysis of water productivity gaps and effects of interventions on livestock water productivity in mixed crop livestock systems. *Experimental Agriculture* **47**, 21-38.

Deutsche Welthungerhilfe e. V, International Food Policy Research Institute and Concern Worldwide (2012) The Global Hunger Index. http://dx.doi.org/10.2499 /978089 629 9429

deVries M, de Boer IJM (2009) Comparing environmental impacts of livestock products. A review of life cycle assessments. *Livestock Science* **128**, 1-11.

Duncan A, Tarawali SA, Valbuena D, Descheemaeker K (2013) Integrated crop-livestock systems: a key to sustainable intensification in Africa. International Grassland Congress 2013. (this proceedings).

FAO (2009) The state of food and agriculture: Livestock in the balance. (FAO, Rome)

FAO (2010) Greenhouse gas emissions from the dairy sector. A life cycle assessment. (FAO, Rome)

FAO (2011a) World Livestock 2011 – Livestock in food security. (FAO, Rome)

FAO (2011b) The state of food and agriculture: Women in agriculture—Closing the gender gap for development. (FAO, Rome)

FAO (2012a) The State of Food and Agriculture. Investing in agriculture for a better future. (FAO, Rome)

FAO (2012b) Livestock sector development for poverty reduction: an economic and policy perspective – Livestock's many virtues, by J Otte, A Costales, J Dijkman, U Pica-Ciamarra, T Robinson, V Ahuja, C Ly and D Roland-Holst. (FAO, Rome)

Grace D (2012) The deadly gifts of livestock. *Agriculture for Development* **17**, 14-16.

Hazell P, Poulton C, Wiggins S, Dorward A (2007) The Future of Small Farms for Poverty Reduction and Growth. 2020 Discussion Paper No. 42. (International Food Policy Research Institute, Washington, D.C)

Herrero M, Thornton PK, Notenbaert A, Msangi S, Wood S, Kruska R, Dixon J, Bossio D, van de Steeg J, Freeman HA, Li X, Parthasarathy Rao P (2009) Drivers of change in crop–livestock systems and their impacts on agro-ecosystems services and human well-being to 2030. (ILRI, Nairobi, Kenya)

Herrero M, Gerber P, Vellinga T, Garnett T, Leip A, Opio C, Westhoek HJ, Thornton PK, Olesen J, Hutchings N, Montgomery H, Soussanai J-F, Steinfeld H, McAllister TA (2011a) Livestock and greenhouse gas emissions: The importance of getting the numbers right. *Animal Feed Science and Technology* **166– 167,** 779– 782.

Herrero M, MacMillan S, Johnson N, Ericksen P, Duncan A, Grace D, Thornton PK (2011b) Improving Food Production from Livestock. Chapter 14 in State of the World 2011. (WorldWatch, US)

Herrero M, Grace D, Njuki J, Johnson N, Rufino M (2013a) The roles of livestock in developing countries. *Animal* **7s1**, 3-18.

Herrero M, Conant RT, Havlik P, Hristov AN, Smith P, Gerber P, Gill M, Butterbach-Bahl K, Henderson B, Thornton PK (2013b) Greenhouse gas mitigation potentials in the livestock sector. *Nature* (accepted).

IAASTD (2009) International Assessment of Agricultural Knowledge, Science, and Technology for Development Global Report. (Island Press, Washington, DC)

ILRI (2007) Learning the lessons of Rift Valley fever: improved detection and mitigation of outbreaks. Participatory assessment of Rift Valley fever surveillance and rapid response activities. USAID Office for Foreign Disaster Assistance (OFDA), International Livestock Research Institute (ILRI) and Government of Kenya Ministry of Livestock and Fisheries Development, Department of Veterinary Services.

ILRI (2010) Demand for pork by Vietnamese consumers: Implications for pro-poor livestock policy and development agenda in Vietnam. Research Brief 1. (ILRI, Nairobi, Kenya)

ILRI (2013) Better lives through livestock—Livestock research for food security and poverty reduction. ILRI strategy 2013–2022. (ILRI, Nairobi, Kenya)

Jabbar MA, Baker D, Fadiga ML (Eds) (2010) Demand for livestock products in developing countries with a focus on quality and safety attributes: Evidence from case studies. Research Report 24. (ILRI, Nairobi, Kenya)

Jones BA, Grace D, Kock R, Alonso S, Rushton J, Said M, McKeever D, Mutua F, Young J, McDermott J, Pfeiffer D (2013) How do agricultural intensification and environmental change affect zoonoses with a wildlife-livestock interface? A systematic review. *Proceedings of the National Academy of Sciences* (in press).

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

McDermott J, Staal SJ, Freeman HA, Herrero M, van de Steeg J (2010) Sustaining intensification in smallholder livestock systems in the tropics. *Livestock Science* **130**, 95-109.

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

The Montpellier Panel (2012) Growth with Resilience: Opportunities in African Agriculture. (Agriculture for Impact, London)

Msangi S, Rosegrant MW (2011) Feeding the future's changing diets. Implications for agriculture markets, nutrition and policy. 2020 Conference: Leveraging Agriculture for Improving Nutrition and Health. Conference Paper 3. (IFPRI, Washington DC)

Neumann C, Harris DM, Rogers LM (2002) Contribution of animal source foods in improving diet quality and function in children in the developing world. *Nutrition Research* **22**, 193–220.

Peden D, Tadesse G, Misra A (2007) Water and livestock for human development. In 'Water for Food, Water for Life: A Comprehensive Assessment of Water Management in Agriculture'. (Ed D Molden) pp 485-514, (Earthscan, London, UK and International Water Management Institute, Colombo, Sri Lanka)

Pretty J, Toulmin C, Williams S (2011) Sustainable intensification: increasing productivity in African food and agriculture systems. *International Journal of Agricultural Sustainability* **9**, 5-24.

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

Rockstrom J, Lannderstad M, 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.

Rulli MC, Saviori A, D'Odorico P (2013) Global land and water grabbing. *Proceedings of the National Academy of Sciences* **110**, 892-897.

Sadler K, Mitchard E, Abdi A, Shiferaw Y, Bekele G, Catley A (2012) Milk matters: The impact of dry season livestock

support on milk supply and child nutrition in Somali Region, Ethiopia. (Feinstein International Center, Tufts University, and Save the Children Addis Ababa, Ethiopia)

Silvestri S, Osano P, de Leeuw J, Herrero M, Ericksen P, Kariuki J, Njuki J, Bedelian C, Notenbaert A (2012) Greening livestock: Assessing the potential of payment for environmental services in livestock inclusive agricultural production systems in developing countries. (ILRI, Nairobi, Kenya)

Singh O, Sharma A, Shing R, Shah T (2004) Virtual water trade in dairy economy. Irrigation water productivity in Gujarat. *Economical and Political Weekly* **39**, 3492-3497.

Smith JW, Sones K, Grace D, MacMillan S, Tarawali SA, Herrero M (2012) Beyond milk, meat and eggs: Livestock's role in food and nutrition security. *Animal Frontiers* **3**, 6-13.

Steinfeld H, Gerber P, Wassenaar T, Castel V, Rosales M, de Haan C (2006) Livestock's long shadow: Environmental issues and options. (FAO, Rome)

Steinfeld H, Mooney H, Schneider F, Neville L (2010) Livestock in a changing landscape: Drivers, consequences, and responses. (Island Press, Washington, DC)

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

Thornton PK, Herrero M (2010) The potential for reduced methane and carbon dioxide emissions from livestock and pasture management in the tropics. *Proceedings of the National Academy of Sciences* **107**, 19667-19672.

UNICEF (2008) State of the world's children 2009: Maternal and newborn health. (UNICEF, New York)

Valbuena D, Erenstein O, Homann-Kee Tui S, Abdoulaye T, Classens L, Duncan AJ, Gerard B, Rufino MC, Teufel N, van Rooyen A, van Wijk M (2012) Conservation agriculture in mixed crop–livestock systems: Scoping crop residue trade-offs in sub-Saharan Africa and South Asia. *Field Crops Research* **132**,175–184.

Westhoek H, Rood T, van den Berg M, Janse J, Nijdam D, Reudink M, Stehfest E (2011) The protein puzzle: The consumption and production of meat, dairy and fish in the European Union. (PBL Netherlands Environmental Assessment Agency, The Hague)

Wiggins S, Kirsten J, Llambi L (2010) The future of small farms. *World Development* **38,** 1453-1526.

World Bank (2012) Carbon sequestration in agricultural soils. Economic and sector work report no. 67395-GLB. (World Bank, Washington DC)

World Economic Forum (2013) Achieving the New Vision for Agriculture: New Models for Action

A report by the World Economic Forum's New Vision for Agriculture initiative. Prepared in collaboration with McKinsey & Company. (World Economic Forum, Geneva, Switzerland)

Young VR, Pellett PL (1994) Plant proteins in relation to human protein and amino acid nutrition. *American Journal of Clinical Nutrition* **59**, 1203S–1212S.

Ziraba AK, Fotso JC, Ochako R (2009) Overweight and obesity in urban Africa: A problem of the rich or the poor? *Public Health* **9,** 465.