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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, which also addresses concerns of environment, equity and human health.

Resumen

Para el 2050, la alimentación de la población mundial es el mayor desafío dentro de la agenda global. En los años recientes, ha surgido nuevamente la importancia de la agricultura para hacer frente a este reto, ya que los temas de seguridad alimentaria se consideran de una manera más holística que antes. No obstante, el papel de la ganadería como parte de la solución a menudo no es tomado en cuenta. En este artículo se presenta una breve revisión del reto de la seguridad alimentaria global y se considera el mayor enfoque holístico en los sistemas alimentarios. Se sostiene que la ganadería es relevante para este reto global el cual es complejo, multifacético y dinámico. Sin embargo, para que las soluciones basadas en la producción pecuaria lleguen a ser una realidad, es necesario considerar una serie de verdades parciales y compensaciones recíprocas, asociadas a menudo con la ganadería y la producción de alimentos. El papel de los sistemas de producción animal en el futuro de la seguridad alimentaria se discute en relación con las diferentes posibilidades de desarrollo del sector. Se destacan las oportunidades para asegurar que la contribución de la producción pecuaria a la seguridad alimentaria global sea positiva y que aborde los temas relacionados con el medio ambiente, la equidad y la salud humana.

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 also quality requirements 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. 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 1 Gt (1 billion tonnes) of cereals (IAASTD 2009), 1 Gt of

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dairy and 460 Mt 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 those from 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 be adapted to meet these changes and challenges? The answer to these important questions will depend largely on the policy and institutional framework that nations, regions and the global community develop and the incentives and barriers these create.

All too often livestock are 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 get 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, however, it acknowledges that: livestock production has the potential to do harm to the environment; the sector is a significant source of greenhouse gases; and it can be detrimental to human health. However, 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, while 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 2 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 1 refers to the eradication of poverty and hunger, recognizing that these 2 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, i.e. 'to eliminate poverty and hunger by 2040'. It further recognized 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 (von Grebner et al. 2012) is a measure of progress towards the target of eradicating poverty and hunger. The index combines 3 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 children under 5 years. Globally, although the index has fallen steadily since 1990, the overall score for the World is categorized as 'serious'.

The poorest 2 regions of the World are South Asia and sub-Saharan Africa. The hunger index for South Asia fell markedly between 1990 and 1996, but has failed to maintain this rate of improvement. In sub-Saharan Africa, as a result of improvements since 2000, the index score for 2012 was below that for South Asia. Of the top 10 countries which have made the most improvement in the index since 1990, none is in South Asia and only one, Ghana, is in sub-Saharan Africa; of the 6 countries, whose scores have deteriorated most during this period, 5 are in Africa and another, DR Congo, misses the list only 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 go to bed hungry; 2 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 2 other shifts in emphasis. The first is: '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; in addition, that 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 production must include the sustainable and responsible use of natural resources, food distribution and access, balanced nutrition and access to and management of natural resources (von Grebner et al. 2012). It considers that addressing these aspects demands policy steps to include responsible governance 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 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 and mitigation of climate change and ecosystem services (UN 2008).

A number of studies also recognize that food security in the future needs to include managing risk and ensuring reduced vulnerability of 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 by being severely affected when food prices spike. The Montpellier Panel (2012) stresses the need for agricultural growth (especially in Africa) to be underpinned by resilient markets, agriculture and people.

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 2012) 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. Likewise, 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 Mha of land (and the associated water) has been allocated in this way, with 90% of this 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 misconception 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 season 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 which time frame agricultural systems will evolve in relation to this. Today, a considerable amount of food is produced by smallholders; 500 million smallholders support 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, multidimensional 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 occupy less than 2 ha; in sub-Saharan Africa smallholders contribute more than 80% of livestock production; and globally farms with a few ruminants, such as 2 cattle and half-a-dozen sheep or goats, i.e. 2 tropical livestock units (TLU), and 2 ha 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 (Otte et al. 2012).

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 rely mostly on food that is not available to people (grass, fodder, residues and wastes).

Feeding the World – are livestock part of the solution?

While 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, come 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 most expensive 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, but also they are often a vehicle for people to transmit pathogens present in the environment or shed. While foods derived from animals 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 situations 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 scales and quality of production, marketing and consumption of livestock commodities. As with all aspects of food production, there is a need to consider the diversity of livestock production systems and scales 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.

With the objective to position better research and development efforts in order to encompass the diversity of livestock systems, 3 potential livestock growth scenarios have been identified recently, which capture the dynamics of the sector better than the conventional pastoral, mixed crop-livestock and industrial categorization. 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 (AU-IBAR et al. 2012), 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-dependent societies, small-scale mixed farmers and city populations.

The 3 trajectories are:

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 lowly

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 systems with higher potential and good market access.

These rapidly changing scenarios provide real opportunities to apply approaches such as sustainable intensification (Pretty et al. 2011), which describes 7 key components to sustainable intensification summarized 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 for feeding 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, 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 limited attention paid to the sector is puzzling. This might, perhaps, be related to a number of misconceptions. 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 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 impacts on human health, the environment and climate change. Understanding and making appropriate choices amongst trade-offs is essential if the positive attributes are to be realized and the negative ones 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). However, the contribution of livestock to the World's food supply is often under-appreciated. Mixed crop-livestock systems contribute significantly 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, plus traction for land preparation and transport, and generate income that can be used to purchase seeds of improved varieties, fertilizer, labor 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 (Blümmel 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 estimated that 1.3 billion 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 Mt of plant protein are fed to livestock to produce 58 Mt of animal protein (Steinfeld et al. 2006). Feed crops occupy an estimated half a billion hectares of land; including grazing land, livestock account for four-fifths of all agricultural land (Steinfeld et al. 2010).

Extrapolating from current trends, by 2050 an additional 1 Gt of grain will be needed world-wide, about 40% of which will be required for feeding livestock, mostly pigs and chickens (IAASTD 2009).

It is often overlooked that raising fewer livestock and consuming less animal products is unlikely to make more grain available for human consumption; for the billion undernourished people in the World, releasing grain by not feeding it 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, and found little, if any, positive results. Importantly, it is not the livestock of the poor, which compete 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; 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 eat. 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 that such grassland-based systems provide 12% of the milk and 9% of the meat annually. Differences in these estimates 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. 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 is 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 the use of crop residues for animal feed, maintaining 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).

There are significant opportunities to improve animal productivity without introducing high grain-based diets (Tarawali et al. 2011), thereby achieving win-win efficiency and greenhouse gas mitigation, especially in those systems that have the potential for strong growth.

Animal-source foods and human health

Poor people don't care what they eat

It is true that poor consumers are sensitive to prices, 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 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 3 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. However, it is often not appreciated how important foods derived from animals 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 micronutrients, 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 undernutrition effectively, 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, from the perspectives 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 problem of obesity in poor countries, but 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 paramount.

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 USA and noted that, compared with 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 characterized by significant increases in average herd and farm size, a phenomenon not yet observed to a significant 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 livestock products are sold in informal markets (Costales et al. 2010). While smallholders may continue to be competitive in the dairy sector, a more rapid switch to industrial systems is likely for pig and poultry production (Tarawali et al. 2011).

Standards of disease management and biosecurity are also considered 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 antimicrobials and thus emergence of antibiotic resistance. It may also lead to reduced levels of genetic diversity, which may promote evolution of pathogens 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 and 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, the livestock sector provides the greatest opportunities for mitigating the greenhouse gas emissions, 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.

Emissions per unit of production of milk at the farm gate in sub-Saharan Africa are more than twice the global average (FAO 2010) and similar inefficiencies are reported for beef (Capper 2011). In the USA dairy sector, a 4-fold increase in the efficiency of production, attributed to better feeding, breeding and animal health, took place over a 6-decade period (Capper et al. 2009). Real opportunities exist 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 2012).

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: feed from cropland uses 37% of the water used for crop production and biomass grazed by livestock represents 32% of the evapotranspiration from grazed lands; direct consumption for drinking is relatively insignificant, 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 3-fold (Descheemaeker et al. 2010a; 2010b). 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 have been a hotly contested issue; highly diverse estimates of up to 4.6 m^3 (Singh et al. 2004) and a global average of 0.77 m^3 water per liter of milk produced (Chapagain and Hoekstra 2003) and a range of 10–100 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 Paustian 2002), has the potential to sequester up to 8.6 Mt of carbon per year in Africa (compared with 1.9 with light grazing and 6.1 with heavy grazing). Supporting such schemes and implementing them in practice, however, are areas that require new research and development efforts to address the complexities of institutional and certification mechanisms, benefit sharing and co-benefits (Silvestri et al. 2012; The World Bank 2012). These areas could have significant dividends for livestock systems undergoing fragile growth.

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 equity issues.

Responding to rising food demand and uncertainty of supply and prices in recent years put agriculture firmly back on the development agenda. Yet, 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, plus 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.

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