Energy and protein metabolism and nutrition in sustainable animal production

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edited by:
James W. Oltjen
Ermias Kebreab
Hélène Lapierre

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EAAP – European Federation of Animal Science

The University of California

Department of Animal Science

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4th International Symposium on Energy and Protein Metabolism and Nutrition

Sacramento, California, USA

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The 4th EAAP International Symposium on Energy and Protein Metabolism and Nutrition was organized in Sacramento, California (USA) on 9-12 September 2013. A special symposium as tribute to the late Professor R. Lee Baldwin was also organized on 12 September 2013.

The symposium was chaired by:
- James Oltjen

The scientific programme of the symposium was co-chaired by:
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- Hélène Lapierre

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- Phil Miller
- Gordon Murdoch
- Daniel Ouellet (Editorial)
- Luis Tedeschi

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Preface

The 4th EAAP International Symposium on Energy and Protein Metabolism and Nutrition (ISEP) was held at the Sheraton Grand Hotel in Sacramento, California, USA from September 9th to September 12th, 2013. This followed the 3rd ISEP in Parma (2010), the 2nd ISEP in Vichy (2007), and the 1st ISEP in Rostock-Warneműnde (2003). These follow the previous Energy Symposium and Protein Symposium which were held separately, all under the auspices of the European Association of Animal Production and the Commission on Animal Nutrition; it is also the first time the symposium had been held in North America.

As world population increases, demand for food, particularly animal products, is expected to grow substantially. Because of limited area for expansion of animal agriculture and increased consumer concern for the environmental impact of animal production, gains in animal efficiency will have to be part of the solution. The 4th International Symposium on Energy and Protein Metabolism and Nutrition addressed key issues of how energy and protein are utilized and interact in farm animals from the molecular to the whole animal and even to the herd or group level of organization. Key issues addressed include energy/protein interactions, methodology such as *in vitro* and *in vivo* techniques, regulation including pre-natal programming and endocrine regulation, modeling/systems biology, products and health of animals, tissue metabolism, and environmental sustainability in agriculture. ISEP also included a tribute to the late Professor R. Lee Baldwin of the University of California, Davis, a leader in the field.

The 4th Symposium began with the premise that improved understanding of animal energetics and protein metabolism will be required for sustainable animal production. Over 200 participants, from 27 countries, made theatre and poster presentations; two-page abstracts for contributed papers and full length papers by invited speakers are contained herein.

Attendees at the ISEP heard significant new research, with invited speakers and oral and poster communications by participants. The Symposium combined fundamental research with applied research and practical applications. Because energy and protein metabolism and nutrition cannot be addressed separately, a better and deeper understanding of nutrient metabolism and nutrition can be achieved only by integrating the outcomes of scientists conducting research on different aspects.

Participants and accompanying persons were housed in one hotel and shared common meals in an effort to increase networking possibilities and stimulate interactions; they were also treated to a showcase of California agriculture and hospitality.

We thank all those who helped make this Symposium successful, especially the sponsors and the International, North American, and Local Organizing Committees. Finally, we would also like to thank all the participants for making possible a meeting with a great deal of interaction; we hope this meeting has given us more tools to address questions that need to be answered for a real sustainable agriculture scientifically.

James W. Oltjen

Keynotes

Feeding the planet: key challenges

M. Herrero
Commonwealth Scientific and Industrial Research Organisation, 306 Carmody Road, St Lucia 4067, QLD, Australia; m.herrero@cgiar.org

Abstract

The notion of feeding 9 billion people sustainably in the next forty years presents considerable challenges. Population growth and human dietary changes remain the key drivers of the large increases in future food demand. While the world food system can respond to meet this demand, there are challenges to ensure this happens sustainably, equitably and within our conceived limits of a safe environmental space. This paper discusses the key trends in food production and consumption, and the key challenges for feeding the planet. Especial attention is given to livestock, a key part of the puzzle for ensuring sustainable nutritional security and environmental sustainability for future generations.

Introduction

The global food system is experiencing profound changes as a result of anthropogenic pressures. The ever-increasing human population (to reach 9 billion by 2050) together with changes in consumption patterns (i.e. increasing demand for livestock products) caused by urbanization, increasing incomes, and nutritional and environmental concerns, are shaping what we eat, who eats, and how much, more than ever. The double burden of nutrition (overconsumption and under-nutrition) is defining research agendas, policies and conceptions about food in different ways around the world.

Against this background is a global food system that will have to improve its resource use efficiency and environmental performance significantly in order to ensure the sustainability of global food production and consumption within established planetary boundaries of greenhouse gas emissions, and water and nutrient use amongst others.

Livestock, the largest land use sector on Earth is an important part of this puzzle and many solutions to the challenges facing how to feed the world sustainably lie in how we manage this sector. This brief paper aims to discuss some of the key ways in which we could increase the sustainability of the world food system, and some of the challenges to overcome.

Key challenges: the future demand for food

Table 1 shows the FAO projections of global food consumption to 2050 (Alexandratos and Bruinsma, 2012). The main conclusions from these projections, as well as others (ie. IAASTD 2009), is that a shift to diets with more animal products and fats, is likely to happen, mostly in the developing world as a result of increased incomes and urbanization. While the consumption per capita of cereals is likely to stabilize, population growth will increase the total quantities of both meat (almost doubling) and cereals (50%) needed to feed the world in 2050.

The supply response of the global agriculture and livestock sectors is likely to be able to accommodate these demand increases (Alexandratos and Bruinsma, 2012). All recent projections have important common features: (1) Local production under current yield trends in many parts of the world, like Sub-Saharan Africa (SSA) and parts of Asia, will not be able to meet local food demand. Hence increases in food trade are projected to increase in the future in some parts of the world. This is a key aspect of balancing the food supply and demand equation. (2) While increases in the yields of crops and livestock have occurred in most regions of the world (apart from SSA), all projections show a variable increase in cropland and grassland expansion to meet demand (Smith *et al.*, 2010)

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Table 1. Projections of global demand for food to 2050 (Alexandratos and Bruinsma, 2012).

	2005/2007	2050
Population (millions)	6,584	9,306
Cereals for food (kg per capita)	158	160
Cereals for all uses (kg per capita)	314	330
Meat consumption (kg per capita)	38.7	49.4
Oil crops for food (kg per capita)	12.1	16.2
Oil crops for all uses (kg per capita)	21.9	30.5
Meat production (million tonnes)	258	455
Cereal yields, rice paddy (t/ha)	3.32	4.30
Arable land area (million ha)	1,592	1,661

and (3) also an increase in animal numbers, but with monogastric production (pork and poultry) growing at faster rates than ruminants (meat especially, and less so for milk). (4) These factors lead to net increases in greenhouse gas emissions (GHG) from the agricultural and livestock sectors, but a diminishing trend in the emissions intensities across commodities (GHG per unit of product). (5) projections of water use show increased pressure on total fresh water resources, notably on blue water (irrigation), and moderate increases in the efficiency of green water use (CA, 2007). Other studies have also demonstrated large quantities of reactive nitrogen used and a potential depletion of phosphorus stocks in the future (Bouwman *et al.*, 2011). Hence, food production can be attained under current productivity and demand trends, but not necessarily making inroads in the improvement of our environmental goals.

Several authors (Foley *et al.*, 2011; Garnett and Godfray, 2011; Godfray *et al.*, 2010; Herrero *et al.*, 2010) have suggested different mechanisms for improving the sustainability of the world food system. The three most often mentioned are:

1. Increasing productivity (managing the supply side): Increasing agricultural productivity and overall food production have been the pillar for designing strategies for feeding the world since the industrial revolution. Notable gains have been made in many parts of the world (developed countries and Latin America and Asia). There is significant ongoing research on how to sustainably intensify global food production, how to bridge yield gaps of crops and livestock and how to improve value chains so that both producers and consumers benefit from potential yield increases, while using less, the same, or slightly more inputs.
2. Reducing waste in food value chains. This subject has received attention recently (Godfray *et al.*, 2010), and it has been estimated that food waste can account for up to 40% of losses relative to food production. Figure 1 (Godfray *et al.*, 2010) shows that in the developing world these losses occur mostly due to post-harvest activities like deficient harvesting and storage methods, pests, export regulations and others. In the developed world this occurs mostly at the post-consumption stage, due to poor management of product sell-out dates in the value chain and direct food disposal by consumers (i.e. discarding food from fridges).
3. Consuming more sustainable diets (managing the demand for food): There is evidence that modifying what we eat could have significant impacts on the use of resources like land and water, it could reduce GHG emissions and it could have important health and nutritional benefits. A lot of emphasis has been put in the potential benefits of reducing red meat consumption and the promotion of 'healthy' diets (Stehfest *et al.*, 2009) (Table 2). These studies have shown that reductions in livestock consumption could lead to reduced land use change, directly from less land clearing for raising animals or for producing feed crops. These land sparing gains, in turn lead to lower GHG emissions in general.

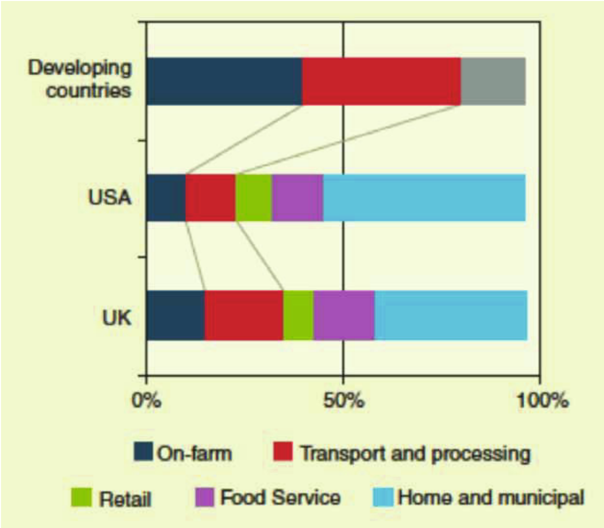

Figure 1. Make up of total food waste in developed and developing countries (Godfray et al.*, 2010).*

This is a significant finding. However, this space has not been explored sufficiently to provide suitable, practical, regional/country guidance for consumers and for policy makers to effect the necessary changes in local food systems, and to modify consumer behavior. At the global level, this concept has only been studied superficially, and without considering important dimensions such as dietary diversity and cultural preferences extending beyond measures of kilocalorie consumption, and what would be the social and economic impacts of reducing the size of the livestock sector. These additional dimensions are essential for understanding the biological and socio-economic implications of diet sustainability on the global food system. We need to go beyond simplistic recommendations like 'stop eating meat' to make this area of research useful, and provide alternatives and practical guidelines for achieving these kinds of gains. This is of particular importance for the developing world, where livestock product demand projections demonstrate that even with significant consumption growth, consumption per capita will remain significantly lower than in the developed world (IAASTD, 2009).

The implementation of these strategies is not straightforward. There are many challenges and trade-offs and they are complex because there are competing economic, social and environmental claims to their implementation. Additionally, human nature, the single biggest ingredient in this mix, plays a key role in defining our choices. These choices are not always in favor of long-term sustainability. More often the attainment of shorter term gains prevails, especially in a world of

Table 2. Land use emissions in 2000 and 2050 for the reference scenario and four variants of dietary composition (Stehfest et al.*, 2009).*

	GtCeq
2000	3.0
2000 – reference	3.3
2050 – no red meat	1.7
2050 – no meat	1.5
2050 – no animal products	1.1
2050 – healthy diet	2.1

increasing resource limitations and with significant pressures on livelihoods. Some of these key challenges are explained below.

Closing yield gaps of crops and livestock and increasing adoption rates of key technologies in the developing world

Closing yield gaps, mainly of crops, has been the strategy of choice for increasing food production worldwide (Foley *et al.*, 2010; Van Ittersum *et al.*, 2013). Significant productivity gains have been observed in the last 40 years, however in many smallholder systems in the world, low productivity still prevails (Tittonell and Giller, 2013). In terms of livestock yield gaps, there has been continuous productivity increases in the developed world or in parts of the developing world where market orientation has been a thrust for the livestock sector. A notable example, presented by Capper *et al.* (2009) demonstrates that milk yields per animal in the US have increased several-fold since the 1940s, while at the same time reducing the size of the dairy herd considerably in the process. However, we still lack solid global information on livestock yield gaps to inform the potential productivity gains for different parts of the world. This is an area that requires significant research, especially for guiding research in the developing world, where most of the potential for increasing yields lies.

In livestock systems, attaining yield gaps has essential pre-requisites. The availability of inputs (high quality feeds, fertilizers, etc.), services (veterinarians, extension) and in many cases, the development of markets and their associated value chains need to be developed (McDermott *et al.*, 2010), as these are key incentives for systems to intensify (Herrero *et al.*, 2010; McDermott *et al.*, 2012). Currently, adoption of better feeding practices, like improved forages, have shown low adoption rates. For example Thornton and Herrero (2010) found adoption rates of dual purpose crops, agroforestry practices and improved pastures in the order of 15-25% of farmers in selected developing regions, over a 10-15 year horizon. Increasing adoption rates will require significant public and private investment and institutional change to be able to not only increase the % of farmer adopting, but also for reducing the adoption lag times that are often large.

Achieving sustainable intensification without its potentially perverse incentives

The concept of sustainable intensification sounds to many as a win/win strategy to increase resource use efficiencies. From a livestock perspective, most well managed intensification practices in the past have led also to improved systems profitability (i.e. pasture intensification and supplementation in the tropics has significantly improved milk and meat production). As a result, farmers have often increased the size of the operation (more animals, more land use changes) in order to increase even further the economic returns. This growth in turn has led to increased environmental problems (more deforestation, increased GHG emissions, land degradation). A critical challenge ahead is how to regulate intensification so that it is truly sustainable and operates within limits of production growth, protects biodiversity and other ecosystems services, and attains net or near net reductions in the use of resources. This is of particular importance, as having less animals, but of higher productivity, seems to be essential to maximize the environmental benefits (i.e. reductions in GHG emissions and land use) of productivity growth in livestock systems (Thornton and Herrero, 2010).

What we eat matters: how far can we go towards modifying human diets in different parts of the world?

The debate on human diets is dominated by the concerns of the developed world and the middle classes of middle income countries, on the negative health impacts of livestock product over-consumption (McMichael *et al.*, 2007), and by the global integrated assessment community interested in reducing GHG emissions from the agriculture, food and land use sectors (Smith *et al.* 2013; Stehfest *et al.*, 2009). At the same time, the discourse in the developing world is changing towards the recognition that achieving nutritional security might be a more important target than just promoting a higher kilocalorie consumption (Herrero *et al.*, 2013). According to these authors, this does not mean that we should take as given the projected trajectories of animal consumption proposed by the so called 'livestock revolution'. They are not inevitable. Part of our responsibility is to challenge these future trajectories, and ensure that we identify consumption levels for different parts of the world that will achieve the best compromise between a culturally-appropriate, healthy diet that includes livestock products (or not), economic growth, livelihoods and livestock's impacts on the environment. The other part of the agenda is ensuring that policies geared towards the promotion of healthy sustainable diets occur throughout the food systems (from the regulatory bodies, the food industry, all the way to the different value chain actors.

Structural change and competitiveness in the livestock sector

Large parts of the food systems of the developing world have as a starting point the smallholder mixed crop-livestock farmer or the vulnerable pastoralist. Some of these systems produce a significant amount of food, mostly for local consumption, they have significant, exploitable, yield gaps in crops and livestock, and in many cases they have low opportunity costs of labor. If livestock is to be used as an engine for poverty reduction, it is essential that these producers become market-orientated. The degree of competitiveness of smallholders against imports from countries that can produce vast amounts of animal products, at lower production costs, will be a crucial factor to determine the success of many men and women livestock farmers in the developing world, especially as the volume of traded livestock products increases due to trade liberalization. Formal and informal markets will need to ensure the supply of cheaper, locally produced, safe livestock products to adequately compete. This implies a significant reduction in transaction costs for the provision of inputs, increased resource use efficiencies, and very responsive, innovative and supporting institutions for the livestock sector in developing countries (FAO, 2009). Hence investment in developing efficient value chains (including market development, service provision, adequate institutional support, etc.) should be high in the development agenda, to create incentives for smallholders to integrate in the market economy, formal or informal.

Recently land consolidation has occurred in many parts of Africa, as foreign investors buy large blocks of land for developing them into large farms. Advocates of large scale farming argue in favor of the higher efficiencies of resource use often found in these systems and how simple it is to disseminate technology and effect technological change. However, we lack comprehensive information on the impacts of different farming avenues and their future evolutionary pathways on water cycles, biodiversity, social aspects (nutrition, incomes, employment), coping with production risks (i.e. climate variability and change, commodity prices) and others.

A thriving environmentally-responsible, diversified, commercial smallholder sector, that helps feed the world and lifts people out of poverty; together with a large scale efficient livestock sector that efficiently produces food while generating enough employment for rural people should co-exist. The balance between these ways of farming is likely to be different in different regions of the world, but understanding where the balance should lie for achieving socially and environmentally goals is still the question that merits significant research.

The success of paying for environmental services (PES)

PES schemes as an income diversification strategy, for mitigating climate change or for protecting important regional or global goods that regulate essential biogeochemical cycles have received a lot of attention recently. However, not many successful examples exist with smallholder livestock producers or pastoralists (Herrero *et al.*, 2013). Proofs of concept that test how these schemes could operate in very fragmented systems, with multiple users of the land or in communal pastoral areas are necessary. Research on fair, equitable and robust monitoring and evaluation frameworks and mechanisms for effecting payments schemes that work under these conditions is necessary. The promise of PES schemes as a means of deliver the income diversification for the poor, and natural resource protection necessary to produce food while protecting the world's ecosystems is yet to be seen on a large scale.

Institutional and market mechanisms for reaching smallholders

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

Animal health and food safety: regulation and surveillance in an era of more animals, higher volumes of food trade and more diseases

Security of animal source foods, health threats to animal assets, and food safety are inextricably linked. Animal disease threatens livelihoods and economies. For intensive livestock farmers, animal health costs while a small part of overall farm enterprise costs are a large part of avoidable costs, and hence a leverage point for increasing productivity. For poor livestock-keepers, animal health typically represents one of the largest single costs and epidemic animal disease one of the biggest and most feared risks to livestock-keeping.

Animal disease is also the main obstacle to trade in animals and animal products. Despite recent attempts at liberalization, sanitary and phytosanitary regulations still allow importing countries to take a precautionary 'if in doubt, keep it out' approach. This denies people-poor but livestock-rich countries an opportunity to trade their way out of poverty while imposing unpredictable shocks on all countries for which livestock trade is important (for example the Rift Valley Fever pandemic has periodically interrupted the lucrative trade in live sheep and goats from the horn of Africa to the Arabian Peninsula).

We are living in an era of unprecedented ecosystem change and the current upsurge in emerging disease (75% of which are zoonotic) is predictable. An ecosystems perspective sees farming and natural systems as containing pools of pathogens with circulate among hosts, vectors and the environment. In systems which are stable, connected and diversified, hosts and pathogen co-evolution favors lowered pathogenicity and less disease. However, anthropogenic incursion into ecosystems and ecosystem alteration allows pathogens to encounter new hosts and new diseases to emerge. An example of ecosystem provision of disease regulation services is the flare-ups of human sleeping sickness seen in West Africa after African swine fever killed village pigs leading the tsetse vector of sleeping sickness to shift closer to houses and bite more people.

Food safety is increasingly viewed as inseparable from food security and while intensive agriculture can produce cheap products it also introduces new health risks for both animals and people. This is of essential importance to consider how far we go in intensifying livestock production, and the food system in general. In particular, intensification selects pathogens hard to detect in animal populations or (such as *Campylobacter* spp. in poultry or diarrhoeagenic *Escherichia coli* in cattle) or survive conventional treatment (such as antibiotic resistance). The wide geographic scale and large volume of consolidated food distribution systems means that food-borne diseases can spread rapidly and affect large numbers of people greatly removed from the point of production.

Can the food system adapt to climate change and mitigate GHG emissions at a fast enough pace?

Climate change is likely to cause severe impacts on livestock systems and on poor vulnerable producers. According to Herrero *et al.* (2013), the capacity and speed of adaptation of smallholders will play and important role in defining the contribution of livestock to livelihoods under climate change. At the same time, in a low carbon economy, it will be essential that the sector mitigates GHG effectively in relation to other sectors. Demonstrating that these options are real with tangible examples is essential to generate the evidence for increasing the investments in climate change adaptation and mitigation for the livestock sector. This becomes more imperative as the global food system prepares to become part of the climate change negotiations.

Conclusions

Feeding 9 billion people is a formidable but attainable task. Doing it sustainably will depend on several things, including our capacity to reach more equitable and healthy levels of consumption, our ability to invest in key food production systems of the world, on maintaining well regulated and economically viable production systems, and on achieving a balance between environmental and social goals.

The livestock sector, the largest land user on Earth, holds a large stake on how to achieve the balance between food production, livelihoods and environmental objectives. A mixture of sustainable intensification, protecting biodiversity and ecosystems services, together with strategies and policies to reduce animal numbers simultaneously, may yield a suitable compromise for achieving these goals.

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Role of animal products in feeding the planet

J.E. Hermansen, M.T. Knudsen and T. Kristensen
Aarhus University, Blichers Allé 20, 8830 Tjele, Denmark; john.hermansen@agrsci.dk

Abstract

Livestock products contribute today by approximately 13% of calories and 28% of protein to the global human population with a huge difference between developed, transition and developing countries. As a consequence of increased consumption per capita and a larger population, it is projected that global meat consumption will increase by 40% in 2030 and 70% in 2050. This has large resource use implications and furthermore the foreseen increased production is to happen within the context of growing scarcity of natural resources and challenges posed by climate change. All this put challenges on the livestock production systems. The major growth in livestock production will take place in intensive industrialized systems very much focused on poultry and pork. It will be important that the feeds can be based on very high yielding new crops that serve both as feed and other purposes in order to reduce land use requirements. This asks for new knowledge and technology that can transform the biomass from the high yielding crops to high quality feed. Also, it will be very important that the energy left in the manure is recovered to substitute fossil energy or energy produced from new biomass. Still, a major part of dairy and beef production will take place in mixed systems, which in some parts of the world are rather inefficient in their use of natural resources. Such systems have to increase efficiency having more of the feed consumed transformed into food instead of feed requirements for animal maintenance. Food from extensive grazing systems will in particular be important to support the nutritional needs of populations in food-insecure areas. The major challenge here is to stop land degradation and restoring the functioning of the grassland, including grassland role to sequester carbon and contribute to other eco-system services.

Introduction

Although the expressions 'feeding the planet' and 'food security' may be perceived as two distinct challenges, it is clear that when considering animal products, they are two sides of the same coin. Animal products clearly have a role in ensuring food security – food security including the dimensions: availability, access, stability and utilization for all human communities. At the same time, however, it is beyond arguing that the ecological costs of animal products typically are much higher than for plant products. While in a typical Northern European diet it is estimated, that animal products covers approximately 25% of the calorie coverage of the diet, the animal products are responsible for more than 60% of the carbon footprint of the typical diet (Hermansen and Olesen, 2009). At the same time it is well recognized that production of feed for livestock is a major driver of land use change (Steinfeld *et al.*, 2006) putting pressure on global biodiversity, and enhance emissions of carbon dioxide to the atmosphere as a consequences of transforming grassland, forest, and savanna to arable land. E.g. UNEP (2011) estimates an increase in soybean production from 6250 square km in 1992 to almost 10.000 square km in 2009. Thus, there are good reasons to focus on the role of animal products in our diets and in relation to the overall environmental concerns of today.

Several developments in addition tend to aggravate these environmental concerns. Thus, besides the growth in global population, during the latest 20 years the overall food production has increased considerable more than the growth in population to ensure a better food supply and this trend is expected to be maintained (UNEP, 2011). Further, the consumption of meat has increased considerable more than the population growth. Figure 1 shows the global dietary change towards higher per capita meat consumption in the period from 1961 to 2009 (FAOSTAT, 2013). The meat consumption per capita in Europe and North America, though flattening out, is still considerably higher than in Asia and Africa. Recently, the meat consumption per person has shown a larger increase in Asia than in

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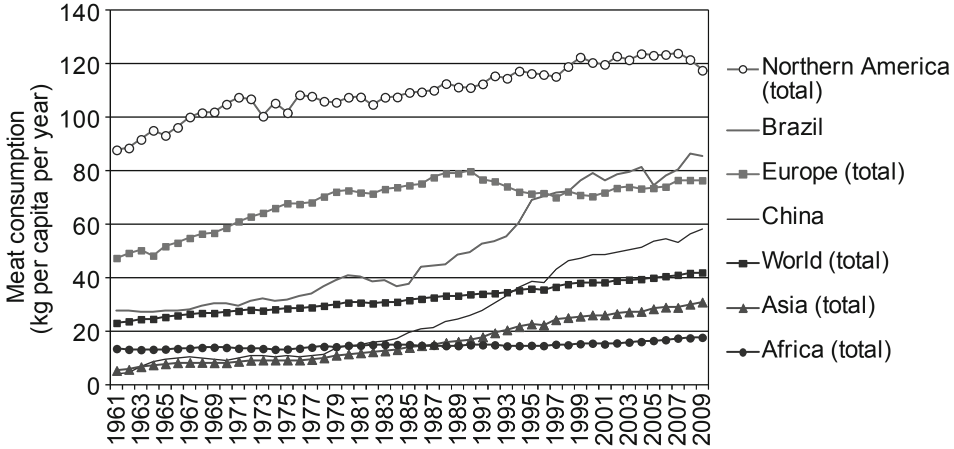

Figure 1. Meat consumption per capita per year on average in the world, in Europe, North America, Asia, Africa and in China and Brazil (FAOSTAT, 2013).

Africa and especially China has shown a remarkable increase during the last 30 years. Projections of future meat consumption predict that China by 2030 will have a per capita meat consumption of approx. 75 kg/person/year and Brazil is predicted to have a per capita meat consumption of almost 90 kg/person/year by 2030 (Msangi and Rosegrant, 2011). Thus, the Internal Food Policy Research Institute (IFPRI) predicts that over the next decades, virtually all growth in demand for meat will come from the transition economies and the developing world (IFPRI, 2012).

At the same time, there is competition for land for biomass production for other purposes than food, in particular energy, which contributes to the overall pressure on land resources. The overall transformation of land to agricultural land ranged between 5-10 million ha per year during the latest 40 years with a particular increase in the latest years.

All this being said, livestock contribute with around 13% of global calories for human consumption, but approximately 28% of protein through provision of meat, milk and eggs (FAO, 2011). In the developed world the numbers are 20 and 48%, respectively. While in the wealthiest part of the world, the protein coverage is easily met, and actually can be met for the major part by animal protein, this is not the case in the poorest part of the world. In these regions lack of calories and protein seems to go hand in hand and here livestock products often play a significant role in ensuring protein as well as other essential nutrient. Even in small amounts livestock products contribute to ensure the proper nutrition of poor families due to the content and bioavailability of important micro-nutrients. In addition, livestock has a role in supporting food security in vulnerable small-holder populations, through delivering stability of food and income. FAO (2012) estimates that close to one billion of the world's poorest people rely on livestock for their livelihoods.

Thus, animal products have a significant role in feeding the planet, but the production is challenged by ecological side-effects which need to be addressed. These side-effects naturally depend on type of animal production system and how they are managed.

Global livestock production and livestock production systems

Livestock are produced in different ways in different parts of the world. Thus, the contribution to food supply and food security as well as the ecological impact of production differs markedly among different livestock products and livestock systems. In Table 1 is shown the global production and the

Table 1. Changes in global livestock production total and per person 1967 to 2007 (after FAO, 2011).

	Production (million tonnes)			Production per person (kg)		
	1967	2007	2007/1967	1967	2007	2007/1967
Pig meat	33.9	100.0	294%	9.8	14.9	152%
Beef and buffalo meat	36.5	65.6	180%	10.6	9.8	93%
Eggs, primary	18.2	64.0	353%	5.3	9.6	183%
Milk, total	381.8	680.7	178%	110.3	102.0	92%
Poultry meat	12.4	88.0	711%	3.6	13.2	369%
Sheep and goat meat	6.5	13.1	202%	1.9	2.0	105%

supply per capita, inclusive the changes in the 40 year period from 1967 to 2007. For all products the production increased by a factor 2-7 in that period, most pronounced for poultry meat but also very pronounced for pigs and eggs. Also per capita production increased except for beef and milk, which were almost unchanged. Thus, from a food supply point of view, poultry- and pig products became much more important during that period. Projections estimate total meat consumption in 2030 of 376 million ton – an increase of 40% from the numbers given in Table 1.

The increasing demand for meat on the world markets will mainly be supplied by Brazil, USA, Oceania and Europe. In an international trade perspective, Brazil is expected to play a major role being a strong net exporter of livestock products (FAO, 2012) and has currently the world's largest export of both beef and chicken meat (FAOSTAT, 2013).

Data on what type of production from different production systems are less updated, but Table 2 gives a good picture of the relative importance of the different productions systems for each product. Grazing systems include both extensive grazing system and intensive grazing systems. The extensive systems are prevailing in dry areas that are marginal for crop production and sparsely populated (Southern Africa, central and western Asia, Australia and western North America) and these systems provides for about 7% of beef production and 12% of sheep and goat meat production. The intensive grazing systems appear in the temperate zones where high quality forages can be grown (most of Europe, North America and South America) and account for about 17% of total beef and sheep and goat meat production.

The mixed farming systems are systems where cropping and livestock production are interlinked activities and where at least 10% of the total value of production comes from non-livestock activities. Most of the milk and beef produced comes from such systems – the rain fed systems prevailing

Table 2. Global livestock production average by production system 2001 to 2003, million ton (after FAO, 2011).

	Grazing	Rainfed mixed	Irrigated mixed	Landless/industrial	Total
Beef	14.6	29.3	12.9	3.9	60.7
Mutton	3.8	4.0	4.0	0.1	11.9
Pork	0.8	12.5	29.1	52.8	95.2
Poultry meat	1.2	8.0	11.7	52.8	73.7
Milk	72	319	204	-	594
Eggs	0.5	5.6	17.1	35.7	58.9

in temperate Europe and North America as well as sub-humid regions of tropical Africa and Latin America, and the irrigated systems prevailing in East and South Asia. It is worth mentioning also, that approximately 50% of the world's cereal production in developing countries comes from mixed systems (Herrero *et al.*, 2010), and as highlighted by Smith *et al.* (2013) by providing manure and – in the case of many smallholder systems – draught power for field operations, thereby supporting the production of this staple food.

The industrial systems are defined as those systems that receive at least 90% of the feed from other enterprises. The major part of poultry are produced in such systems often found near large urban centres, and thus relying on global feed resources, and slightly more than half of pork production takes place in such systems.

Ecological impacts related to livestock production

The livestock production is related to a range of ecological impacts affected by the production system and its efficiency. While not designed for it, the carbon footprint of livestock products can be a good indicator of the overall impact, since often a good correlation exist between the carbon footprint and impacts like eutrophication, fossil energy use and acidification. The reason is that the carbon footprint aggregates the CO_2 emission related to use of fossil energy, the global warming effect of emission of nitrogenous substances from feeds and animals, and the methane emissions related to enteric digestion as well as from manure management, both of which are related to overall feed use. Thus, feed use is a very important aspect when considering the carbon foot print of livestock products (Hermansen and Kristensen, 2011). This is not to say that the carbon foot print is the only relevant indicator, but it helps to get an overview in the broad sense. Furthermore, the carbon footprint is a highly relevant indicator in policy for consideration of combating climate change.

Table 3 shows typical numbers for carbon footprint and land requirements mainly representing relatively productive Western European systems. Red meat clearly has a higher carbon footprint

Table 3. Land requirement (m^2) and carbon footprint (kg CO_2eq) of products, per kg product. Sources for carbon footprint: De Vries and De Boer (2010); Nguyen et al. *(2010, 2011). Importance of iLUC after Audsley* et al. *(2009) (~0.15 kg CO_2/m^2) and Schmidt* et al. *(2012) (0.75 CO_2/m^2)*

	m^2	Carbon footprint without and with accounting for indirect land use changes (iLUC)	
		Without iLUC	To be added with iLUC
Milk	1-2	~1	+0.2-1.5
Egg	4-7	4-5	+0.6-5
Broiler	5-7	2-4	+0.8-5
Pork	6-8	3-5	+0.9-5
Beef	15-45		
– Intensive bulls 12 mo.	~17	~12	+3-13
– Steers 24 mo.	~23	~22	+2-10
'Productive land'	~13		
'Less productive land'	~10		
– Suckler system	~43	~25	+2-10
'Productive land'	~13		
'Non productive land'	~30		

Meat is given per kg weight of carcass.

than ‘industrialized’ poultry and pork. The carbon footprint of the red meat, however, is very must dependent on how the beef is produced – intensive beef from one year old calves being produced with the lowest carbon footprint whereas the suckler system results in the highest carbon footprint of around 27 kg CO_2eq per kg carcass. For reference, Desjardins *et al.* (2012) in a review of carbon footprint of beef found that beef cattle from Canada, US, EU, and Southern Australia had similar carbon footprints on average but with large regional differences, whereas the carbon footprint from cattle grazing under extensive conditions, such as Northern Australia and Brazil, were likely to have a higher carbon footprint.

In the numbers given above no consideration was given to how the production affects land use changes. As already mentioned requirements for feed is a main driver of land use changes, which in turn is a considerable source of CO_2 emissions. Thus, it is estimated that such continues land use changes are responsible for 12% of the world’s yearly CO_2 emissions (World Resources Institute, 2009), because huge stocks of carbon in vegetation and soil are released to the atmosphere. Some attempts have been made to include indirect land use changes in the assessment of the carbon footprint of the land based products. Eg. Audsley *et al.* (2009) argue that all land use results in a pressure on the global (limited) land resources, and consequently that all crops have to carry this burden proportionally. Audsley *et al.* (2009) found that on average every cultivated ha of land resulted in an emission of 1.43 ton of CO_2 as a results of indirect land use changes following that occupation. This corresponds to a load of 140 g CO_2 per occupied m^2 globally. In contrast, Schmidt *et al.* (2012) modeled the marginal effect of including 1 extra ha land for cropping, and found that this effect results in on average 7.83 t CO_2eq per occupied ha (depending on the productivity of the land used) or as a global average 783 g CO_2eq per m^2.

In Table 3 we illustrate the impact on the carbon footprint of including this effect of indirect land use changes using the value from Audsley *et al.* (2009) as the most conservative estimate and the results from Schmidt *et al.* (2012) as the highest estimate. Using the lowest estimate means that the carbon footprint of most products are increased by 25-30%, while using the highest value increase the carbon foot print by more than 100% for the non-grazing based systems, and for the grass based systems the increase is about 50%. The estimates by Schmidt *et al.* (2012) seems close to the values found by Laborde (2011), which are used to evaluate the consequences of increased use of land for energy purpose as recommended for use in the EU. Thus, in a situation where the meat production does expand rapidly globally, it seems most reasonable to include this high value in the overall assessment.

In the assessments given in Table 3, we distinguished between use of productive cropland (including cultivated grassland) and less productive grass land that in fact does not represent a resource for other biomass production purposes. This separation of land use in the different systems is of course not universal, but was specific for the case investigated. However, this distinction has a huge impact on the assessment of the environmental impact as illustrated in Table 3, when indirect land use changes are included.

Like there is a close connection between land use and impacts on global warming, when taking indirect land use changes into account, the same is true when considering impacts on biodiversity. Impacts on biodiversity are challenging to describe satisfactorily. However, some concepts are present to support assessment of land use related impacts on biodiversity. Thus, De Schryver *et al.* (2010) established a framework where the damage to biodiversity was expressed as Potential Disappeared Fraction (PDF) of vascular species compared to a baseline that would be the natural vegetation of the area in question. This characterization factor is unit-less and can be aggregated according to different types of m^2 of land occupied for a given product. Based on UK conditions they established the PDF’s as given in Table 4.

It is clear from Table 4 that while use of land for intensive cultivation has a huge negative impact on biodiversity, use of land for grazing, and in particular grazing on low fertilized land has a much lower negative impact on biodiversity and may even enhance biodiversity compared to a semi natural forest. Thus, such aspects need to be brought into the picture when assessing land use requirement of different livestock products, but as also mentioned the methodology is only in its virgin stage. It is obvious, that a huge reduction in complexity takes place when reducing the biodiversity aspect to the species richness of vascular plants, but on the other hand this indicator clearly catches important elements of biodiversity, since most often there is a correlation between species richness of vascular plants and species richness of insects and mammals (e.g. birds).

While no doubt the industrial livestock systems to a wide extent is based on feed that compete with foods for humans directly or indirectly, and in this way is in a land competition situation and causing land use changes, this is not always the case for other systems. Thus, systems that primarily depend on grazing compete less with resources that could be used for human food, and such systems produce about 12% of global milk and 9% of global meat production (FAO, 2011). Considering the contribution of livestock products to the protein supply, FAO estimated the edible protein output/input ration for different countries. In countries with huge landless production of monogastrics, like USA and Germany, this ration was less than 1 (0.5-0.6), in Brazil and China approximately 1, in India around 4 and in Mongolia and East African countries beyond 10 (FAO, 2011). In a huge country like India this positive protein balance supplied by smallholder livestock systems amount to 3.4 mill ton which can be compared to a protein 'deficit' of livestock in USA and Germany of approximately 8.9 mill ton.

The estimations as mentioned above are related with huge uncertainties, but it is important to have this overall picture in mind when considering the efficiency of livestock production in feeding the planet. Also, as pointed out by Smith *et al.* (2013) in most mixed crop-livestock system used by small holders the main animal feed consists of crop residues. When considering the challenges and prospects in the future, it is important that these features of such systems are not deteriorated, but in fact enhanced.

Table 4. Damage to biodiversity expressed as Potential Disappeared Fraction (PDF) of vascular species for different types of land use (modified after De Schryver et al.*, 2010).*

Type of land use	Median	Min (2.5%)	Max (2.5%)
Baseline (semi-natural forest)	0.00		
Grazing organic infertile grassland	-0.33	-0.56	0.13
Grazing organic fertile grassland	-0.01	-0.18	0.15
Grazing less intensive fertile grassland	0.36	0.14	0.52
Organic arable land	0.36	0.15	0.51
Less intensive arable land	0.44	0.31	0.54
Intensive woodland	0.55	0.44	0.65
Grazing intensive fertile grassland	0.65	0.56	0.72
Intensive tall grassland	0.70	0.61	0.77
Intensive arable land	0.79	0.73	0.83

Challenges and prospects for different livestock production systems

Taking the point of departure in the different livestock systems presented in Table 2, the challenges and opportunities seem to differ substantially as also highlighted in the 'Global Agenda for Action in support of sustainable livestock sector development' (FAO, 2013).

Landless/industrial systems

Looking at the trend in production of different types of livestock, the increased demand for meat globally seems to a wide extent to be covered by pork and poultry products. Today these production systems are by large based on feed that heavily compete with human food (or produced on land which potential could be used for human food). A further expansion is foreseen to have significant negative consequences in relation to land use changes and the connected effects such as global warming and reduction of global biodiversity, and to be in sharp competition with the request for biomass for other purposes. On the other hand given the expected growth in human wealth in the long term in transition and developing countries, this increased demand will no doubt substantiate, and thus this form of livestock production must be foreseen to get a steady more significant role in supplying the growing population's nutritional needs.

In addressing this challenge, the production efficiency needs to be considered further. Looking at the livestock part in itself, substantial improvements have been obtained in reducing feed use per kg of meat produced during the last decades. This is still an important issue, but two issues should be given more focus: the feed stock supply and the waste treatment.

Regarding feed stock, at the moment significant efforts are put how best to use the byproducts from the biofuel industry as feed, like Dried Distillers Grains with Solubles (DDGS), which constitute a significant feed source. This is very important in aiming for lowering the environmental impact of the food produced, but the main feed needed still seems to be cereals and soybean, both crops with a relatively low yield of biomass per unit of land occupied. In temperate areas of the world mixtures of grass and legumes typically can produce 50% or more of both dry biomass and protein per ha compared to cereals, and – if legumes are included – typically with less resource use like fertilizer and pesticides. This biomass it not directly suited for monogastrics, but given the demand for biomass for a range of purposes, the introduction of bio-refinery processes may transform part of this biomass to high quality feed, leaving other parts of the biomass for other high quality products or biofuel. It is a challenge for animal nutritionists to contribute with insights and options for new feeds based on very high yielding crops that are not immediately suitable as feed.

Regarding waste treatment, still in many places the manure nutrients (50-70% of the input) are not efficiently used for plant production but represent an environmental overload. Further, approximately 30% of the energy input is present in the manure. Efficient use of this resource for biogas constitutes a major potential for counteracting the emission of greenhouses gasses of producing livestock products. Thus, we estimated that utilizing manure in the form of slurry from the pig production for biogas potentially reduced the carbon footprint of the pork meat by 30%, partly as a result of energy recovery and partly because less a greenhouse gas emissions were released from the manure (Nguyen *et al.*, 2010). Such an efficient utilization requires a good infra-structure. However, in particular for the systems in consideration with bigger and bigger enterprises, and mainly systems based on liquid manure, this should be possible to establish.

Mixed systems

A very huge part of the global food supply is produced in mixed systems, not least for milk and beef. One can distinguish between large scale mixed systems in temperate areas of the developed world and small scale mixed systems in the developing world. The large scale mixed systems in fact also often rely to a wide extent on feed that compete with human food, and in the development of such system to further fulfill their role in global food supply, the same aspects as described for land less systems should be addressed.

Regarding small scale mixed systems, the main challenge is with the words from the Global Agenda of Action in support of sustainable livestock development (FAO, 2013) to 'Closing the efficiency gap'. It is recognized that a number of technological possibilities or production concepts are yet not fully exploited in such systems. Mixed systems in the developing world is estimated to supply 65% of the beef, 75% of the milk and 55% of the lamb meat (Tarawali *et al.*, 2011) in these regions, where the demand for animal products (per capita and not least in total due to increased population) are expected to increase markedly. Thus, it is very important that the production is better optimized. Taraweli *et al.* (2011) pointed out a number of issues to be dealt with to allow a better optimization of such systems. Main issues are to allow for keeping fewer animals with higher productivity, thus turning more feed energy into production instead of maintenance. This includes better feeding and understanding of importance of small feed supplements to local feed sources, use of better genotypes, and improved multipurpose crops, including legumes. While realizing that such changes are not easy since livestock has other important roles than as direct food in such communities, it is found imperative that intensification has to happen which results in more food produced without compromising use of natural resources.

Grazing systems

Approximately 50% of the land used for livestock production is extensively used grassland for grazing. While the supply in absolute terms to global animal based foods are limited, these systems support nutrition and livelihood of many vulnerable and food insecure people. In fact livestock provide more food security in arid regions than do crop production (Kratli *et al.*, 2013). Due to climatic conditions, it is not likely that the biomass yield from such systems can be increased, except in cases where the land was been partly degraded. It is estimated that at least 20% of such land are degraded due to inappropriate management resulting in lower biomass yield and high erosion. Thus the challenge for the extensive grassland based systems is on the one hand to improve grazing management by adapting the stocking rate to the carrying capacity, and hereby avoid further degradation. In fact better grazing practice may as a results have such areas to contribute significantly to global carbon sequestration (Wilkes *et al.*, 2012).

Conclusion

While the consumption of livestock products seems to have reached a plateau per person in developed countries, it is increasing rapidly in transition and developing countries. As a consequence of increased consumption per capita and a larger population, it is forecasted that global meat consumption will increase considerably. While the livestock sector provides high value food and other social functions, its resource use implications are however large. Livestock uses the major part of the agricultural land through grazing and consumption of feed crops, and plays a major role in emissions related to climate change and reduced biodiversity, which are all major concerns of today.

To overcome the challenges mentioned, it will be very important that the feeds can be based on very high yielding new crops that serve both as feed and other purposes in order to reduce land use requirement, and that animal nutritionist are active in exploring these possibilities. For dairy and beef production taking place in mixed systems, some of which are rather inefficient in their use if natural resources, it is imperative to increase efficiency having more of the feed consumed transformed into food instead of feed requirements for animal maintenance. Also extensive grazing systems need to be adapted to ensure stop of land degradation and enhance the role of grassland to sequester carbon and contribute to other eco-system services.

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