Animal production in a sustainable agriculture

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Abstract   This paper discusses the role of animal production systems in a sustainable society; sustainability problems within animal production systems; and four measures for the improvement of the contribution to societal sustainability from animal production. Substantial potentials for improvements are identified that were not previously known. The methodological basis is multi-criteria multi-level analysis within integrated assessment where elements in Impredicative Loop Analysis are integrated with management tools in Swedish agriculture and forestry developed during thousands of years, during which the well-being of the Swedish society and its economic and military power were functions of the land-use skill. The issue—the sustainability footprint of global animal production—is complex and available data are limited. The Swedish case is used as a starting point for an analysis of international relevance. Data from FAO and OECD support the relevance of extrapolating results from the Swedish case to level. The four measures are (i) decrease the consumption of chicken meat in developed nations with 2.6 kg per capita and year; (ii) develop the capacity of ruminants to produce high-quality food from otherwise marginal agroecosystems; (iii) improve milk production per cow with a factor four on global level; and (iv) increase feeding efficiency in milk production globally would substantially improve the societal contribution in terms of increased food supply and decreased pressure on land. The impact of measures (i), (iii) and (iv) on increased global food security was estimated to in total 1.8 billion people in terms of protein supply and a decreased pressure on agricultural land of 217 million ha, of which 41 relate to tropical forests. The 41 million ha of tropical land are due to a decreased demand on soymeal, where this represents more than a halving of total area now used for the production of soymeal. These impacts are of the character either or. The quality of the measures is as first-time estimates, supporting choices of where to direct further efforts in analysis. Two areas were identified as critical for achieving this potential: Feeding strategies to dairy cows as well as methods commonly used to evaluate the sustainability contribution of animal production needs adjustment, so that they comply with the "laws" of diminishing returns, Liebig's "law" of the minimum

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and Shelford's "law" of tolerance, that is, in agreement with well-known principles for efficient natural resource management and the priorities of UN Millennium Development Goals. If not, global food security is at risk.

Keywords Agroecosystems · Integrative assessment · Animal production · Sustainable animal production · Food security · Climate change

1 Introduction

There is a growing concern regarding the capacity of global terrestrial ecosystems to support humanity given

1. socio-economic trends regarding urbanisation, population, material welfare, change of diets towards more animal products;
2. biophysical trends regarding

   a. depletion of non-renewable natural resources, such as fossil fuels and phosphorus;
   b. increased demand of renewable resources such as water, food, fibre and fuels produced from forest and agricultural land; and
   c. increased environmental impacts such as climate change, eutrophication, loss of biodiversity due to emissions and land-use changes.

Aspects 2.a and b relate to ecological source restrictions due to different sets of availability limits for non-renewable and renewable natural resources; 2.c relates to ecological sink restrictions. Hellstrand et al. (2009, 2010) treat this in detail with references to original work in this area.

In that context, animal production systems and ruminant production systems are of special interest. Of total global agricultural land of around 4.9 billion ha, 3.4 billion ha (≈ 70 %) are classed as permanent pasture (FAOstat 2009). Furthermore, quite huge shares of arable land, for example, in Scandinavia and Northern Europe are best used for the production of feeds to ruminants. The reason is that ley and pasture produce well where ruminants have the capacity to convert the energy and nitrogen compounds in forages to high-quality food. For substantial parts of arable land, the alternative in this region is forestry. Increased cereal production is no option due to climatic conditions. The importance is reflected in the low prevalence of adult native people that lack tolerance to lactose (Hellstrand 2006). Lactating ruminants has for so many 1,000 years improved the capacity of land to support people with food so much, that it has caused a thorough genetic adaptation.

The reason why ruminants substantially expand global food production capacity is a trick that the enzymes of the rumen microbes allow ruminants to perform, which monogastric animals such as pigs, poultry and people cannot perform. Due to optical isomerism, the enzymes of rumen microbes can split the long chains of the polysaccharide cellulose built by units of glucose. The symbiosis between rumen microbes and the host animal allows ruminants to support their own physiological demands of energy and protein from fibre and simple nitrogen compounds such as urea. That explains why ruminants offer a path by which the products of the photosynthesis can be upgraded to high-quality food in regions where the biophysical conditions are such that the capacity to carry humans otherwise is poor or lacking. The domestication of ruminants has in these types of agroecosystems substantially improved the carrying capacity regarding sustainable human food

supply. A price that ruminants pay for this unique ecological niche is emissions of methane from the processes in the rumen. Another is that high-quality protein is broken down in the rumen. Thus, one aspect to handle in the current discussion about climate change and ruminants is the trade-off between benefits to global sustainability through increased food supply and costs in terms of increased emissions of methane which contributes to global warming. One guideline from the international community is the first Millennium Development Goal, to end poverty and hunger. Climate change is in that structure found as one of fifteen aspects at the level below four sub-goals to the seventh of eight Millennium Development Goals (UN 2012). Another aspect relates to the issue of the reference value. What is the natural rate of emissions of methane from ruminants before humans become a major ecological player? Smith et al. (2010) found that within 1,000 years after the arrivals of humans to North- and South America by 11,500 years ago, 80 % of large-bodied herbivores such as mammoths, camelids and giant ground sloths were extinct. They estimated that this reduced annual enteric emission of methane by 2.3–25.5 Tg. Johnson (2009) suggests that this was a general pattern, showing that at different continents, the arrival of humans coincided with a substantial loss of megafauna, often its extinction. He concludes: "Living large herbivores are a small remnant of the assemblages of giants that existed in most terrestrial ecosystems 50,000 years ago. …. In several parts of the world, palaeoecological studies suggest that extinct megafauna once maintained vegetation openness, and in wooded landscapes created mosaics of different structural types of vegetation with high habitat and species diversity. Following megafaunal extinction, these habitats reverted to more dense and uniform formations." FAO (2006) estimated global enteric emissions of methane from dairy cattle to 15.7 Tg and suggested that animal production in total contributed to the emission of 7.1 Gt CO_2 equivalents annually of a total anthropogenic contribution of 40 Gt. Of that, 1.8 Gt is estimated to originate from enteric fermentation, due to the emissions of 85.6 Tg methane.

The findings of Smith et al. (2010) and Johnson (2009) suggest that before humans in a substantial way affected populations of larger wild animals, (i) the natural level of emissions of methane from wild animals globally might have been at the same level as current emissions from wild and domesticated animals together; (ii) global storage of carbon in plant biomass in forests and grasslands increased after the extinction of megafauna, that is, the level of carbon dioxide in the atmosphere decreased. Thus, systems of grazing cattle might have a higher potential to mimic natural ecosystems than other land-use alternatives in agriculture.

FAO (2006) identifies mitigations options within animal production systems regarding climate change through carbon sinks where grasslands dominate of the same size as the estimate of total contribution to emissions.

Together, this indicates that in optimal solutions satisfying societal demands regarding food security, biodiversity and climate change, cattle production systems may play a positive and vital role. As illustrated in Hellstrand (2006), cattle production may also harm sustainability goals. The point here is that cattle production has a contribution to make, if well designed.

In this paper, I investigate the capacity to through four measures increase the sustainability performance of global animal production systems: (i) decrease the consumption of chicken meat in developed nations; (ii) utilise the full potential of ruminants to produce valuable food from otherwise marginal agricultural land that way improving global food security and releasing good agricultural land for biofuel production (when food supply needs have been met); (iii) improved milk yield per cow as global average that way

decreasing feed (i.e. land) appropriation per kg milk produced; (iv) increase feed efficiency in milk production in developed nations while maintaining high production levels per cow.

Section 2 provides context, approach and points of departure. The role of animal production in a sustainability context is defined in Sect. 3. Section 4 gives an overview of animal production in a broader societal and environmental perspective. It is based on FAO (2006). Section 5 presents four examples of how to enhance the contribution from global animal production systems to the sustainability base of society. Section 6 treats methodological aspects regarding feeding standards and methods to measure the sustainability performance of animal production systems where corrections substantially can improve the sustainability delivery. Section 7 provides final conclusions.

2 Contexts, approach and points of departure

The paper follows the perspective of a sustainable development as expressed in the contributions from the policy sphere through,

- On global scale: UN Millennium Development Goals (UN 2010), OECD's perspective of a sustainable development (2001) and Millennium Ecosystem Assessment (MEA 2009);
- On regional scale: the Baltic Sea Action Plan regarding a sustainable Baltic Sea (HELCOM 2009); and
- On national scale: the Swedish environmental objectives with the ambition to secure the ecological foundation for a sustainable Sweden (SEPA[1] 2009a).

Scientific contributions of importance are the ones within systems ecology and ecological economics from Odum (1988, 1989, 1991), Daly (1990), Daly and Cobb (1989) and Costanza (1994); in agricultural production biology and economy from Nanneson from the first half of the twentieth century (e.g. Nanneson et al. 1945), Renborg from 1950 to 1985 (Renborg 1957; Johnsson et al. 1959), Ebbersten (1972), and Wiktorsson (1971, 1979) from around 1970–2005; and in agroecology from Pimentel and Pimentel (2008) and Giampietro (2003).

Contributions from these sources have been integrated in a process generating a toolkit for the analyses and management of any production system, not the least animal production systems, supporting a sustainable development (Hellstrand 1998, 2006; Hellstrand and Yan 2009; Hellstrand et al. 2009, 2010).The tools within this toolkit have generated the results presented in the following.

3 Role of animal production

The major role of animal production systems is to act as a means that enhance the food support capacity of global ecosystems, mainly from arable land and permanent pasture. Other functions are as sources of traction power, wool, skin and assets. This indicates that the evaluation of the contribution from animal production to global sustainability presupposes a sufficiently developed combined eco-agricultural and agricultural-social perspective ending up in an eco-agro-social perspective. Without that, the capacity to improve human needs per unit ecological resource at hand, given factual ecological source and sink

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[1] Swedish Environmental Protection Agency.

restrictions at hand, cannot be accurately estimated. As an example, Rockström et al. (2009) estimated nine biophysical limits that humanity had to obey in order to maintain a safe operating space. They end their paper with the conclusion that if doing so, the possibilities for a sustainable economic and social development were good. That conclusion has a weakness. The restriction regarding nitrogen implied that an annual application rate of 87 kg nitrogen per ha arable land as the sum from fertilisers and N-fixating crops should be reduced to 20 kg per ha. That would severely decrease yields globally, increasing starvation and social tension. In their analyses, agriculture was not included. They lacked the link agriculture in the eco-agro-social perspective required in this type of analysis.

Of total terrestrial land of 13 billion ha, 1.4 billion ha is arable land and 3.4 billion ha is permanent meadows and pasture (FAOstat 2009).[2] In total, agricultural land covers 4.9 billion ha (ibid.). Through feeds, animal production systems appropriate 70 % of the total amount of biomass produced on agricultural land (permanent pasture plus arable land) that supports the global food production system (Wirsenius 2000). Of these 70 %, two-thirds actually are recycled to agricultural land as manure and crop residues, supporting future production. The huge appropriation of agricultural biomass by animal production systems is reflected in the appropriation of land: 30 % of the land surface of the planet supports animal production systems (FAO 2006).

4 The FAO perspective

Livestock's Long Shadow (FAO 2006) has synthesised a substantial amount of knowledge about animal production systems globally and on regional level, considering aspects such as environmental impacts, geographical areas, animal production systems and level of industrialised animal production systems.

On global scale, animal production has a major influence on emissions/discharges contributing to climate change, eutrophication and acidification, while it through land-use changes is an important factor behind loss of tropical forests and biodiversity, and a major contributor to climate change. Pollution of antibiotics and hormones contribute, for example, to the emergence of antibiotic resistance and may cause feminisation or masculinisation of fish (ibid.).

During recent decades, the poultry production has shown the highest growth, while pig production also has grown substantially. Milk and meat from ruminants have increased at a slower pace. FAO concludes that as pig and poultry production compared to ruminants has a substantially higher dependency on high-quality feeds which can be used as food directly such as wheat and soya, and due to their higher growth-rate in human consumption, they are more important factors behind animal production driven deforestation in tropical areas. This conclusion needs modification. FAO (2006) does not analyse actual feeding rations to dairy cows. It is not unusual in dairy production in developed nations that the amount of concentrates to dairy cows is 50 % or more on a dry matter basis and that soymeal is a substantial part of the concentrates. Thus, dairy cows do not demand feeds that can be used as food as well. However, it is not uncommon that they are feed such high-quality feeds.

The physiological aspect is stressed, where ruminants through the rumen microbes have the capacity to utilise feeds and thus ecosystems that for monogastrics such as poultry, pigs

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[2] FAOSTAT (2009), http://faostat.fao.org/site/377/DesktopDefault.aspx?PageID=377#ancor, accessed 2009-07-17.

and people are useless or of low nutritive quality. They can convert biomass from more marginal and often fragile production systems such as permanent pastures to food. In poorer regions, this is not a question of maximal economic output per hour of labour, but a question of survival. Of course, the grazing system if not managed well may cause over-grazing. Regarding other environmental problems such as eutrophication and acidification, FAO stresses the contribution from pig and poultry systems as they are mainly indus-trialised, and they quite commonly have higher level of geographical concentration.

The substantial carbon sink capacity in pastures supporting ruminant production is identified.

Although economically not a major global player, the livestock sector is socially and politically very significant. It accounts for 40 % of agricultural gross domestic product. It employs 1.3 billion people and creates livelihoods for one billion of the world's poor people. Growing populations and incomes, along with changing food preferences, are rapidly increasing demand for livestock products, while globalization is boosting trade in livestock inputs and products. Global production of all meat is projected to more than double from 229 million tonnes in 1999/2001 to 465 million tonnes in 2050, and that of milk to grow from 580 to 1,043 million (FAO 2006).

The global supply of whole milk per capita and day was in 2006 132 and 109 g meat (FAOstat 2009). Animal protein per person per year makes up 37 % of a person's protein diet. To provide the animal protein for the world human population, humans in 2006 raised 58 billion poultry, 1.3 billion pigs and around 540 million cattle worldwide (FAOstat 2009).

5 Enhanced sustainability contribution from animal production

Four measures enhancing the contribution from animal production to global sustainability are presented below. They represent substantial potentials for win[3] solutions (i.e. eco-logical, economic and social sustainability) not earlier known, where the same measure substantially improves

- *Economic* sustainability through farmers net incomes, thus the viability of rural societies,
- *Ecological* sustainability through decreased ecological footprints for the same production regarding natural resource use as well as emissions, and
- *Social* sustainability through improved food security.

The measures are as follows: (1) decreased amounts of chicken meat consumed in developed countries; (2) utilise the full potential of ruminants to produce valuable food from otherwise marginal agricultural land that way improving global food security and releasing good agricultural land for biofuel production (when food supply needs have been met); (3) improved milk yield per cow as global average that way decreasing feed (i.e. land) appropriation per kg milk produced; (4) increase feed efficiency in milk production in developed nations while maintaining high production levels per cow.

(1) The first measure was chosen, due to two reasons. In the debate regarding climate change and animal production, it is often claimed that if animal products are to be con-sumed, chose pork or chicken meat due to the higher feeding efficiency compared to ruminant products. Often, it is then ignored that monogastrics such as pigs and poultry, compete with humans about food/feed. Furthermore, as monogastric animals demand quite high shares of soymeal (or soymeal substitutes) in their feeding rations, they on the margin

may cause tropical deforestation. (2) Of agricultural land, 3.4 billion ha are classed as permanent pastures of a total of 4.9 billion ha. Of arable land of 1.4 billion ha, a substantial fraction, which often is poorer in quality, is used to produce ley and coarse grains as feeds, e.g., to ruminants. The case of agriculture in the northern parts of Sweden is used to illustrate how otherwise marginal agroecosystems through ruminant production may contribute to a spectrum of sustainability assets, where this type of production systems are important on global scale, not the least for the close to 1 billion of the poorest people, dependent on cattle production in marginal socio-ecological systems. Northern Sweden, of course, does not belong to this class. However, the general significance for global food security of this kind of marginal agroecosystems can be illustrated by this example. (3) In the debate, a common proposal is that through decreased ruminant production, land earlier used to produce feeds can be released to produce crops for human consumption or bio-energy purposes. In developed nations, the increase in milk yield per cow during the twentieth century is quite amazing. This has substantially improved the natural resource efficiency in production. A corresponding development of milk yields per cow can be anticipated globally. This illustrates how improved ruminant production may at the same time produce the same amount of products and decrease land appropriated. (4) Hellstrand (2006) shoved a fast increase in the use of crop protein feeds in Swedish cattle and milk production 1991–1999, with associated substantial negative sustainability impacts. In an effort to probe whether this was a change towards a lower feeding efficiency level common globally; data from international official sources were combined, suggesting that the Swedish trend was towards a situation that is common in milk production in OECD nations. Of total cow milk produced globally, 48 % come from OECD nations (analysis of data from FAOstat[3]). This suggests that it is alright to utilise the results from Sweden (Hellstrand 2006) to get a first-time measure on global level of sustainability improvements to obtain by increased feeding efficiency at constant milk yield. As the presentation above shoves these choices partly are a function of the own pre-understanding of global animal production systems, thus has an element of arbitrary choices.

Cattle and milk production are focused. The first reason is the significance of cattle production globally. On global scale, milk alone provides 36 % of total consumption of energy from animal products, milk and meat from ruminants 47 % while products from pig meat, poultry meat and eggs together represent 42 %. For protein, the corresponding values are 28 % for milk, products from ruminants 38 %, and pig meat, poultry meat and eggs together 35 %. Among the 20 most valuable agricultural products in 2007, animal products contributed with 50 %, and among the contribution from animal products, ruminant products represent 58 % (milk alone contributed with 34 % of the whole) while meat from poultry and pigs together with egg represented the remaining 42 %. The significance of ruminant production in terms of food supply and in economic values is reflected in the area of agricultural land appropriated. Permanent pasture corresponds to 69 % of all agricultural land where ruminants are the dominating "harvesting equipment."[4] The second reason is that a common interpretation is that the high share of agricultural land supporting ruminant production systems reflects genuinely inefficient choices among the native population as kg of food produced per ha is low compared to other agroecosystems (see Azar 2011; Chum et al. 2011; Wirsenius et al. 2010, 2011). I suggest that it is the other way around: The high share of global agricultural land supporting ruminant production systems illustrates that thousands of years of selection of farming systems supporting human societies has proven

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[3] http://faostat.fao.org/site/569/DesktopDefault.aspx?PageID=569#ancor, accessed 2012-10-18.

[4] Based on own processing of data from FAOstat (2009).

that this is efficient land use. Other land-use options have not been competitive in these eco-agro-social contexts.

A third reason to focus cattle and milk production is to provide some data regarding the resource efficiency of ruminant production systems in a broader sustainability context than otherwise common. As just shown, it can be argued that ruminant production is resource-efficient both in developing and developed nations where the production options in available agroecosystems otherwise are limited. Lindberg and Wiktorsson (1995) who analysed the efficiency by which protein in feeds were converted to food (see Table 1), showed that this was the case in the Swedish context.

Conversion efficiencies in milk, and integrated milk and cattle meat production, are high compared with any other production system. This is despite the lower quality of the feeds they consume compared to other animal systems. Ruminants can maintain high conversion efficiencies for protein while using protein of lower quality than monogastric animals. The authors provide similar results with high energy conversion efficiencies for milk production compared to pig and poultry.

Table 2 summarises impacts on land appropriated, global food security and climate change of the four measures analysed.

Based on Swedish production technology, measure 1 estimates the impact of reducing chicken consumption by 7 g per capita and day in developed nations. The climate change effect through decreased pressure on tropical forests was estimated using methodology and data from FAO (2006). FAO estimates the amount of carbon in soils and in living biomass for forests, pastures and arable land. At deforestation, a huge amount of carbon in the biomass of forests are oxidised to carbon dioxide. That process may take decades. Eventually, all carbon has been oxidised. FAO allocates the cumulative amount of carbon dioxide emitted through this path to the year of clearing the land. This approach can be criticised as it implies that in the same accounts, figures regarding stocks are added to figures regarding fluxes. Furthermore, this measure is essential for the overall results in FAO (2006). Of total emissions of greenhouse gases, 34 % relates to deforestation. In Table 2, the expression "one-time event" is used to distinguish estimates related to the oxidisation of a stock of carbon from estimates of annual fluxes.

Impacts are estimated on global scale. Measure 2 investigates the importance of uti-lising ruminants as ruminants, that is, forages dominate the feeding rations. In the northern

Table 1 Efficiencies in the conversion of proteins in feeds to protein in food in some animal production branches, given Swedish conditions around 1990 (based on Lindberg and Wiktorsson 1995)

	Protein in animal products through protein in feeds
Milk	0.37
Cattle meat[a]	0.18
Meat and milk from the dairy cow stock	0.33[b]
Cattle meat, cows only for meat production	0.07
Egg	0.34
Chicken meat[a]	0.36
Pig meat[a]	0.18

[a] The terms "cattle meat," "pig meat" and "chicken meat," respectively, are used, as these are the terms used in FAOstat

[b] This is the average value estimated for the protein from the mix of meat and milk delivered from the stock of dairy cows

Table 2 Sustainability impacts of four measures in animal production

| Measure	Agricultural land released, million ha	Food security, million people, protein supply	Climate change, gigaton CO_2 equivalents	Comment
1. Decreased consumption chicken meat, 7 g per capita and day developed nations	16.0 (9.1 soybeans; 7.0 wheat production)	470	−5.2 as a onetime event	Land estimated through global average yields for concerned crops
2. Ruminants used as ruminants on otherwise marginal agroecosystems (400,000 ha)	0.42, of which 0.29 is in Europe and 0.13 in Brazil	14.1	−0.09 as a onetime event +0.0007	Swedish level; decreased climate change impact through decrease land pressure and increased through more methane emissions; on global level, there are 3.4 billion ha marginal land as pastureland
3. Increased milk production per animal globally with constant total production	150			44 % of current appropriation for milk production released, divided on pasture land and arable land proportionally
4. Increased feeding efficiency	51 of which 32 are tropical forests	1,300	−22.4 as a onetime event	Increased economic result with around 40 billion US$
Summed effects measure 1, 3 and 4	217 of which 41 are tropical forests, 67 are arable land specified	1,770	−27.6	67 million ha specified as arable land, 150 not specified

For details of alternative 2–4, see Hellstrand and Yan (2009); for alternative 1 contact the author

parts of Sweden, 400,000 ha arable land produce forages and coarse grain. If the total production was used for milk production, the milk production could increase with a factor 3.5. The measure was originally developed in order to illustrate the importance of a combined eco-agro-social perspective of animal production. The northern part of Sweden is located at the same latitude as the northern half of Hudson Bay. Although the Gulf Stream makes the climate milder, the agroecosystems of this area are marginal. They are best suited for the production of forages (pasture, hay, silage) and to some extent coarse grains (oats and barley). Through ruminants, these areas can make substantial contributions to a sustainable development, not the least to global food security (Hellstrand and Yan 2009). Measure 3 examines the importance of increasing the production capacity per cow assuming constant total production of milk globally. At the global production level of 2007, every kg milk produced cost 13.7 MJ (ME) (Metabolizable Energy). The production is slightly less than 2,000 kg per cow. If the production level per cow is doubled, the amount of energy needed per kg milk produced is decreased to 9.7 MJ ME. At the Swedish production level in 2000 (8,000 kg milk), one kg milk on average costs 7.7 MJ ME to produce. This level can be achieved on feeding rations with a high share of forages with an energy content of >10 MJ ME per kg dry matter (DM), and coarse grains supplemented with some crop protein feeds. The measure shows the sustainability gains of increasing the average global production level with a factor four to the Swedish level around 2000 (Hellstrand and Yan 2009).

Measure 4 presents the results of increased feeding efficiency in global milk production at constant production level per cow. The basis is the spectrum of sustainability costs associated with the increase in concentrate feeding, especially crop protein feeds, in Sweden to cattle from 1991 to 1999 identified by Hellstrand (2006, 2008a). Although cattle have the capacity to utilise protein in forages in the production of food, the reality is that high amounts of high-quality feeds such as soymeal, rape meal and other crop protein feeds often are used in cattle production. From 1991 to 1999, the amount of crop protein feeds in purchased feeds to cattle (85 % of purchased feeds to cattle go to dairy cows) in Sweden increased from 201 million kg to 536 million kg (Hellstrand 2006). In 2006, the amount was 644 million kg, following the same route of estimation. This results in an application of 320 kg of crop protein feeds per dairy cow in 1991, increasing to 1,020 in 1999 and 1,410 in 2006. This did not increase yields and thus depressed the economic result (ibid.). Official statistics suggest that the nitrogen efficiency in Swedish milk production from 1991 to 2006 moved towards a lower level common in developed nations.

Thus, of total influxes of nitrogen on farm level in Sweden in 2006 of 72.6 million kg through purchased feeds, 66 % was through feeds to cattle. Protein feeds to cattle such as soymeal alone contributed with 52 % of the total of this nitrogen influx (Fig. 1).

Figure 2 shows that the high influx of nitrogen on farm level through purchased feeds to cattle in 2006 is in line with a fast increase from 1991 and onwards. As milk production over this period was constant, this reflects a decreased feeding efficiency in terms of amount of milk produced per kg protein feed. An important question is why this occurred. My proposal is that the overall effect of three major changes of official feeding standards in Sweden during the 1990s in combination with how organisations dominating extension services in this area to commercial farms applied the same standards caused this decrease in feeding efficiency. This is further treated in Sect. 6. It can be noted that the dominating firm producing purchased feeds, Lantmännen, in the second half of the 1990s introduced their own feeding standards and feed evaluation system in Sweden called the LFU system. Quite surprisingly, their ambition was to press down the amount of crop protein feeds, that is, their own products, in the feeding rations (see Lantmännen 2003). The LFU system
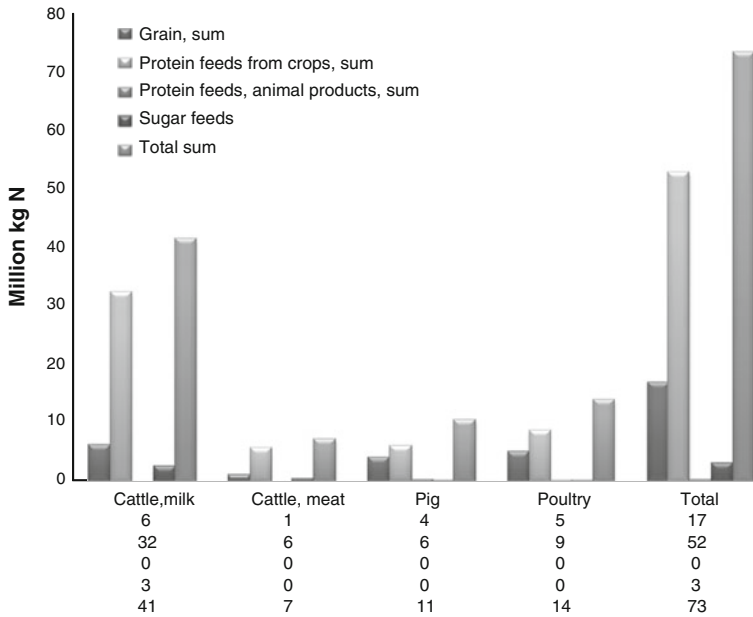
Fig. 1 Influxes of nitrogen on farm level through purchased feeds in Swedish animal production systems in 2006. Material and method Hellstrand (2006), analysis updated by data for 2006
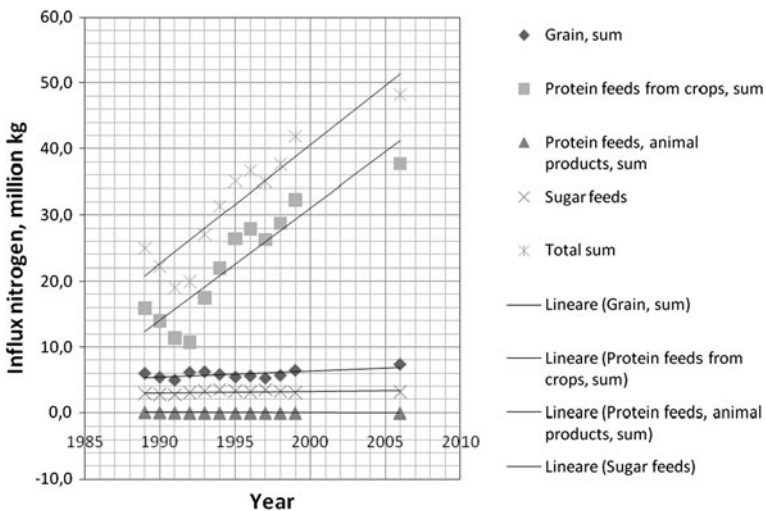
Fig. 2 Nitrogen influxes through purchased feeds to cattle production in Sweden 1989–1999 and 2006. *Source*: See Fig. 1. Of purchased feeds to cattle, 85 % are feeds to dairy cows

steers towards a higher feeding efficiency. This follows from the comparison of feeding standard systems in Norfor (2004).

A few of the leading national researchers in rumen physiology in Sweden had around 1995 left SUAS and started to work at Lantmännen, E. Lindgren and M. Murphy. They

constructed the LFU system. Thus, by their actions, they showed such a low confidence in the official feeding standard system in Sweden, after three major changes 1991–1995, that they rejected the whole system and constructed another one from other points of departure. This suggests another possible cause behind discussed trends in feeding of purchased feeds, especially protein feeds. Two substantially different systems regarding feeding standards and feed evaluation for dairy cows are in charge in Sweden since around 1997, one is used by the organisation that dominates the production of purchased feeds when they design what they believe will be optimal for the farmers, another and very different system are used when the organisation dominating extension services actually from their believe try to optimise the feeding rations to farmers. National trends regarding the use of crop protein feeds, the increase in milk yield per cow and total production of milk show that this has not worked out well. Thus, the word "believe" is relevant. For the Swedish farmers, it should be a concern that they through two of their own organisations pay twice for the mainte-nance of two conflicting feeding standard systems that in combination results in suboptimal feeding strategies.

As shown in some more detail later, the trend in Swedish milk production is towards a lower nitrogen efficiency earlier established in other OECD nations. Milk production per kg feed (dry matter) consumed, and the nitrogen efficiency is higher in diets in Northern Europe than in North America (Huhtanen and Hristov 2009).

The impact of an increased production level per cow, releasing 150 million ha of agricultural land, would substantially improve the capacity to support global food security and/or the carbon sink capacity. This measure has been obtained by assuming that milk yield on global level was increased a factor four per cow and year. That would decrease the energy demand per kg milk produced, thus also the total feed requirements for a constant global production that is transferred to an area of land supporting the feeds required. For details, see Hellstrand and Yan (2009).

As the 150 million ha is not divided in pastureland and arable land, estimates partitioned on these different qualities of agricultural land cannot be provided.

FAO (2006) estimated the contribution from the livestock sector to climate change emissions to 7.1 gigaton of a total anthropogenic contribution of 40 gigaton. Compared to those estimates, the potentials to decrease the contribution to climate change through measures 1–4 in Table 2 are significant. It shall be noted that here the mitigation option that FAO (2006) identified through the carbon sink capacity in grassland and rangeland of 6.2 gigaton carbon dioxide (87 % of the FAO estimate of total contribution from livestock sector to emissions of climate change gases) is not considered. Nor the discussion earlier presented in this paper about the accurate reference value to use, before humans become major ecological actors (Sect. 1).

The release of 217 million ha agricultural land, of which 67 are specified as arable land (Table 2), are of global importance, given that total area of arable land is 1.4 billion ha. The reduced need of 41 million ha of soybean production as estimated is compared to the use of soymeal as feeds that in 2003 corresponded to 70 million ha soybean production (see below).

The increased feeding efficiency would increase farmer's incomes by 1.2 billion SEK[5] (Hellstrand 2008a). On a principal level, the route for achieving this is discussed in Sect. 6. SEPA (2009b) has presented a proposal for how Sweden should reduce its nitrogen and phosphorus discharges to the Baltic Sea with 21 million kg. In their proposal, 5.5 million kg nitrogen reduction is lacking. The marginal cost for reduced discharges is around 1,000

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[5] Currently (October 2012), 6.5 SEK correspond to around 1 US$ and 8.5 SEK correspond to around 1 €.

SEK per kg nitrogen. Reclamation of the same efficiency in the use of purchased feeds in Swedish milk production from the lower level in 1999 to the higher level as of 1991 would result in annual societal benefits from reduced contribution to global climate change, acidification, and eutrophication from emissions of N_2O and ammonia of 2.7 billion SEK.[6] If allocating the cost of yearly using of the natural capital tropical forests over a period of 50 years, and valued through the emissions of carbon dioxide the deforestation causes, and assuming Swedish preferences for avoiding such emissions used by authorities, the annual cost is 3.4 billion SEK (assuming zero interest rate). Thus, the societal value of increasing the feeding efficiency sums to 6.1 billion SEK to be added to the estimated value of its contribution (2.5 million kg N) in the reduction of nitrogen discharges to the sea in that part of the Baltic Sea where the proposals from SEPA do not meet the set objectives, with a marginal price of 1,000 SEK per kg/N that is estimated at 2.5 billion SEK. This gives in total 8.6 billion SEK.[7] To that, the reduced production costs for the farmers of 1.2 billion SEK shall be added to get an estimate of the welfare-economic impacts, through mentioned factors and given preferences, expressed in the Swedish socio-economic system. Thus, in total, this measure—reclaiming the higher nitrogen efficiency in Swedish milk production in 1991 from the lower level in 1999—is estimated to increase the welfare-economic value of Swedish milk production by 9.8 billion SEK (slightly more than 1 billion €), allocated on approximately 400,000 dairy cows. This corresponds to the value of the total milk production in Sweden. In this calculation, the value of a reduction of nitrogen discharges with 3.5 million kg in other parts of the Baltic Sea is not considered.

Of course, this is a theoretical approach. One can ask if anyone really cares about, for example, deforestation. Swedish authorities use this kind of estimates in connection to agricultural policies, environmental policies and when ranking infrastructural investment alternatives. It is one way to evaluate the size of external effects. It shall be remembered that this relates to preferences in the Swedish society. Preferences are context-dependent in time and space. They can hardly be used as a basis for the evaluation of global impacts. Their relevance is to show whether the welfare impacts are substantial or not.

Other estimates provided in this paper, where production economic effects of improvements in milk production are estimated, are substantially stronger related to the production biological as well as the natural resource base. Such measures have a stronger relevance on global scale, also due to the balancing effect of the world market. The majority of sustainability impacts analysed relate to the analysis of causal chains in terms of natural and agricultural sciences. They have the highest general relevance of the mentioned level of measures. In general, the analysed systems are complex. Therefore, all estimates provided should be interpreted with an appropriate level of common sense.

Similar substantial potentials for reduced discharges of phosphorus are obtained when the same route of calculations is performed, keeping track of fluxes of phosphorus.

The eutrophication issue is interesting. Increased feeding efficiency in Swedish milk production in terms of a higher milk output per kg crop protein feed in combination with a reallocation of milk production to areas with low contributions of nitrogen discharges to the Baltic Sea per kg milk produced (due to a combination of agricultural practices and environmental conditions) is estimated to decrease nitrogen discharges to the sea with 6 + 6.4 million kg (Hellstrand 2008a, b). The importance of these measures is not commonly known; neither to reclaim a higher feeding efficiency; nor the regional ecological structural rationalisation indicated. Other sustainability gains such as conservation of

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[6] For details in the calculations, contact the author.

[7] This is based on prices expressed in the Swedish society and economy.

Table 3 Sustainability gains by reclaimed feeding nitrogen efficiency in Swedish cattle production as of 1991 from the level 2006, regarding nitrogen from crop protein crops in purchased feeds (based on Hellstrand 2006, 2008a, b, 2010)

	Dairy production	Cattle meat	Sum cattle production
Ecological gains			
Decreased nitrogen influx, million kg	21.9	4.4	26.4
Decreased appropriation of crop protein feeds, million kg soymeal equivalents	269	55	323
Decreased eutrophication of the Baltic Sea, million kg N	6.5	1.2	7.7
Deceased contribution climate change, onetime event, million ton CO_2	108	22	129
Tropical reforestation, potential in ha	154,000	31,000	185,000
Economic gains			
Increased farmers economic result, billion SEK[a]	1.5	0.30	1.8
Social gains			
Increased food supply capacity, protein supply million people	6.3	1.3	7.6

[a] SEK is Swedish Crowns, 1 US$ corresponds to around 6.5 SEK; 1 € to 8.5 SEK

Not all effects are additive

tropical forests, preservation of the cultural landscape in marginal areas in Sweden, the conservation of biodiversity and a more efficient use of the non-renewable resource phosphorus are favoured.

In 2007, global production of soybeans appropriated 90 million ha,[8] of which 70 million ha were used to produce feed. Table 2 identifies a potential to reduce this appropriation by 9 million ha if reducing the consumption of chicken meat consumed in developed nations, and by 32 million ha with an increased feeding efficiency in milk production. The estimates are rough but they indicate the magnitude of potentials, since they are based on solid knowledge within agricultural sciences especially animal husbandry. Still, this is new knowledge to most people in the field of agriculture and environment.

On the other hand, the results presented are basically a product of applying the same methods and knowledge that I successfully used when being the main responsible for extension services regarding animal production in the county of Värmland in Sweden 1982–1986. At that time, that represented the main stream in animal husbandry in Sweden and dairy production science and had been doing so during most of the twentieth century. At individual farms, improvements in production biological and economic terms up to twice the size per animal were achieved (see Hellstrand 1988), as the ones that give the potentials for improvements presented in Tables 2 and 3. The core of the model for the analysis of production biological and economic performance in milk production generating the results presented in this paper was first presented in two publications from the Swedish University of Agricultural Sciences more than 20 years ago (Hellstrand 1988, 1989). This proven empirical relevance shows that the philosophy underpinning the analyses presented in this paper is relevant on real-world farms. The proposals regarding feeding standards as well as methods for the analysis of environmental impacts criticised below either have

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[8] From FAOstat, http://faostat.fao.org/site/567/DesktopDefault.aspx?PageID=567#ancor, accessed 2009-08-16.

records from real-world systems that sign problems, or have not been probed against reality.

6 Methodological issues

There are two methodological issues needed to review further:

- Do feeding standards to dairy cows in developed nations result in feeding strategies that are suboptimal in terms of farmer's economic result and the sustainability performance?
- What are the sustainability risks of extrapolating methods developed within engineering sciences in the evaluation of the sustainability performance of production systems in general and ruminant production systems in particular?

Feeding standards are the rules used to estimate the feeding rations that meet the physiological nutritive requirements of the individual animal. Feeding standards are relevant when cows are fed in cowshed as well as during pasture.

6.1 Feeding standards to dairy cows

The use of crop protein feeds in Swedish cattle production increased dramatically from 1991 to 2006, from 201 million kg to 644 million kg. Sustainability aspects of these trends are analysed in the following. Furthermore, the international relevance of the Swedish trends is examined. Then, the issue whether this is caused by the design of feeding standards to dairy cows is treated.

6.1.1 Feeding trends and sustainability impacts

Figure 1 shows the influxes of nitrogen through purchased feeds to different animal production systems in Sweden in 2006. Fluxes of nitrogen and of protein are similar measures. Crude protein in feeds to dairy cows is defined as amount of nitrogen multiplied with 6.25.

In the Swedish system, 66 % of these influxes relates to cattle production.

Figure 2 shows the trends regarding nitrogen influxes through purchased feeds within cattle production in Sweden 1989–1999 and 2006. A phase of fast decrease in nitrogen influxes via purchased feeds to cattle 1989–1991 was abruptly changed to a period of a fast increase from 1991 to 1999 with a prolongation to 2006. Of the total amount of purchased feeds to cattle, approximately 85 % are classed as feeds to dairy cows. The dominating part of the increase was due to the increased use of crop protein feeds (Fig. 2).

In Fig. 3, the results in Fig. 1 are expressed in terms of soymeal equivalents in million kg, allocated on the major animal production branches in Sweden. The reason is that soymeal has a similar role as oil on the global energy market. In 2002, the feed demand for soymeal was 130 million tonnes, while it was 20.4 million tonnes for rape and mustard seed meal, the second largest oilcake (FAO 2006). Thus, based on the crude protein content of different crop protein feeds, standardization can be made to soymeal equivalents. Here, two allocation problems have been treated. It is assumed that feeds for milk production relates to the dairy cow, that is, feeds for milk and maintenance. Feeds for the production of the recruitment heifer are treated as a cost for meat production, which is eventually delivered when the dairy cow is slaughtered. Feeds for gestation, growth and maintenance during the growth period are included. Gestation requirements are requirements for the
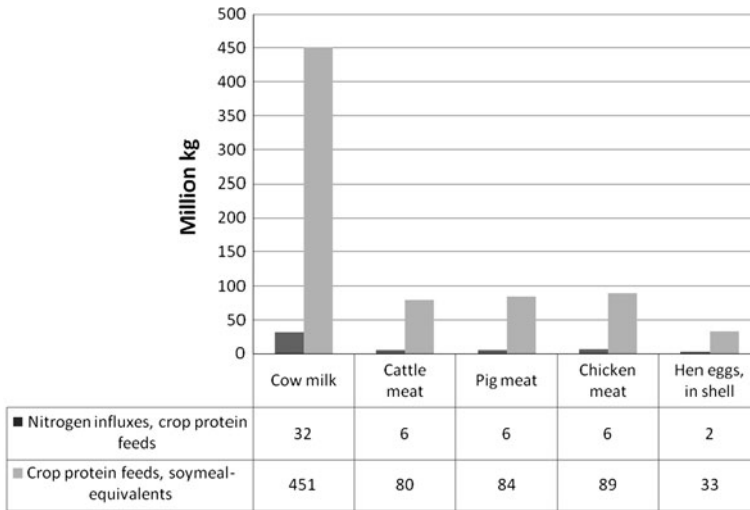
Fig. 3 Use of crop protein feeds in purchased feeds in soymeal equivalents in million kg in Swedish animal production in 2006. *Source*: Hellstrand (2010)

growth of the foetus, that is, for meat production. This implies that of the total nitrogen influx to cattle via crop protein feeds in purchased feeds, 15 % is allocated to meat production and 85 % to milk production.

Regarding poultry production, in the official feed statistics in Sweden, 44 % is classed as feeds to laying hens, 40 is for chicken meat production and 2 % go to turkey production. It is assumed that all purchased feeds are evenly allocated to egg and poultry meat production. Feeding standards suggest that for per kg feed, the amount of crop protein feeds is 2.73 times higher in feeds to chicken meat production than for laying hens (30 % compared to 11). This is assumed to be the case also in purchased feeds to poultry production. This gives the results in Fig. 3.
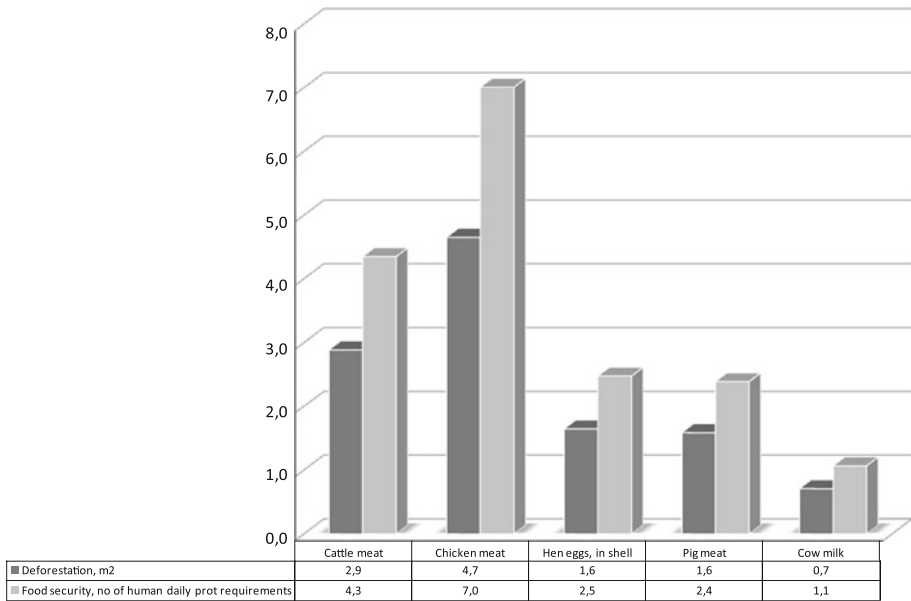
By expressing the use of crop protein feeds in soymeal equivalents, and relating it to the production levels, it is possible to estimate different sustainability impacts per kg animal product. These measures support farmers to improve their sustainability efficiency, facilitate for authorities to establish relevant sustainability standards for farmers to meet and can form a basis for payment systems, for example, within the European Agricultural Policy, providing incentives that make it rational for farmers to contribute to a sustainable development. Of course, they can be used in direct communication between producers and consumers when reliable data regarding sustainability performance make a difference.

The basis for the analysis is Hellstrand (2006) with the methodology developed and the results it generated in the analysis of sustainability impacts due to the increased use of concentrates in Swedish milk production 1991–1999, combined with the information in FAO (2006) regarding the impact on carbon dioxide emission when tropical forest are converted to arable land. By considering yields of soybeans per ha and the fraction of total yield that becomes soymeal, the results in Fig. 4 are obtained.

Figure 4 provides results regarding impact on deforestation and food security through the impact on supply of protein for humans when protein feeds are fed to animals that can be used by humans.

Figure 5 shows the impact on global climate change.

	Cattle meat	Chicken meat	Hen eggs, in shell	Pig meat	Cow milk
■ Deforestation, m2	2,9	4,7	1,6	1,6	0,7
■ Food security, no of human daily prot requirements	4,3	7,0	2,5	2,4	1,1

Fig. 4 Sustainability impacts per kg animal product due to the use of crop protein feeds in Swedish animal production in 2006. *Source*: Hellstrand (2010). Deforestation concerns tropical deforestation because of the use of crop protein feeds used in the production measured in soymeal equivalents. The amount of soymeal equivalents represents an area of tropical deforestation on the margin, for producing more soymeal to the world market that is eventually used in the concerned production. This relates to the concept of ecological footprints. In a corresponding way, the use of crop protein feeds in animal production if directly used by humans as feed can support global food security, in terms of human protein requirements fulfilled. These two effects are of the kind either or. Daily production per capita and day in Sweden was in 2006 41 g cattle meat, 30 g chicken meat, 80 g pig meat, 30 g eggs and 954 g milk. Production from http://faostat. fao.org/site/569/DesktopDefault.aspx?PageID=569#ancor, Swedish population from http://www.ssd.scb. se/databaser/makro/SaveShow.asp, both accessed 2010-06-04

Table 3 gives sustainability gains, if the higher nitrogen efficiency in the use of crop protein feeds in purchased feeds to cattle in Sweden of 1991 was once again obtained from the lower efficiency level as of 2006. Here, the results are specified for milk and meat production, respectively.

The information above implies that

- important sustainability aspects are closely related to the use of crop protein feeds,
- they are closely related to the nitrogen efficiency in animal production branches, and
- in the Swedish context, milk production plays a major role.

Figures 1, 2, 3, 4, 5 illustrate how the management of animals on the individual herd level can be linked to global sustainability through impacts on climate change, food security and tropical deforestation per kg product, that is, a contribution when considering global impacts in the everyday operations in animal production on commercial herd level. In the prolongation, it indicates how future payment systems, for example, in the European Common Agricultural Policy, can be based on evaluating systems informing about the contribution at individual farm level to societal objectives from local to global community level.
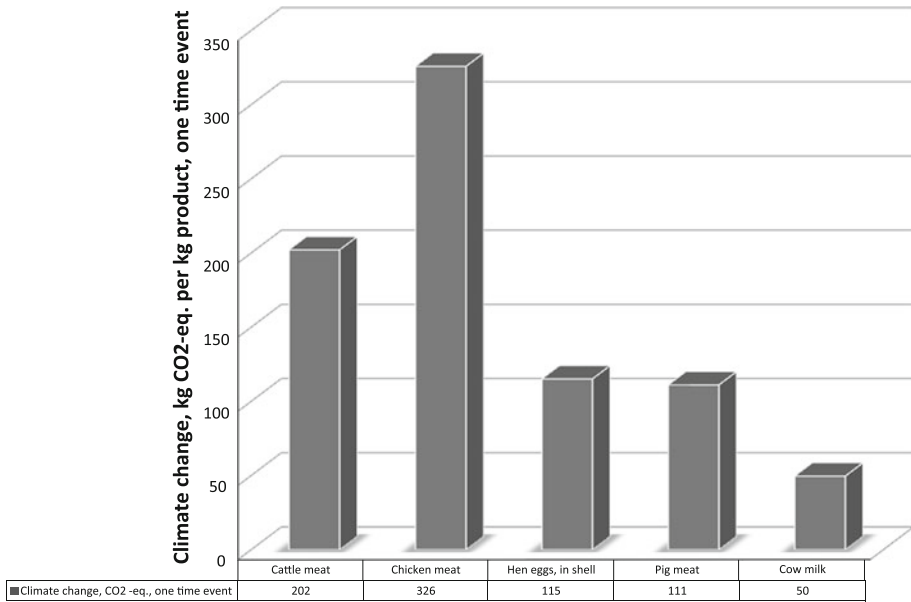
Fig. 5 Impact on global climate change through deforestation due to the use of crop protein feeds in Swedish animal production in 2006. *Source*: Hellstrand (2010). For the production per capita and day in 2006, see Fig. 4
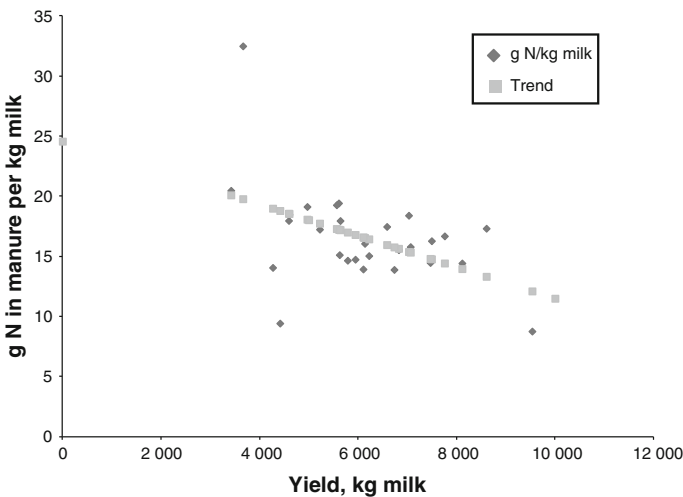
Fig. 6 The amount of nitrogen in manure from dairy cows in g per kg milk produced at different production levels among OECD nations. *Source*: Hellstrand (2010)

Figure 6 indicates the international relevance of the information in Figure Figs. 1, 2, 3, 4, 5. It presents the amount of nitrogen in manure from dairy cows in g per kg milk produced in OECD nations. The estimates are the ration between nitrogen

effluxes in manure per dairy cow[9] and milk production per cow from FAOstat in OECD nations.[10]

The nitrogen balances reflect the nitrogen/protein content in the feeding ration and the total amounts of feeds consumed.

The figure shows that the nitrogen efficiency tends to increase with increasing yields, at the same time as the relationship is not strong: other factors explain 78 % of the variation in Fig. 6. Korea combines a high production level, around 9,500 kg per cow, with a high nitrogen efficiency. The amount of nitrogen in manure ("manure" here is manure + urine) is 8.8 g per kg milk, which is 3.3 g less than the expected value at this high production level. USA has a somewhat lower production, 8,600 kg per cow and year, with 17.3 g nitrogen in manure per kg milk, which is 4.0 g more than expected due to the milk yield level. Among nations with high production levels (>7,000 kg per cow and year), the Netherlands and Denmark have low nitrogen efficiencies; 3 and 2.3 g nitrogen more in manure per kg milk than expected at their respective production levels. Finland is the only nation in the group with high production levels with a lower value than the level predicted from yield, 0.3 g below the trend. The Swedish value in Fig. 6 is close to the expected based on the regression curve. Thus, Fig. 6 indicates that the decreasing nitrogen efficiency in Swedish milk production from 1991 to 2006 is towards a lower efficiency level common among OECD nations. That suggests that the decreasing efficiency in Sweden in that period is an estimate of a potential for improvement, which can be used as a departure for a first rough estimate of global potentials. Hellstrand (2006) investigated whether there were good economic reasons for this decreasing efficiency in the use of crop protein feeds. He found none. Hellstrand (2008a), in a study on behalf of SEPA, investigated the causes behind this trend. The major reason (ibid.) was the abandon of basic principles ruling feeding strategies in Swedish milk production during most of the twentieth century up to the beginning of the 1990s, concerning how to utilise the "law" of diminishing returns and Liebig's "law" of the minimum (see Wiktorsson 1979; Liebig 1840) when searching the economic optimal feeding intensity. Since 1995, the economic result at commercial herd level no longer influences the design of feeding standards in Sweden. For a late example of how to adjust feeding standards due to the variation in prices on feed inputs and milk output in the Swedish system in order to support the economic result on farm level, see Hellstrand (1989).

With a global production of 578 million tonnes cow milk in 2008[11] (FAOstat 2009; Hellstrand 2010), the estimate for Korea suggests a possibility for a nitrogen efflux in manure of 5,000 million kg, while with the lower efficiency of the USA, the nitrogen efflux in manure would be 9,800 million kg, that is, 4,800 million kg nitrogen more. 4,800 million kg nitrogen related to nitrogen in soymeal, correspond to around 34 million ha soybeans production. From that measure, the possible impact in climate change, on global food security, and on farmers' net income can be estimated through same route as earlier used.

To some extent, the differences in values for Korea and USA can be caused by differences in measuring methods and data accurateness. The objective of increasing the sustainability contribution from animal production globally implies a need to further

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[9] From environmental performance of agriculture in OECD countries since 1990, http://stats.oecd.org/Index.aspx?datasetcode=ENVPERFINDIC_TAD_2008, accessed in August 2009.

[10] From http://faostat.fao.org/site/569/DesktopDefault.aspx?PageID=569, accessed 2009-08-08.

[11] FAOstat. http://faostat.fao.org/site/569/DesktopDefault.aspx?PageID=569#ancor, accessed at 2010-01-04.

analyse these values, their differences and causes. That supports methodological standardisation and improvement in international statistics, and the possibility to learn between nations.

The Swedish trend (Fig. 2) and the significant variation in nitrogen efficiency among nations (Fig. 6) are two arguments suggesting that the options for increased nitrogen efficiency in milk production globally are substantial, where this can significantly improve a spectrum of important sustainability aspects through paths discussed above.

6.1.2 Feeding standards feeding feeding trends

The sharp change of the Swedish trend, where a decreasing influx of nitrogen via crop protein feeds to cattle in 1991 was changed to a fast increase, appeared at the same time as a major change in protein evaluation and feeding standard system to dairy cows was implemented. In 1995, the energy feeding standard system to dairy cows was fundamentally changed, while at the same time, major changes of the new protein feeding standard system were made. These changes in feeding standards, I suggest, were driving forces behind the increasing influxes of nitrogen trough crop protein feeds (see also Hellstrand 2008a).

In 1991, the protein evaluation system was changed from digestible crude protein (dcp) to the AAT/PBV system. Gustafsson (1990) probed the outcome of the new system before its implementation in a field study covering 29 cow herds. Regression analysis resulted in statistical significance for the relationship between milk yield (ECM; energy-corrected milk) and consumption of dcp and PBV, respectively, but not between milk yield and AAT. This was quite surprising, as AAT was supposed to provide better estimates of the protein quality than dcp and PBV function as a waste fraction, not supporting milk production. The results suggested that the old system was better than the new system, and that the assumed waste fraction contained protein with a higher capacity to support milk production than the assumed quality fraction. Furthermore, the study showed that energy allowances were on average 14 % above assumed requirements (according to official feeding standards) while the protein allowances were 13 % above measured in terms of dcp. Measured in terms of AAT and using the standards that some year later came into practise, the protein allowance was only 4 % above the feeding standards. Thus, having the same cows, feeds and production levels, and only changing the protein measure used to estimate the feeding rations that exactly would balance assumed requirements of energy and protein, would result in a substantial reallocation of concentrates from coarse grains to crop protein feeds such as soymeal. Assuming that the cows in total consumed 135 kg nitrogen with the dcp system per lactation, and with the number of dairy cows in Sweden, the year of the field study (1987/1988) of 564,550, the total influx of nitrogen with feeds to dairy cows would be 76 million kg. If, with the new system we arrive at the same apparent balance between energy and protein, the shift from the dcp system to the AAT system would instantly increase the protein allowance with 1.13/1.04, i.e., 8.65 %. That would increase the influx of nitrogen to the stock of dairy cows with 6.6 million kg through concentrates. Hellstrand (2006) estimated an increase of nitrogen influxes via purchased feeds to cattle of 22.8 million kg from 1991 to 1999. Of that, 85 % can be allocated to dairy cows, that is, 19.4 million kg. The results of Gustafsson suggest that 34 % of the increased influxes of nitrogen through purchased feeds to dairy cows were caused by the introduction of the AAT/PBV system during the production year 1991.

Hellstrand (2006) estimated the impact of increasing use of purchased feeds 1991–1999 on feeding efficiency to dairy cows considering changes in production levels and the nutritive quality of forages. Hellstrand (2008a) investigated how changes in protein feeding standards 1991 and 1995, and the change of ruling principles in energy standards in 1995 affected nitrogen influxes to dairy cows. He also evaluated the impact of recommendations to further increase the protein allowances per kg milk above the official standards. The source for the later was a study of future and efficient Swedish agriculture performed by the Swedish Environmental Protection Agency (SEPA 1997).

Different paths through which these changes in feeding standards (with supporting feed evaluation system) would affect feeding efficiency are:

- The substantial reduction of assumed available protein in forages ("available" in terms having feeding value) with the introduction of the AAT/PBV system,
- The increase in assumed protein requirements for maintenance in 1991 further increased in 1995 with the AAT/PBV system,
- The change of ruling principle in 1995 for the energy standards from supporting economically optimal feeding intensity to predict milk yield from feed intake,
- The choice to formulate a new energy standard to dairy cows based on the regression analysis of results from feeding trials where in most trials, the cows consumed above economic optimal levels,
- The change of protein standards to a principle where the amount of protein per energy unit was assumed to be constant independent of production level while physiological common knowledge states that low-lactating cows have a lower protein requirement per unit energy due to the higher part of total requirements that are related to maintenance needs, and
- A fashion established in extension services that high-yielding dairy cows demand more protein than the official feeding standards suggest per kg milk produced.

Added to these paths were weaknesses in the probing of the changes made before full-scale implementation. Thus, there was a combination of weaknesses in the theoretical and empirical foundations of made changes, where the control system that should filter against such weaknesses had a corresponding flaw:

The new energy standards introduced in 1995 were based on a work by a student in agronomy (Andresen 1994[12]); the change of the protein standards in 1995 was based on an unpublished memo that the author himself around 10 years later could not find (see Hellstrand 2008a; Spörndly 1995). It is impossible to probe the quality of the analysis resulting in the proposed change in protein standards in a process that follows standard criteria of good scientific praxis simply as the analysis itself no longer exists.

The rationale for the change of the energy standards in 1995 was that high-yielding cows demand more feeds per kg milk than low-lactation cows. The physiological mechanisms behind this assumption are clearly laid out in NRC (2001).[13] That would result in a curvilinear relationship between feed intake and milk production. The intention, therefore, was to replace a linear relationship between energy intake and milk yield with a curvilinear

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[12] This is not a critique against this student work; it is a critique regarding the choice to base such a fundamental change of such a fundamental relation in the most important production branch in Swedish agriculture on a work with such a low formal quality. This has an element of playing hazard with farmers' economy through decreased natural resource efficiency (feed efficiency) as well as with the environment through the spectrum of environmental costs that may cause.

[13] The relevance of this assumption when designing feeding strategies on commercial herd level can be questioned. However, it is outside the scope of this article to treat that issue.

one (Andresen 1994; Gustafsson 2000; Norfor 2004). When analysing the mathematical expression used to transform the earlier linear relation to a curvilinear one (Hellstrand 2008a), it shows that the outcome is a new linear relation. In one sense, this is not surprising, as the earlier linear expression was modified by multiplying it with a constant, then reducing the new value with a term. What as is a concern is that this indicates a lack in the capacity among the group of scientists and other professionals that at that time were responsible for the feeding standards to transform assumed physiological relations in milk production to mathematical expressions. As these expressions steer the programmes by which the feeding rations are calculated for most of the dairy cows in Sweden, this is not of marginal importance. Furthermore, if in such a principally simple task, there are such problems that by itself deflate the credibility regarding other and principally more complex aspects to handle in feeding standards and supporting feed evaluation systems. Such circumstances might contribute to an understanding why Lantmännen around 1997 launched an entirely different feeding standard and feed evaluation system (see Sect. 5).

The mode by which the feeding standards were applied in practice might further have decreased the feeding efficiency. In an evaluation of the international relevance, it was found that the Swedish feeding standards moved towards systems that already were implemented in Denmark, the Netherlands and USA (Hellstrand 2008a). The data behind Fig. 6 show that these nations are the ones with the lowest nitrogen efficiency among nations with high production levels per cow in 2004, while the Swedish efficiency is at an intermediate level.

Reasons why the changed feeding standards caused these effects are (ibid.):

- The protein evaluation and feeding standard system introduced in 1991 was in conflict with basic principles regarding typical features of such complex systems that the protein metabolism of ruminants have. Strict linear causal relations were presupposed in the applied model of this complex system with mutual dependencies between systems and system levels. Long chains of calculations were provided where each step in the calculations decreased the accurateness of obtained estimates. Values of parameters in each step were taken from different trials in different nations with their own specific context, within which the values are relevant, while the relevance is deteriorated when the same numeric values are used outside the contexts defining them.
- The energy feeding standard system was until 1994 based on the principle of diminishing returns. That was expressed in the objective to find that energy feeding intensity, which at the margin caused an increase in yield that had precisely the same value as the costs for the feeds causing that increase in yield. From 1995, the objective of the feeding standard was instead to predict the yield from the feed intake. This may be of interest for a researcher but it is not the prioritised objective for owners of commercial herds. Here, the objective is to arrive at the feeding intensity, that is, the energy allowance per kg of milk, which maximise the economic result. This principle ruled during most of the twentieth century in Sweden, until 1995, in the formulation of energy standards to dairy cows, and still rules the yearly upgrading of the official recommendations regarding fertiliser application rates considering changed prices of fertilisers and crop products.

The same situation as in Sweden is at hand regarding the ruling principles of protein and energy feeding standards and feed evaluation systems in other important milk-producing nations (ibid.). This is an indication that the results from Sweden are of international relevance.

6.2 Engineering science and sustainable ruminant production

Hellstrand et al. (2009) found that a central natural resource concept in physical resource theory, exergy, is defined in a conceptual model of real-world systems where all process restrictions that define ecological, economic and social systems are ignored. As a matter of fact, the mere concept resource becomes meaningless given the condition for its definition of thermodynamic ideality (ibid.) To discuss natural resource management strategies on global scale based on concepts that lack relevance in real-world systems may cause problems (ibid.).

Hellstrand et al. (2010) investigated a number of applications aiming at supporting a sustainable development at operative level. They all have emerged from the basis of engineering sciences. They had four factors in common,

(i) the physiological and biological aspects of the carrying capacity limits of ecosystems are ignored,
(ii) ecosystems affected by production and consumption are located outside the system borders,
(iii) the variation in the conditions of ecosystems in space and time is ignored, and
(iv) the capacity of ecosystems, managed and natural ones, to produce ecosystem goods and services is ignored.

The examples were the following:

- The system of environmental and economic accounts in Sweden (Statistics Sweden 2009),[14]
- Analysis of the environmental impacts, quantifiable and non-quantifiable, from Swedish agriculture, including upstream and downstream effects (Engström et al. 2007),
- Sustainable pig production (Stern et al. 2005),
- Sustainable milk production (Gunnarsson et al. 2005; Sonesson 2005),
- Life cycle assessment of milk production (Cederberg and Flysjö 2004; Cederberg et al. 2007),
- Life cycle assessment of seven different food items (LRF 2002),
- The Integrated Pollution Prevention and Control-directive and its BAT (Best Available Technology) principle,[15] supporting the development of sustainable industries in the European Union,
- The Integrated Product Policy of European Union (Wijkman 2004),
- The main streams approach in life cycle assessment (Baumann and Tillman 2004), and
- The system conditions for sustainability of the natural step.[16]

The consequence is that none of these approaches comply with the principles for sustainable development regarding its ecological dimensions as expressed by Millennium Ecosystem Assessment (MEA 2009), OECD (2001) and the UN Millennium Goals (UN 2010). This is the logical consequence for these approaches common factors (i)–(iv) above.

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[14] The "environmental" aspects concern natural resources entering the economic system and emissions leaving it. The environment itself is located outside the system borders of the system of environmental economic accounts.

[15] http://eippcb.jrc.ec.europa.eu/reference/BREF/ppm_bref_1201.pdf, accessed 2012-10-19.

[16] http://www.thenaturalstep.org/the-system-conditions, accessed 2009-06-14.

A number of the examples above concern animal production system. Hellstrand et al. (2010) found that their impact on agricultural sciences and policies from national authorities as well as in the private sphere were substantial. If that conclusion is valid, as well as that the conclusion that these examples are in conflict with the principles for sustainable development regarding its ecological dimensions as expressed by Millennium Ecosystem Assessment (MEA 2009), OECD (2001) and the UN Millennium Goals (UN 2010), then there is a problem. The possibility and significance of this problem is somewhat elaborated on below.

There are two reasons for why the evaluation of the sustainability performance of ruminant production systems based on engineering sciences in Sweden has failed. Typically, the handling of (i) the metabolism of the cow in interaction with the feeds and (ii) the environmental impacts of the production systems could be better. The short reason is that they are products of engineering sciences, and engineering sciences do not have the competence of excellence regarding the physiology of dairy cows or the ecological, economic and social dimensions of a sustainable development.

As is shown in the following, this may cause substantial impacts on policies from local to global level which ultimately can inflict global food security. This conclusion is so serious that the analysis performed in this study needs to be presented in some detail, thereby facilitating the reader to evaluate the accurateness of the conclusion.

The following will treat both weaknesses in engineering-based approaches, as well as weaknesses in the feeding standard systems in Sweden, and the way they have been applied the latest 20 years. The reason to treat them together is that

- If having accurate methods for the analysis of environmental performance, the increasing environmental load associated with an increase in the use of crop protein feeds to cattle with a factor 3.2 from 1991 to 2006 for a constant or decreasing production had been detected;
- The huge differences in nitrogen efficiency and feeding strategies between conventional and organic milk production cannot be understood, without understanding the problems in the changes in the feedings standard systems from 1991 and onwards, forcing organic producers to manipulate the feeding standard systems in order to be able to feed the cows the amount of forages as the rules of organic milk production state;
- The understanding of the previous two points is needed to see why an evaluation of the sustainability profile of milk production should be based on the animal production and supporting plant production that actually is at hand.

Results and policy suggestions based on the results in Cederberg and Flysjö (2004), Cederberg et al. (2007), Wirsenius (2000, 2003a, b), Wirsenius et al. (2010, 2011) and Azar (2011) are a concern. By the same reasons as the sustainability relevance of a number of engineer-based measures and methods are rejected by Hellstrand et al. (2010); these examples are. Their results are in strong conflict with the perspectives and priorities of a sustainable development expressed in UN Millennium Development Goals, OECD principles for a sustainable development and Millennium Ecosystem Assessment. They focus ruminant production as a major sustainability obstacle by arguments in conflict with the perspectives of FAO (2006). Mainly, this expresses that these contributions are not based on an expertise competence regarding the ruminant, ecological, economic and social systems in which the sustainability contribution from grass ruminant systems are defined.

Some examples illustrate the problems:

Cederberg and Flysjö ([2004](#)) and Cederberg et al. ([2007](#)) estimate the quantity and nutritive quality of feeds grown on the dairy farm, which typically constitute 40–90 % of the feed intake on dry matter basis, by the amount of diesel used on the farm according to the accounting books. In the analysis of fluxes of compounds through the dairy cows, the law of mass constancy is violated. Cederberg and Flysjö ([2004](#)) and Cederberg et al. ([2007](#)) use values from a theoretical calculation about 10 years earlier regarding the protein efficiency in conventional milk production, as a starting point for the evaluation of emissions of N_2O and ammonia from manure from the organic milk production system. As the feeding strategies differ substantially between these systems, this is not relevant. The dominating system for certification in organic farming in Sweden is KRAV.[17] They provide a detailed list of rules to comply with, presented on 156 pages.[18]

The rules state that for milk-producing animals, concentrates may be at most 40 % of the daily dry matter intake. The official feeding standards to dairy cows in Sweden from 1995 (Spörndly [1995](#)) is that lactating cows need 7.6 g protein per MJ ME (protein measured as AAT). Swedish Dairy Association provides "Kvalitetssäkrad mjölkproduktion:—Kvalitetssäkrad utfodring mjölkkor" (Svensk Mjölk [2003](#)). That brochure delivers rules of thumb to advisers regarding the feeding of cows during different lactation phases. For cows in early lactation (the first 100 days), the recommendation is that the AAT allowance ought to be 8.0–8.5 g AAT/MJ. The reference provided is "Mjölkkor" (Dairy cattle in translation).

"Mjölkkor" is a Swedish textbook about milk production. Gustafsson ([2000](#)), in a contribution in this book, treats the issue of economically rational feeding. He argues that by economic reasons, it can be rational to increase the protein allowance above the official standard of 7.6 g AAT per MJ. He mentions that levels up to 8.5 g AAT/MJ are commonly used. In 1991 when the AAT system was introduced, the protein requirement was set to 40 g AAT per kg milk ECM. Gustafsson states (p. 136) that the level 40 g AAT per kg milk was supported by trials showing lower yields if lower allowances, while there were no or small increase in milk production in trials if cows were fed more than 40 g AAT per kg milk. The previous standard of 40 g AAT per kg ECM now is captured in the formulation that the requirements for lactating cows are 7.6 g AAT per MJ ME as the cows need to meet the energy requirements of lactation and maintenance together (ibid.).

Here, there is a contradiction: Empirical evidences showed no or small increase in milk yield for protein allowances above 40 g AAT per kg ECM. A standard conclusion regarding production functions based on dose–response functions in biological systems are that the biological optimum is at a higher input of, for example, feed or fertiliser than the economic optimum. If the biological optimum is at a protein allowance of 40 g AAT per kg ECM or slightly higher, then the economic optimum will be at a lower allowance. And, if the formulation of the protein requirement of 7.6 g AAT per MJ ME equals the one of 40 g AAT per kg ECM, then there can be no economic reason for increasing this protein allowance when generating feeding rations at commercial herd level. Thus, the conclusion by Gustafsson must be rejected: There are no empirical evidences that support the conclusions that by economic reasons, it can be rational to increase the protein allowance above the official standard of 7.6 g AAT per MJ.

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[17] For information, see http://www.krav.se/System/Spraklankar/In-English/KRAV-/, accessed 2009-08-04.

[18] http://www.krav.se/Documents/Regler/englishEditions/Standards_for_krav-certified_produktion_january_2009.pdf accessed 2009-08-04.

Gustafsson presents the changed formulation of the energy requirement in 1995, where one linear expression was replaced by another one (see above), as if the new liner relationship was a curvilinear one (ibid.: p. 134–135).

From this, three conclusions follow.

(i)   It is in conventional milk production recommended to increase the protein allowance with 5–12 % above official standards. This is supported by a textbook used in agricultural education.
(ii)   The understanding of the definition of the optimal level in production functions in production biological and production economic terms is weak.
(iii) The understanding of how to represent a curvilinear relationship between energy intake and milk yield in a mathematical expression is weak.

The latest example where the principle of the relation in (iii) is clearly demonstrated in production biological and economic terms in the Swedish context is Hellstrand (1989). Nanneson et al. (1945) and Wiktorsson (1979) thoroughly treat this subject. This points towards the conclusion that the increasing protein allowances to dairy cows in Sweden 1991–1999, remaining at a high, possibly higher level in 2006 (see Figs. 1, 2) is a function of a decreasing capacity to handle issues regarding optimal intensities in biological and economic terms among the national expertise in Swedish dairy science.

The example here discussed regarding a believed rationality in overfeeding dairy cows with protein in the organisation dominating extension services to farmers is similar with the example in 6.1.2 regarding the feeding rations in milk production delivered by Spörndly in 1996 to SEPA to a study of future, rational Swedish agriculture. The future study was published in 1997(SEPA 1997). The task of the study was to outline what a sustainable and environmentally well-adapted agriculture was, and how it could be conserved, and further developed to the year 2021. The future study worked with two visions. In both set, sustainability objectives were assumed to be possible to achieve. In the one building on a development of conventional agricultural systems, the path towards sustainability and a good environment was described in terms of precise use of commercial fertilisers, pesticides and concentrates. Yields were high and animal production was characterised by high-yielding cows and pigs and poultry with low feed consumption per kg product.

A concern is the design of the feeding rations delivered regarding milk production. In 1995, the official protein standard in AAT terms was changed. The author for the publication where this is established is Spörndly (1995). In 1996, he had a task to provide SEPA with feeding rations supporting an economically efficient and ecologically sustainable Swedish milk production. The feeding rations provided[19] cover the months 1–12 in the lactation. For lactation month 9, the amount of energy and protein exactly matches the requirements according to Spörndly (1995). Then, the production is on average 25 kg ECM per cow. In lactation months 1 and 2, that is, one to 2 months after calving, the production level is 45 kg ECM per day. At that high production level, the allowance of AAT is 2,674 g per cow and day, at the production level 25 kg ECM, it is 1,467. Thus, an increase in production with 20 kg ECM increased the allowance of AAT with 1,207 g AAT, that is, 60.3 g AAT per kg ECM more. The feeding standard as of 1995, to be precise, implies an allowance of 42.2 g AAT per kg milk. Here, the same author as in 1995 published a new official feeding standard in Sweden regarding energy and protein, in a task for the SEPA 1 year later aiming at environmentally sound and economic efficient production for the

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[19] I got them from one of the authors some time after the report from SEPA was published in 1997.

future, increases the protein allowance with 60.3/40.2 per kg ECM, that is, with precisely 50 %. The energy allowance by Spörndly in this task follows close to the official one as of Spörndly (1995). This implies that the amount of protein as AAT per MJ ME that Spörndly in 1996 assumes that is needed at increasing milk yields are 10.6 and not the 7.6 as from 1995 is the official Swedish feeding standard (Spörndly 1995). Such an increase in the assumed amount of protein required per MJ ME needed for milk production will heavily change the solution in the system of linear equations used when determining the amount of energy concentrates and protein concentrates, respectively, required to exactly match the remaining requirements of energy and protein given the weight and production level for the animal, and the allowances of energy and protein through fixed rations of forages.[20] This will cause a substantial substitution of grains typically produced on the farm or at near farms, with purchased protein concentrates, that to a substantial part contain intercontinentally produced soymeal.

Gustafsson is one of the leading experts in the feeding of dairy cows at Swedish Dairy Association the latest two decades, and Spörndly has had a corresponding position at Swedish University of Agricultural Sciences (SUAS) for a similar period. Bertilsson is another of the experts at SUAS. He is the source for the change of the formulation of the protein standards in 1995 (Bertilsson 1994), where the source (se Spörndly 1995) is an internal memo that no longer can be found (Hellstrand 2008a). Bertilsson and Spörndly were supervisors to Andresen (1994) in his student work leading to a new energy standard to dairy cows in 1995 (Spörndly 1995).

The paragraphs above suggest that the decreasing protein efficiency in Swedish milk production since 1991 partly is a function of a decreasing quality in the contributions in dairy science the same period.

The findings in Hellstrand (2008a) suggest that this reflects a movement

- From a good understanding of general principles for a resource-efficient and economically competitive milk production in Sweden, that had a tradition of the major part of the twentieth century, as expressed e.g. in Nanneson et al. (1945) and Wiktorsson (1979),
- Towards a lower level common internationally.

One historical reason why Sweden evolved a higher competence in this field than most nations is the socio-economic and biophysical contexts of the Swedish society over time. Ruminants were a major path to convert sunlight to food. The capacity to nourish the Swedish population was for a long period of time not sufficient. During the nineteenth and the first half of the twentieth century, the development of ruminant production systems in combination with crop rotations with leguminouses and grasses improved soil fertility and food security.

The historically strong dependency of ruminants of the Swedish population for the fulfillment of basic physiological requirements may well have put a higher selection pressure in favour of the development of efficient management strategies regarding milk production.

The changes in the way feeding strategies were constructed in Sweden during the 1990s implied a movement towards approaches common internationally, for example, in Denmark, the Netherlands and USA. Some references for this are Andresen (1994), Berg and Thuen (1991), NRC (2001). Other references are given in Hellstrand (2008a).

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[20] In reality, they are not fixed. When constructing a feeding plan, the steps taken normally imply an assumption of fixed rations of forages. This is a way to come around the problems of milk production and feeding as a typical complex system with mutual dependencies between systems and system levels.

Compared with the previous dcp system, the AAT system implied that the value of protein in forages in relative terms was decreased substantially more than for grains and crop protein feeds. That follows from a comparison of the official feeding table for ruminants in 1989 and 1995, e.g., (Spörndly 1989; 1995). At the same time, the assumed requirements for maintenance per cow and day increased in g when going from the dcp to the AAT/PBV system (ibid.). The typical way of constructing a feeding ration (see Hellstrand 1988) implies in a mathematical way that forages are used to supply the demands for maintenance purposes, and hopefully, the first kg of milk produced. Then, remaining demands for remaining production are met by rations of energy (grains) and protein concentrates (with high fractions of soymeal, respectively).

With the new system, two effects come into place at the same time. Every kg of forages was assumed to have a substantially lower capacity to fulfil the protein requirements for maintenance and the first kg of milk produced. And, the assumed protein requirements for maintenance increased. This resulted in a situation where in the new solution of the system of linear equations needed to theoretically exactly meet the remaining requirements of energy and protein, substantial quantities of grains were substituted with protein feeds.

The rules for organic milk production state that concentrates may be at most 40 % of the total daily dry matter intake. Thus, the fraction of total feed intake that is forages is 60 % or more. (i) The assumed drastic reduction in feeding value of protein in forages in combination with (ii) the higher maintenance requirements in terms of AAT compared to dcp, and (iii) the rule in organic agriculture stating that >60 % of the daily feeding ration should be forages created a situation where the official feeding standards become obsolete. If following the official feeding standards, a well-functioning feeding ration could not be constructed. That resulted in a quite odd situation:

While extension service organisations as well as the expertise at SUAS assumed that conventional and high-yielding dairy cows needed substantially more protein per kg milk than the official feeding standard stated, extension services directed towards organic milk production assumed the opposite. In a similar text as the one advising extension officers to increase the assumed requirements of protein for milk production in conventional milk production, the advice when generating feeding rations in organic milk production was to reduce it (Andresen). Andresen suggest 7–7.5 g AAT per MJ ME during the early phase of lactation compared to the 7.6 that is the official standards; and the 8.0–8.5 recommended in conventional milk production. Gustafsson (1990) in a field study got results, implying that by going from the dcp system to the AAT/PBV system, the theoretically estimated protein requirement would increase with about 10 %.The discussion above suggests some paths that might have contributed to this effect. Here, Andresen proposes a reduction of protein allowances with up to close to 10 %. Thus, the organic system in that sense can represent the situation before the AAT/PBV system was introduced in 1991.

By Andresen's recommendations regarding how to manipulate the official feeding standards,[21] reasonable relations can be maintained between grains and protein feeds also

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[21] A few years ago, I participated when a friend with organic milk production was visited by the extension officer. The feeding plan was constructed by these steps. First, the farmer told the extension officer how he would like the feeding plan to look. Then, the extension officer reported needed data regarding animals and feeds. In the last step in a trial-and-error mode, the extension officer probed different assumed protein allowance levels as the protein standard. When a feeding plan as the farmer believed in was obtained, the officer used the protein allowance behind as the protein feeding standard. This is quite a creative way of using feeding standards that have moved a long distance away from its original purpose, to condense experiences from feeding trials as a guide for farmers to achieve feeding plans fulfilling the physiological demands of the animals and the economy of the farmer.

in organic milk production while feeding the cows high forage rations. One reason why this can work is that in reality, ruminants through the selection advantage that rumination provides over millions of years have developed the capacity to utilise energy and protein from forages. Gustafsson (1990) (see Sect. 6.1.2) probed the outcome on commercial herds of the new protein evaluation system AAT/PBV. The outcome was surprising. The "waste fraction" PBV got statistical significance between level of PBV and milk yield, while allowance of the assumed quality fraction of protein AAT did not. That result indicates that the manipulation of the feeding standards recommended by Andresen can imply a correction of a flaw within the AAT system.

The following suggests one reason that might have caused the result in Gustafsson. A simple statistical analysis of all forages in the official Swedish feeding table for ruminants[22] shows the following R^2 values:

- MJ ME and crude protein 17 %,
- MJ ME and AAT 75 %,
- MJ ME and PBV 8 %,
- MJ and dcp 17 %,
- AAT and crude protein 8 %,
- AAT and dcp 8 %,
- PBV and crude protein 97 % and
- PBV and dcp 97 %.

So, with the new system AAT/PBV and talking in mathematical terms, a measure of the protein dimension of the nutritive content of forages (here "forages" is ley and pasture) was introduced, which mainly was a function of the energy, not the protein content of forages. In mathematical terms, this implies that when in the system of linear equations needed to balance the energy and protein requirements of the animal and when it comes to forages, the protein requirement of the animal is balanced by values that actually reflects the energy content of the feed, not the protein content. Then, the result of Gustafsson (1990) is no longer surprising but expected. A protein fraction with a believed higher quality, that to a substantial part actually is an energy measure not a protein measure, will have limited capacity to fulfil the protein requirements of the cows.

The manipulation of feeding standards proposed by Andresen just described results in a higher dependency of protein in the believed waste-fraction PBV in forages. That fraction has a high correlation with the protein contents of forages as determined by chemical analysis in combination with digestibility trials as reflected in the R^2 values above between PBV and dcp and crude protein, respectively (97 % both cases). The corresponding R^2 values for AAT are low, 8 % for both. Therefore, the chances that this will work on real farms are good.

Thus, by reducing the assumed requirement of protein as Andresen suggests, organic farmers might have corrected the aim of the rifle, so that the shot has a better direction.

The way of expressing the AAT value of forages as mainly a function of the energy content implies that the precision of the "shot" has decreased compared to the previous dcp system. The increase in protein allowances recommended in conventional milk production by the organisation dominating in extension services, Svensk Mjölk and associated organisations can be understood in terms of an insurance against the backlashes a decreased precision might cause. Then, it reflects mistrust in the organisation of the quality of the feeding standard system with associated feed evaluation system.

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[22] Fodertabeller för idisslare 2003, http://www.slu.se/sv/fakulteter/vh/institutioner/institutionen-for-husd jurens-utfodring-och-vard/verktyg/fodertabeller/fodertabell-for-idisslare-vallfoder/, accessed 2012-07-17.

The discussion above concerns the AAT/PBV system the way at it has been applied in Sweden. The problems penetrated can be due to causes on lower system levels, as well as to a principally invalid approach that is outside the scope of this study to evaluate.

The discussion above is needed to understand how it can be that organic and conventional milk production in Sweden commonly uses so different protein allowances in milk production, while the cows themselves most probably are not affected of whether the nitrogen supply to the crops is from commercial fertilisers or from nitrogen-fixating microbes. This knowledge also needs to evaluate whether there is a problem in using values regarding the content of nitrogen in manure for conventional milk production as estimates for organic one as, e.g. Cederberg and Flysjö (2004) and Cederberg et al. (2007) do. The following evaluates the significance of the two opposing ways of manipulating the official protein feeding standards. It also informs about the major differences in the feeding strategies in organic and conventional milk production.

Table 4 presents data for producing the same amount of milk per cow in one organic and one conventional system. The difference in energy concentration of feeding ration at top lactation of 0.70 MJ per kg DM may theoretically support a higher milk yield per cow and year of around 1,200 kg ECM in the conventional system.

The amount of milk produced per cow is constructed from the lactation curve for one organic farm as reported in the official milk recording programme 1998, Höglunda gård in Kil in Värmland. The basis for the biological and economic profile is given by the production branch calculi from SUAS, production year 2009,[23] for the production area Plain districts Svealand. The protein allowances per kg milk follows the feeding ration behind the conventional milk production system in the future study of SEPA (1997) delivered by Spörndly in 1996,[24] where the dairy feeding expertise at SUAS at that time designed a feeding strategy for the future, with the ambition to support a good economic result and high environmental standards through "precise" use of concentrates. Thus, that feeding plan expresses the perception at that time of leading national expertise regarding how to design a good feeding plan in conventional milk production. Here, the protein allowances per kg milk are substantially increased compared with the official feeding standards of that time (see Spörndly 1995), as discussed above. In the organic system, the protein allowances are decreased compared to the official feeding standards as proposed by Andresen. The results in Tables 4 and 5 shall be interpreted as examples of conventional and organic milk production.

Table 4 shows a substantial difference between the two systems in the feeding rations when the amounts of forages, grain and purchased feeds are compared. The influx of nitrogen through purchased feeds is 56 kg higher per cow and year in the conventional system. Due to internal loops of nitrogen on the farm between cows—manure—forages, the difference in the efflux of nitrogen out from the farm is around 20 kg per cow. Still, this is a substantial difference, which will affect emission of ammonia and nitrous oxide to the air, and discharges of nitrate to water systems. Thus, it is not appropriate to use about 10-year-old feeding ratios for conventional milk production as the source for data input regarding the amount of nitrogen in manure among organic farms.

The production biological and economic profiles of the two systems are different. "Value of environmental services" relate to the level of payment for such services the way it is defined within the Common Agriculture Policy of European Union.

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[23] www.agriwise.se, accessed 2012-10-15.

[24] Obtained from one of the authors of the future study.

Table 4 Production biological and economic profile of organic and conventional milk production, explanations see the text

	Organic	Conventional	Organic minus conventional
Energy concentration (MJ per kg DM, at top lactation)	12.05	12.75	−0.70
Production (kg ECM[a] per cow and year)	9,272	9,272	0
Milk delivered (kg ECM per cow and year)	8,577	8,577	0
Forages (kg DM)	4,722	3,040	1,682
Grain (kg)	1,092	1,100	−8
Purchased feeds (kg)	593	2,027	−1,434
Economic result, milk production (SEK)	9,034	−2,723	11,757
Nitrogen in manure (kg)	97	117	−20
Nitrogen influx, purchased feeds (kg)	27	83	−56
Forages (ha)	1.5	0.8	1
Grain (ha)	0.5	0.2	0
"Soya beans" (ha)	0.2	0.6	0
Sum (ha)	2.2	1.6	1
Diesel, field work + silage packing (dm^3)	91	55	36
Mineral fertilisers (kg N)	0	22	−22
Mineral fertilisers (kg P)	0	3	−3
Herbicide, no tablet Express 50 T		0.4	−0.4
Biocide (dm^3 Pirimor)		0.07	−0.07
Fungicide (dm^3 Tilt Top 500 EC)		0.2	−0.2
Value of environmental services	1,074	234	841
Result in crop production	2,394	−240	2,634
Sum result per cow, including supporting crop production, SEK	11,428	−2,963	14,390
Increase in results, SEK per hour (188 SEK per hour in calculus)			379

Value of SEK, see Table 3

[a] Energy corrected milk

If producing all milk in Sweden as organic (see Table 5), it will compared to conventional production

- increase land use in Sweden for the production of grain and forages with around 373,000 ha,
- decrease land use in, for example, Brazil with 151,000 ha,
- increase total land appropriated for the same production of milk with 222,000 ha,
- increase economic result with 5.5 billion SEK, that is, 380 SEK per hour labour,
- increase the use of diesel with 13,800 m^3,
- decrease the use of mineral nitrogen fertilisers with 8,500 tonnes,
- decrease the use of mineral phosphorus fertilisers with 1,250 tonnes,
- decrease the amount of nitrogen in manure with 8 million kg,
- decrease the nitrogen influx via purchased feeds with 21 million kg,
- decrease the use of insecticides and fungicides with 101 m^3 in Swedish agriculture and
- decrease the number of herbicide tablets with 144,000.

Table 5 Production biological and economic profile when producing 3.3 billion milk ECM, in an organic and a conventional system, respectively, assuming production profile per cow as in Table 4, further explanations see Table 4

	Organic	Conventional	Organic minus conventional
Delivered (billion kg ECM)	3.3	3.3	0
Forages (million kg DM)	1,817	1,170	647
Grain (million kg)	420	423	−3
Purchased feeds (million kg)	228	780	−552
Economic result, milk production (million SEK)	3,476	−1,048	4,524
Nitrogen in manure (million kg)	37	45	−8
Nitrogen influx, purchased feeds (million kg)	10	32	−21
Forages (ha)	586,072	299,931	286,141
Grain (ha)	182,750	96,190	86,560
"Soya beans" (ha)	72,964	223,670	−150,706
Sum (ha)	841,786	619,791	221,995
Diesel, field work + silage packing (m^3)	34,826	21,048	13,778
Mineral fertilisers (tonnes of N)	0	8,465	−8,465
Mineral fertilisers (tonnes of P)	0	1,250	−1,250
Herbicide, no tablet Express 50 T	0	144,286	−144,286
Biocide (m3 Pirimor)	0	29	−29
Fungicide (m3 Tilt Top 500 EC)	0	72	−72
Value of environmental services (million SEK)	413	90	323
Result in crop production (million SEK)	921	−92	1,013
Result in milk production, including supporting crop production (million SEK)	4,397	−1,140	5,537

Note, the difference in nitrogen influx of 21 million kg nitrogen is similar as the reported increase via purchased feeds to cattle from 1991 to 1999 of 22.8 million kg (Hellstrand 2006). The modification of the protein standards in this example implies a correction towards the situation just before the introduction of the AAT/PBV system. The conventional system in the example is based on the feeding strategy that leading national expertise chose at that time in a future study by SEPA, aiming at precise feeding supporting economic and environmental sustainability objectives: The results, thus, support the conclusion that changed feeding standards and the way they were used is a major explanation for the decreased nitrogen efficiency in Swedish milk production 1991–1999.

The evaluation of the sustainability of the two production systems in Tables 4 and 5 is not straightforward, as there is a conflict between productivity per ha and other sustainability aspects. The issue is further complicated as the conventional system to a higher degree utilises non-renewable natural resources. How the production levels would be in the conventional system compared to the organic if assuming that only renewable natural resources was used, is an open question.

This strongly inflicts the results in their comparisons between the two production systems given the situation 8 and 11 years later, respectively. In the analysis of the fertilising effect of plant nutrients in biological systems, strict additive effects are assumed between nutrients and between ecosystems globally irrespective of the situation in the concerned ecosystems. The analysis floats free from the context of the system and issue focused. The

complexity and variation of conditions in ecosystems in time and space is reduced to zero. This is in strong conflict with the knowledge frontier regarding the same issue in agricultural and crop production science since the contributions by Liebig (1840) and Shelford (1913).

The model of the global system for food production developed by Wirsenius (2000) named the FPD/ALBIO model uses an efficiency measure expressed as ratio between gross energy in food consumed through gross energy in biomass appropriated. That way the physiological complexity of humans is reduced to the same as wood stoves. In the model, the top soil layer of agricultural land is not included. That implies that the 50 % of total biomass produced annually that is recycled in crop residues and manure to agricultural land in the model is classed as losses. That reflux is around 7 billion tonnes dry matter or 1.4 tonnes dry matter per ha. In reality, these refluxes are preconditions for maintained content of organic matter and plant nutrients securing maintained productivity of agricultural soils, that is, maintained quality of one of the most essential stocks of natural capital providing the physiological necessities for the life of 7 billion people. Azar concludes that meat production is responsible for about 18 % of global greenhouse gas emissions with reference to FAO (2007, should be 2006). The estimate of 18 % provided by FAO is for all animal production not only meat, including emissions in the transportation and processing from mines to food industry. That measure provided by FAO is before considering the annual carbon sink capacity in grassland and rangeland of 6.2 gigaton carbon dioxide (87 % of the FAO estimate of emissions) mainly supporting ruminant production that FAO also identified. Furthermore, Azar concludes with reference to Wirsenius et al. (2010) that a substitution of pork and/or poultry for 20 % of ruminant meat would "drop" pressure on tropical forests. Given the construction of the FPD/ALBIO model (see below), the analytical tool that Azar and Wirsenius et al. rely on, this conclusion cannot be drawn. It is also in conflict with the findings in FAO (2006): pork and poultry production depends on substantial fractions of soymeal, ruminant meat production do not have to utilize high rations of soymeal as their comparative advantage is the capacity to utilize forages (although there are feeding regimes to ruminants dominated by concentrates). FAO (2006) is clear about this and that the reason is that people, pigs and poultry are monogastric creatures, ruminants are not. Given typical feeding rations for pork and poultry in Sweden, one kg of pork or poultry meat replacing one kg of ruminant meat increases the consumption of soymeal with 0.8 kg. That results in an extra pressure on tropical deforestation of 3.6 m^2, which increases the emissions of carbon dioxide with 250 kg according to the route of calculations in FAO (2006).

Still though, a fact that can be confusing: In reality, cattle can use significant amounts of crop protein feeds (Figs. 1, 2, 3), while this is not a physiological requirement. Thus, in some production systems, cattle are reared as if they were pigs, and this is not efficient from a sustainability perspective. The conclusion from that is not to decrease cattle production but to improve its socio-ecological efficiency.

One reason why Azar has not realised this relation is that his argument is based on Wirsenius et al. (2010), which is based on Wirsenius et al. (2011[25]). The later is based on results from different LCA studies regarding animal production systems, e.g., Cederberg and Flysjö (2004). These LCA studies have not considered the impact of changed land use. Thus, when Azar draws conclusions regarding the positive impact on climate change mitigation and conservation of tropical forests of replacing ruminant products with products from pork and poultry, he provides an example of the risks of extrapolating results

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[25] The version available on line in 2010.

from a part of reality investigated, to other parts not investigated. The conclusion is based on results from analyses that ignore the possibility of these impacts, while in reality, the causal relations are strong. That is one reason why that conclusion is in conflict with FAO (2006).

Wirsenius et al. (2011) have utilised the mentioned FPD/ALBIO model of global food production. The most detailed description is Wirsenius (2000). One limitation in its usefulness is that it does not consider the protein requirements of animals. Another is that it wrongly presupposes that dairy cattle do not use crop protein feeds. Therefore, when Azar refers to work that is based on the results in Wirsenius et al. (2011), in claiming that a substitution of pork and/or poultry for 20 % of ruminant meat would "drop" pressure on tropical forests, this cannot be supported by the provided reference, as the used analytical tool lack the capacity to on the margin link how changes between and within different animal production systems will affect demand on protein feeds. Without considering the physiological protein requirements of different animals used for different purposes, the used analytical tool lack capacity to relate such changes to, for example, changed pressure on tropical deforestation for soya production.

The work of Azar (2011) and Wirsenius et al. (2010, 2011) now influence or have the ambition to influence policy work from local community level, over regional level to Swedish Environmental Protection Agency to the EU level to the scientific committee of IPCC regarding climate change, renewable energy, and the perception of how to meet societal demands on food and biofuels (see also Chum et al. 2011 e.g. p. 230; SEPA 2011; Länsstyrelsen i Värmland 2012). With its weak foundation in agricultural sciences, where some of the weaknesses have been pointed out above, the issue at hand is whether the capacity of agricultural soils to provide enough food will be harmed, if suggested policy measures are enforced.

An epistemological issue is by what scientific criteria the professionals within one discipline can claim the right to extrapolate their methods and concepts to pressing issues in such fields of reality where they have no professional training.

More important, which this paper shows, development of ruminant production systems may at the same time make a substantial contribution in improving global food security, increasing land area available for bioenergy purposes, and supporting conservation of biodiversity and forests. This is not to deny that there are sustainability problems in current animal production systems. This stresses the need to handle them with accurate professional skills.

7 Conclusions

The paper shows that animal production is of great importance for global food production and for environmental issues related to agriculture. Around 40 % of total production value in agriculture relates to animals products. Of total land area of 13 billion ha, 1.4 billion are arable land and 3.4 are permanent pastureland, in total 4.9 billion ha agricultural land. Around 70 % of total biomass appropriated in food production from agriculture support animal production systems. Two-thirds of these 70 % are re-circulated in system-reinforcing feedback loops through manure and crop residues.

Substantial potentials for sustainability improvements in animal production systems have been identified through moderately decreased consumption of chicken meat in developed nations; develop the capacity of ruminants to produce high-quality food from

otherwise marginal agroecosystems; increased milk production level per cow; and increased feeding efficiency in milk production.

For example, better feeding of dairy cows on global level in terms of improved nitrogen efficiency decreasing the assumed requirement of protein feeds would in rough terms, half the total area of the current acreage now devoted for soymeal production for feed purposes. The potential positive impacts on farmers result, conservation of tropical forest and of biodiversity, climate change, eutrophication and acidification, deterioration of the stratospheric ozone layer, global food and bioenergy supply are substantial.

The development of sustainable animal production systems requires methods that can measure ecological, economic and social impacts of production systems within a sustainability context, and identify potentials for improvements. The paper provide examples of such methods, basically through the upgrading of traditional management and analytic methods in agriculture that over centuries have been used and through a process of trial and error in the real world improved their capacity to successfully manage the complex ecological economic production systems that agriculture and animal production are. This upgrading has been achieved by integrating common tools for farm management with contributions within post-normal science as Impredicative Loop Analysis, and the analytical approach in Millennium Ecosystem Assessment. Contributions from systems ecology, economic theory and complex systems theories are integrated as well.

Furthermore, incentives on societal level are needed that support choices among households and enterprises that support a sustainable development.

Within animal production sciences, two critical areas are (i) ruling principles behind common systems for the formulation of energy and protein standards in milk production and (ii) methods now commonly used with the ambition to measure the sustainability performance in animal production systems. Interestingly, in general terms, the paper suggests the same measures in (i) and (ii). In order to improve feeding regimes in dairy production as well as general management strategies for sustainable natural resource management, there is a need to consider the "laws" of diminishing returns, the minimum and of tolerance in biological systems in such a way that economically feasible and ecological sustainable production is achieved.

The paper stresses the importance of strengthening the role of agricultural sciences in the sustainability context. That implies to go back to central findings in agricultural sciences regarding production systems that meet demands on sufficient productive and sustainable production systems; considering thresholds, irreversibilities and resilience phenomenon that agriculture during thousands of years of practice has learnt to deal with; and re-utilise this knowledge about the production factor land on societal level in the general sustainability context. It is suggested that in that process, methods and concepts in agricultural science are integrated with the latest contributions within the field of agroecology such as Impredicative Loop Analysis, for improving management of complex agroecosystems.

This is a prerequisite for the development of agricultural systems with increased capacity to support a sustainable society. In this context, animal production is of a significant importance. If not, global food security is at risk.

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