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Sustainable production of protein of animal origin – the state of knowledge. Part 2. Aquirements, objectives and ways of sustainbility improvement

G. Flachowsky and U. Meyer[1]

Institute of Animal Nutrition, Friedrich-Loeffler-Institut (FLI), Federal Research Institute for Animal Health
Bundesallee 50, 38116 Braunschweig, Germany

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[1] Corresponding author:
e-mail: ulrich.meyer@fli.bund.de

ABSTRACT. This part describes challenges to improving sustainability during the production of food of animal origin. Some potential advancements in the sustainability of producing food of animal origin, such as feeds that do not compete with human nutrition, plant and animal breeding, trends in animal nutrition, potential alternative protein sources, alternatives of animal products in nutrition, including lower food losses, are discussed in the paper. The potential for reducing gaseous emissions is also an important chapter in this contribution. Complex calculations employing parameters of efficient use of limited resources and reduction of emissions seem to be helpful in finding optimums in production of food of animal origin.

Challenges to improving sustainability during production of food of animal origin

There are currently many ways to overcome food deficiency and to produce food in more sustainable ways. More efficient animal nutrition, feed that is non-competitive with human nutrition (e.g., grassland, co-products of agriculture, food and biofuel industries (Makkar, 2012) or other biomasses), reduction of loss and waste in agriculture, food processing, trade and households, as well as in plant and animal breeding are the most promising (Niemann et al., 2011; Flachowsky et al., 2015). Other options, like the use of insects as food (EFSA, 2015) or other alternative foods, or changes in eating patterns are under discussion. More details are given in the following sections.

Plant breeding

Plant breeding can be considered the starting point of the food chain (Part 1; Figure 2) for sustainable plant (feed) production (SCAR, 2008; The Royal Society, 2009; Flachowsky et al., 2013a). It has a large and strategic potential for global feed and food security.

Developing high-yield, stable and highly digestible crops with low external inputs of non-renewable resources, such as water, fuel, arable land, fertilizers, etc., low emissions of gases with greenhouse potential during cultivation, high resistance against biotic and abiotic stressors, including adaptation to potential climate change (Reynolds, 2010; Newman et al., 2011; Fischer et al., 2014) and low concentrations of undesirable substances in the plants, are important challenges for plant breeders. Plants with these properties would allow more sustainable production in the future and would be important in human and animal nutrition. Such an ideal crop (Pennisi, 2010) may contribute to sustainable plant production. Additional aspects for plant breeders from the viewpoint of animal nutrition are:

- consideration of forages and grassland
- biofortification of plants is not so important because many feed additives is available
- the feed value of co-products after processing 'new' plants for food and biofuel
- recommended animal feeding studies with target animal species to evaluate the nutritional effects and safety of the changes induced in the plants (Flachowsky, 2013; Van Eenennaam and Young, 2014)
- cooperation between plant breeders and animal nutritionists in the early stages of breeding programmes.

Traditional breeding, as well as 'green' biotechnology ('green' chemistry, genetic engineering; Guillou and Matheron, 2014) can contribute to fulfilling the objectives mentioned above. Genetically modified plants may achieve these objectives faster and with greater precision (Tester and Langridge, 2010; Flachowsky, 2013), but are under critical public discussion presently. More activities and more public-supported research in these fields are necessary for sustainable utilization of natural limited resources and for improved use of unlimited resources such as sun energy/light, CO_2 and N_2 from the air, or the global gene pool. All methods of plant breeding that contribute to more resource-efficient production of high and stable yields of available biomass should be used. Ruane et al. (2013) and Andersen et al. (2015) analysed new breeding techniques for organic farming and came to the conclusion that the most efficient methods are based on modern biotechnology techniques, which have yet to be embraced by the organic farm movement. In addition, the potential use of new breeding technologies in organic farming is limited in the EU, where the current regulatory framework is process based and would classify products produced using new technologies as genetically modified organisms (GMO). The question arises whether the adoption of biotechnological methods is feasible not only from the perspective of sustainability, but also from conceptual, socio-economic, ethical and regulatory perspectives.

Animal breeding

An important contribution to meet the increasing needs for food of animal origin and mitigating undesired effects in animal husbandry is to enhance the efficiency of animal growth, reproduction, lactation and laying performance (Wu et al., 2014a). The breeding of domestic animals has a long-standing and successful history, starting with domestication several thousand years ago, when man kept animals in his proximity and used products thereof. Using the technical options that were available in each time period, humans have propagated those populations that deemed useful for their respective needs and purposes. Selection mostly occurred according to desirable traits. Scientifically based animal breeding has only existed for about 50 years, supported mainly by population genetics and statistics.

Modern animal breeding programmes include biotechnological procedures, of which artificial insemination (AI) is the most prominent. Presently, AI is employed in more than 90% of all sexually mature female dairy cattle in countries with advanced breeding programmes. Strategies to breed animals that more efficiently process feed into animal-derived food and concomitantly decrease emission per product unit may contribute to more sustainable livestock production (Thornton, 2010; Niemann et al., 2011). The objectives of these strategies comprise:

- higher feed intake of animals (NRC, 1987; Forbes, 1995) to improve the ratio between energy/nutrient requirements for maintenance and animal yields (Part 1; Table 5)
- higher digestibility of feed (Tillie et al., 2013) to make energy and nutrients more available from the same amount of feed
- using the advantages of ruminants (Hungate, 1966; van Soest, 1994; Hobson and Stewart, 1997) and reduction of energy losses from the digestive tract, e.g., CH_4 (Baldwin, 1995; Kebreab et al., 2006)
- higher absorption of the digested nutrients
- lower energy and nutrient requirements for maintenance of the animals
- lower energy needed for protein synthesis in the body
- stimulation of anabolic processes and decreasing catabolic processes in the animal
- lower fat content in animal bodies, lower excretion of fat in milk and eggs and of lactose in milk (lower energy content in products)
- improved animal health, specifically higher resistance against biotic and/or abiotic stressors and lower losses may contribute to longevity (e.g., of dairy cows) and more efficient conversion of feed.

In summary, the strategies discussed above show that breeding strategies may contribute to lower energy requirements of animals and to more efficient feed conversion. In the future, existing and emerging breeding technologies could be instrumental in producing livestock with much greater feed efficiency and in improving the sustainability of animal husbandry. Ruane et al. (2013) analysed 12 case studies of application of biotechnology in livestock and aquaculture and concluded that these techniques have great potential for improving on-farm productivity and living conditions of farmers.

Contributions of animal nutrition

Progress in feed science, nutritional physiology and animal feeding are important key elements for more efficient conversion of feed in food of animal origin and lower emissions per animal product (Flachowsky et al., 2013a; Makkar and Ankers, 2014). There are some strategies that contribute to this objective, such as:

- production, conservation and preparation of high quality feeds
- higher feed intake of animals to improve the ratio between energy/nutrient requirements for maintenance and animal yields (e.g., Niemann et al., 2011)
- better knowledge about animal requirements in essential nutrients (e.g., amino acids, minerals, vitamins) and supplementation of feed with adequate nutrients and some non-essential feed additives
- meeting the protein and amino acid requirements more precisely by ration calculation on the basis of adequate animal requirements (e.g., precaecal amino acids; GfE, 2008, 2014) and supplementation with amino acids
- supplementation with feed additives for better digestion and utilization of feeds or special nutrients in feed (availability of P from phytate-P with the enzyme phytase).

These and further measurements contribute to more efficient conversion of feed. For example, feed use per kilogram of egg mass decreased in Europe from 3.1 (1968) to below 2 kg (EU, 2008) or the phosphorus excretion of fattening pigs (35–115 kg body weight) decreased from 625 (without phytase) to 350 g per animal with phytase supplementation (GfE, 2008). Wu et al. (2014a) analysed pork production in the United States between 1959 and 2009 and found improvement in the feed:gain ratio from 6.6 to 4.4 $kg \cdot kg^{-1}$ of dressed carcass, a decrease in the CF from 8.4 to 5.5 kg per kilogram dressed carcass and in the efficiency of land use from 365 to 1672 kg of dressed carcass per hectare. Feed efficiency can be considered a key driver of productivity, resource use and greenhouse gas (GHG) emissions (Herrero et al., 2013).

In relation to nutrient requirements and further improvement of feed efficiency, the NRC (2015) concluded that ‘research should continue to develop a better understanding of nutrient metabolism and utilization in the animals and the effects of those nutrients on gene expression. A systems-based holistic approach needs to be utilized that involves ingredient preparation, understanding of ingredient digestion, nutrient metabolism and utilization through the body, hormonal controls and regulators of nutrient utilization. Of particular importance is basic and applied research in keeping knowledge of nutrient requirements of animals current.’

Use of feeds that do not compete with human nutrition

Some feeds such as grassland, co-products from agriculture, the food and biofuel industries, etc., do not compete with human nutrition. Therefore, they do not compete with arable land and further limited resources and have a large potential for animal nutrition.

Ruminants are generally independent from grains or concentrates because their rumen microbial population is capable of digesting plant fibre. They are able to produce edible protein as milk and meat from permanent meadows and pastures. Their advantages compared with non-ruminants are very often described (e.g., Hungate, 1966; van Soest, 1994) and will not be further discussed here. Pastoral systems may contribute to meeting human demand for food of animal origin, and are more efficient in producing food per unit of area of dryland than other forms of agricultural land used under such conditions (HLPE, 2012). Pastoralist are also efficient users of resources like manure (Powell et al., 2013). Because of the predominantly high fibre content of roughage from grassland and low animal yields, the methane emissions and carbon footprints (CFs) per kilogram edible protein may be higher under such extensive conditions (FAO, 2010; Gill et al., 2010); GHG mitigation measurements are, therefore, important (Hristov et al., 2013a,b; Opio et al., 2013).

Besides roughages and concentrates, not only co-products from agriculture, such as cereal straw, but also from food production and the biofuel industry are commonly used in animal feeding. Co-products are by-products of main processes such as grain production (e.g., straw, stalks, husks), processing of raw products in the food industry (e.g., extracted oil meals from the oil industry, bran from cereal processing, beet pulp or bagasse from the sugar industry, animal co-products from milk, fish, or meat processing) or from the biofuel industry (e.g., dried distillers grains’ with solubles called DDGS; cakes and meals from rape and other oil seeds). According to FAO (2010), between 10 and 50% of concentrate comes from co-products in various global regions. In some countries, up to 100% of concentrate may be based on co-products. Co-products are mostly inedible to humans and otherwise would be wasted or used for energy production. They are used in various amounts and proportions in animal diets. Cereal straws and other co-products rich in plant cell walls are poorly digestible and thus are poor energy and protein sources. They are fed to ruminants with low animal performance or to meet their maintenance requirements. In the nutrition of yielding ruminants they can be considered only as a source of fibre. They are not used in the feeding of non-ruminants.

Co-products from the food and fuel industries usually contain more nutrients not removed by processing than raw materials (e.g., protein in the case of DDGS). They can be used as valuable sources of protein, minerals and other nutrients, depending on the raw material and chemical or physical processing without any land footprint. In the future, more cereal grains will be used for food and fuel and more co-products will be available for animal nutrition. More details about the nutritive value and utilization of co-products from the biofuel industry in animal nutrition were recently compiled by Makkar (2012). Also some other biomasses such as algae, seaweed, duckweed, leaves and twigs of trees and shrubs, etc., do not compete with human nutrition and are used as animal feed (van der Spiegel et al., 2013).

The NRC (2015) concluded that 'research should continue to identify alternative feed ingredients that are inedible to humans and will notably reduce the cost of animal protein production while improving the environmental footprint. These investigations should include assessment of the possible impact of changes in the protein product on the health of the animal and the eventual human consumer, as well the environment.'

Potential of insects and other protein sources

Apart from developments in plant and animal breeding and nutrition, the utility of insects (e.g., Makkar et al., 2014; Morales-Ramos et al., 2014), molluscs, snails and microbial biomasses (Anupama and Ravindra, 2000; Zepka et al., 2010) are being studied as alternatives in order to stabilize and improve human and animal nutrition.

Presently, insects as feed and food are considered a 'hot topic' in Europe. Some European countries (e.g., Belgium, France, Iceland, the Netherlands) have performed risk assessments related to insects as food and feed. In May 2014, Wageningen University (the Netherlands) organized in collaboration with the Food and Agricultural Organization of the United Nations (FAO) an international conference entitled Insects to Feed the World. The European Food Safety Authority (EFSA) submitted a Scientific Opinion on the 'Risk Profile Related to Production and Consumption of Insects as Food and Feed' (EFSA, 2015) and the Wageningen Academic Publishers started in 2015 to publish a scientific journal entitled Journal of Insects as Food and Feed.

More than 1900 insect species in various development stages (van Huis, 2013) are eaten by humans worldwide. The most commonly eaten insect groups are from the orders: *Coleoptera* (beetles), *Lepidoptera* (caterpillars of butterflies and moths), *Hymenoptera* (bees, wasps, ants), *Orthoptera* (grass - hoppers, locusts, crickets, termites), *Hemiptera* (cicadas, leaf and plant hoppers, true bugs, scale insects), *Odonata* (dragonflies) and *Diptera* (flies) (EFSA, 2015).

Because of the large variety of insects consumed, it is difficult to give a representative review of their nutritional composition. There are, however, some papers that summarize compositional data (Table 8). The chemical composition depends on the species and developmental stage (eggs, larvae, pupa, adults) and the diet fed to insects. Handling, preparing and processing of insects may also influence their composition and nutritive value (van Huis, 2013; Makkar et al., 2014; EFSA, 2015). In insects prepared for human consumption, wings, legs and gastrointestinal contents are often removed, possibly also due to different analytical approaches. Because the nutritional composition of insects is difficult to establish, only some general statements can be made. Table 8 shows the range of proximate compositions of insects according to different authors. Tryptophan, lysine and histidine are considered the most frequent limiting amino acids in insect proteins (Finke, 2004; Sanchez-Muros et al., 2014).

Notwithstanding tradition and ethical reasons, more research on the nutritive value and on the microbiological and chemical hazards of insects, insect products and other 'new' feeds and foods is necessary. Safety research should be also intensified when insects are growing on bio-wastes, including manure or in regions with undesirable substances in the food chain (EFSA, 2015).

Alternatives to protein of animal origin

Foods of plant origin with a high protein concentration such as grain-based products, legumes and nuts can replace animal protein in the human diet. The protein concentration varies among the different plant sources from approximately 10 to 30% (EFSA,

Table 8. Examples of different insect species proximate body composition ranges by various authors (crude nutrients by Weender analysis; in % of dry matter)

Authors	No of samples, species	Crude protein (N x 6.25)	Crude fat (ether extract)	Carbohydrates (NFE[1], fibre, NDF[2])	Crude ash
Rumpold and Schlüter, 2013	234	4.9 – 74.8	0.7 – 67.2	3.0 – 86.3	0.6 – 26.0
Sanchez-Muros et al., 2014	72	9.5 – 70.1	1.5 – 56.1	1.8 – 77.7	0.6 – 26.0
Makkar et al., 2014	Black soldier fly larvae	41.1 – 43.6	15.0 – 34.8	7.0	14.6 – 26.8
	Housefly maggot meal	42.3 – 60.4	9.0 – 26.0	1.6 – 8.6	6.2 – 17.3
	Tenebrio molitor	47.2 – 60.3	31.1 – 43.1	7.4 – 15.0	1.0 – 4.5
	Locust or grasshopper meal	29.2 – 65.9	4.2 – 14.1	2.4 – 14.0	4.4 – 10.0
	House cricket	55.0 – 67.2	9.8 – 22.4	15.7 – 22.1	3.6 – 9.1
	Silkworm pupae meal	51.6 – 70.6	6.2 – 37.1	2.5 – 5.8	3.3 – 10.6

[1] NFE – N-free extractives, [2] NDF – neutral detergent fibre

2012; Day, 2013). There are some alternatives to protein of animal origin and initiatives have been taken to replace it in other ways and by producing similar products (e.g., soya milk, tofu, rice milk). Such food is usually produced from valuable protein sources of plant origin (e.g., soyabean, wheat, rice, maize, barley, pea, sorghum, lupine and chickpea). Developers try to create new meat and milk analogue products by combining proteins from various plant sources (Aiking, 2011; Day, 2013).

Cultured muscle cells (Dodson et al., 1997; Post, 2014) from bovine skeletal muscle stem cells produced beef with the same nutritional value as livestock and can also be an alternative to 'traditional' protein of animal origin. Protein synthesis by cultured skeletal muscle cells should be very efficient. Further studies including psychological obstacles concerning public acceptance are necessary for optimization of the protein and fat content of cultured beef. Research in this field is a great challenge for the future.

Reducing food losses and changing eating patterns

The issue of global food losses and wastes has recently received much attention. According to FAO (2013b), about one-third of food produced for human consumption – about 1.3 billion tones of edible food – is lost or wasted globally per year. This amount is the equivalent of about 24% of all the calories currently produced for human consumption (Lipinski et al., 2013). In developing countries, food waste and losses occur mainly in the early stages of the food chain; in medium- or high-income countries, food is wasted or lost mainly in later stages of the food chain (FAO, 2011). Reduction of these losses is essential for improving food security, sustainability of food production and for reducing the environmental footprint of food systems.

Recently HLPE (2014) analysed and summarized the reasons for food losses from the field to the consumer and gave the following recommendations to reduce these losses:

- improvement of data collection and sharing knowledge on food losses and waste
- development of effective strategies to reduce food losses and waste, at the appropriate levels
- implementation of effective steps to reduce food losses and waste
- better coordination of policies and strategies in order to reduce food losses and waste.

More details about reducing food losses and waste can be found in some recent papers and reviews (Parfitt et al., 2010; FAO, 2011; Lipinski et al., 2013; Blanke, 2015).

Human eating patterns may also influence the sustainability of agriculture and animal husbandry. Higher demand for food of animal origin as a result of growing incomes (Keyzer et al., 2005; Kastner et al., 2012) requires higher plant yields and/or more area for feed production (Gerbens-Leenes and Nonhebel, 2002; Wirsenius et al., 2010), as well as more animals and/or higher animal yields and an increase in agricultural trade. Therefore, some authors propose a redefinition of agricultural yield and agriculture: 'from tons to people nourished per hectare' (Kastner et al., 2012; Cassidy et al., 2013) and ask for more sustainable animal agriculture (Kebreab, 2013; SAFA, 2013). On the other hand, changing eating patterns (Guyomard et al., 2012) and eating less or no livestock products, especially meat, are often seen as possible solutions to reducing the environmental impact of animal agriculture (Pimentel and Pimentel, 2003; Baroni et al., 2007) and per capita land requirements (Peters et al., 2007; Flachowsky et al., 2015) and should contribute to more sustainable animal production.

Table 9. Feed measurements to reduce enteric methane emission, importance on farm level and research need in ruminants

Measurements	Significance (esp. for Europe) on farm level	Research need
Feeds and feeding		
• more concentrate, less fibre in diet	Limited, because of high concentrate amounts already in many diets	~
• forages with high digestibility, low fibre content	Consideration in plant breeding and practical feeding	⇑
• fats and fatty acids in diets	Limited, because of some side effects in the rumen	⇑
Application of feed additives		
• halogen compounds (e.g., chloral hydrates)	Banned in the EU	~
• Ionophores (e.g., monensin)	Banned in the EU	⇑
• addition of hydrogen acceptors, such as fumaric acid, acrylic acid, etc.	Presently no significance	⇑
• addition of phytogenic substances (essential oils; plant extracts or plants containing such substances, e.g., garlic); tannins; saponines	Presently no significance	⇑⇑
• addition of 3-nitrooxypropanol and other nitrooxy carboxylic acids	Presently no significance	⇑⇑
• further additives, such as yeasts, enzymes, etc.	Presently no significance	⇑
Selection of ruminant species with low CH_4 emission	Presently no significance	⇑⇑

⇑⇑ – high need; ⇑ – need; ~ – not so important

Reduction of emissions

As already mentioned (Part 1), methane (CH_4) is the most important GHG associated with animal husbandry coming directly from animals (e.g., Hristov et al., 2013a), from excrement management (Hristov et al., 2013b; Montes et al., 2013), or from land use changes (Rounsevell et al., 2012; Havlik et al., 2013). Carbon dioxide (CO_2) from animal metabolisms will be recycled by plant growth (Part 1, Figure 2) and nitrous oxide (laughing gas, N_2O) is not directly excreted by animals (see Part 1). Therefore, the possibilities of reducing methane emissions (Part 1, Methane (CH_4)) will be discussed below.

Some possibilities for reducing methane emission in ruminants, such as increasing forage digestibility and digestible forage intake, dietary lipids, higher dietary concentrate proportions, or the application of various feed additives are shown in Table 9 and are mentioned by some authors (e.g., Blaxter and Czerkawski, 1966; Beauchemin et al., 2009). Potential reduction strategies have been grouped in three complexes in Table 9:

- effects of feeds/feeding/ration composition
- ration supplementation with feed additives
- selection of ruminant species.

GHG emissions can be reduced by increasing animal productivity and feed efficiency using metabolic modifiers, such as growth hormones and ionophoric antibiotics, but the applicability of these mitigation practices is limited to regions where their use is permitted. Ranga Niroshan Appuhamy et al. (2013) have analysed the data from 22 controlled feeding studies on the potential of methane reduction by the ionophoric substance, monensin. Its mitigation effects were small (12 or 14 $g \cdot d^{-1}$ in dairy cows and beef cattle) when adjusted for dose.

Hydrogen acceptors, such as fumaric acid, acrylic acid and other substances may also contribute to H_2-binding in the rumen, but the *in vivo* effects are small and inconsistent (Bayaru et al., 2001; Remling et al., 2014).

Many studies have been done with substances of plant origin such as tannins, non-tannins, phenols, saponins, essential oils, and whole plants or parts of plants. The development of new feed additives, mainly based on plant extracts, to decrease methane production within the rumen has attracted much research over the last 20 years. The results remain variable and contradictory, as summarized by Benchaar and Greathead (2011). The effects of plants or plant extracts having a high content of saponins, flavonoids and tannins varied depending upon the source, type and level of secondary metabolites present in the plant material. These may limit the demand and use of such substances in the animal feed market for reasons related to several factors, including the lack of persistency of the effects when they are tested *in vivo* due to the adaptation of the microbial ecosystem, the variability of concentration of active compounds in plant extracts, the stability of the active substance within the rumen, and possible side effects that compromise overall rumen fermentation (Hart et al., 2008).

Most of the substances were tested in *in vitro* studies and they may have a potential to reduce methane emissions from ruminants, although their long-term effects have not been well established and some are toxic or may not be economically feasible. Impressive results of *in vitro* studies were mostly not repeated under *in vivo* conditions. Therefore, Flachowsky and Lebzien (2012) proposed a five stage programme to evaluate the effects of such additives, with special consideration of phytogenic substances:

- botanical characterization of the plant(s) and their composition
- analytical characterization of the active phytogenic substance(s)
- *in vitro* studies to test effects of substances on rumen fermentation and methanogenesis (i.e. screening)
- *in vivo* studies comprising feed intake, rumen fermentation and CH_4 emissions
- long-term feeding studies with target animal species/categories (animal health and performance, quality and safety of food of animal origin, environmental impact, adaptation of microbes).

Another reason for the restricted use of phytogenic substances as methane inhibitors may be their potential transfer from feed into food of animal origin and possible residues in animal products and their effects in humans (EFSA, 2009; Speijers et al., 2010).

The development of synthetic compounds with specific activities to influence metabolic pathways essential to ruminal archaea may overcome some drawbacks of phytogenic compounds. Inhibition of methyl-coenzyme M reductase which catalyses the last step of reduction of CO_2 to CH_4 by hydrogenotrophic methanogenic archaea (Attwood and McSweeney, 2008) has been studied extensively. In preliminary studies by Martínez-Fernández et al. (2013) and Romero Perez et al. (2013), the authors tested the effects of inhibitors of methyl-coenzyme M reductase, such as nitrooxy propionate compounds on ruminal fermentation and methane emissions. These substances are able to reduce the final step of CO_2 to CH_4 by methanogenic archaea (Duval and Kindermann, 2012). Martínez-Fernández et al. (2014) studied the effect of ethyl-3-nitrooxy propionate (E3NP) and 3-nitrooxypropanol (3NP) *in vitro* and *in vivo* in non-lactating sheep on ruminal methane production, fermentation pattern, abundance of major microbial groups and feed degradability. In an *in vitro* batch culture trial, substantial reduction of methane production (up to 95%) without affecting the concentration of volatile fatty acids was found. Methane production in sheep decreased by 29% without any effect on rumen dry matter degradation in comparison with the unsupplemented control.

Reynolds et al. (2014) tested the effects of feeding two doses of 3NP on methane emissions, digestion and on the energy and nitrogen balance of lactating cows. The substance was administered through a rumen fistula. Daily methane production was reduced by 6.6% and 9.8% for 0.5 and 2.5 g of $3NP \cdot d^{-1}$, respectively. Homogenous mixing with feed or a slow-release bolus may be effective ways of application. Haisan et al. (2014) applied 2.5 g 3NP (per cow and day) by hand-mixing into the total mixed ration (TMR) and found a reduction of methane emission by about 60% without a significant effect on dry matter intake, milk yield or milk composition. The additive increased body weight gain, indicating that the reduction of methane emissions increased energy availability to animals. Further studies are needed to understand the mode of action of 3NP in the rumen (Flachowsky and Lebzien, 2012).

Conclusions

Sustainability of the production of food of animal origin requires a comprehensive approach. Improvement of particular segments of the food chain does not essentially improve the whole system. Increase of farm animal productivity or feed efficiency may also decrease the emissions of gases and the contamination of soils and water per unit of food of animal origin.

More complex calculations when it comes to parameters of efficient use of limited resources and reduction of emissions seem to be helpful in finding an optimum in production of food of animal origin. The following parameters should be considered in future calculations:

- use of arable land (competition between various users)
- efficient use of water for feed and animal production
- minimization of the use of fuel and other limited natural resources in the food chain
- utilization of permanent grassland and co-products from agriculture and industry
- feed efficiency as a key driver of productivity, resource use, and greenhouse gas emissions
- reduction of greenhouse gas emissions per product or per kilogram edible protein and along the entire food chain
- conservation of biodiversity
- plant and animal breeding as the starting points of the human food chain
- comparison of production of food of animal origin with other protein sources, including vegetarian foods (e.g., milk, meat based on soyabeans)
- calculation of land use per inhabitant accounting for the eating patterns of the population; changing eating patterns
- reduction of food wastage.

Producing food of animal origin is a very complex process. Cooperation among animal scientists (nutritionists, breeders, animal keepers/farmers, veterinarians, etc.) with scientists working in the fields of plant and feed science, ecology and economy seems to be necessary to solve the problems and to develop better and reliable land footprints.

In summary, more (food) for more (people) with less (resources and emissions) is one of the most important challenges for all those involved in feed/food science and production.

Public funding of plant and animal research may be considered an important challenge for meeting future animal protein demand (NRC, 2015) and improving sustainability along the entire food chain.

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