# Challenges for animal nutritionists in the 21$^{st}$ century

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## Abstract

The main points of research in animal nutrition moved from energy and nutrient requirements of farm animals to the production of safe and high quality food of animal origin under consideration of the following aspects:

- Resource efficiency along the food chain,
- Animal health and welfare,
- Environmental friendly production,
- Sustainability, live cycle studies along the food chain.

The following aspects will dominate the research in animal nutrition in the future:

- The competition between food/feed, fuel, areas for settlements and natural protection for land will increase during the next years.
- New and modified feeds as by-products from fuel production or plant biotechnology will be real challenges for feed science.

In summary there are enormous challenges for feed science and animal nutrition to double the production of food of animal origin up to 2050. The paper informs about some details of these topics.

*Keywords: animal nutrition, resource efficiency, food security, food safety, feed science*

## Zusammenfassung

**Herausforderungen für die Tierernährer im 21. Jahrhundert**

Die Schwerpunkte der Tierernährungsforschung veränderten sich von der Ermittlung des Energie- und Nährstoffbedarfes landwirtschaftlicher Nutztiere zur Erzeugung von sicheren und qualitativ hochwertigen Lebensmitteln tierischer Herkunft unter Berücksichtigung folgender Aspekte:

- Ressourceneffizienz entlang der Nahrungskette (Wertschöpfungskette),
- Gesundheit und Wohlbefinden der Tiere,
- Umweltfreundliche Erzeugung der Lebensmittel tierischer Herkunft,
- Nachhaltigkeit, Ökobilanzen (Life Cycle Studien) entlang der Nahrungskette.

Folgende Themen werden zukünftig für die Tierernährungsforschung noch bedeutungsvoller:

- Der Wettbewerb um die begrenzt verfügbare Fläche und weitere Ressourcen (z.B. Wasser, Phosphor) zwischen Lebens-/Futtermittel, Bioenergie, Siedlungs- und Naturschutzgebieten wird in den nächsten Jahren weiter zunehmen.
- Neue und modifizierte Futtermittel als Nebenprodukte der Bioenergiegewinnung oder aus der Pflanzenbiotechnologie sind große Herausforderungen für die Futtermittelkunde.

Zusammenfassend kann eingeschätzt werden, dass die zu erwartende annähernde Verdopplung der Erzeugung von Fleisch und Milch bis zum Jahr 2050 eine enorme Herausforderung für die Fachgebiete Futtermittelkunde und Tierernährung darstellt. Im Beitrag wird über verschiedene Details informiert.

*Schlüsselwörter: Tierernährung, Ressourceneffizienz, Ernährungssicherung, Lebensmittelsicherheit, Futtermittelkunde*

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## 1 Introduction

According to the FAO statistics human population will increase from current about 6.5 to 9 billion people (about 40 % more) in 2050 (Steinfeld et al., 2006), but the estimated need for meat (from 229 to 465) and milk (from 580 to 1043 mio t per year) will nearly double in this time. The reason for such a development is a higher demand of food of animal origin with increased income in many countries (Delgado et al., 1999, Keyzer et al., 2005). The consumption of meat, fish, milk and eggs contributes to meet the human requirements in amino acids and many trace nutrients (Wennemer et al., 2005). Furthermore, foods of animal origin have a considerable enjoyment value and are considered as a parameter of living standard.

The production of food of animal origin is consuming high amounts of resources (Flachowsky, 2002) and need much land for feed production. In addition to the traditional competition of land use between production of vegetarian food for human consumption and feed production for animal production, land area is increasingly being used for bio-energy/fuel production in response to the challenge of global warming, as areas for settlements and as natural protected areas. Possible strategies to overcome this situation include:

- Continued investments to increase plant yield and animal performances with traditional and innovative biotechnology.
- Improved efficiency of utilizing resources (land, water, fertilizer, fuel etc.).
- Lower consumption of animal protein by people with current over consumption.

In consequence there are real challenges for animal nutritionists. The most important previous objective of animal nutrition was to meet the energy and nutrient requirements of animals in dependence on animal species/categories and level of performance. Apart from this the objective moved to such topics as food safety and quality, animal health and welfare, feed resources, nutrient economy, environmental aspects and further topics (Figure 1). That means animal nutrition moved from a more natural science to a science of public interest along the total food chain.

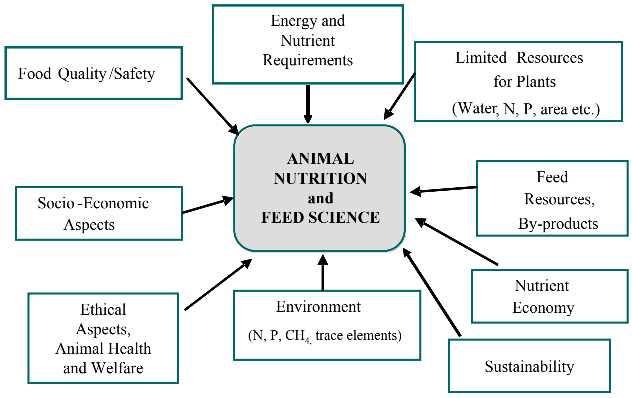


Figure 1:
Influencing factors on animal nutrition and feed science

Such changes are quite normal, if we consider the development after the second World War in Europe (Figure 2).

New challenges result in new developments/consequences in research. We have to use those chance and we should communicate with the public in order to show the potentials

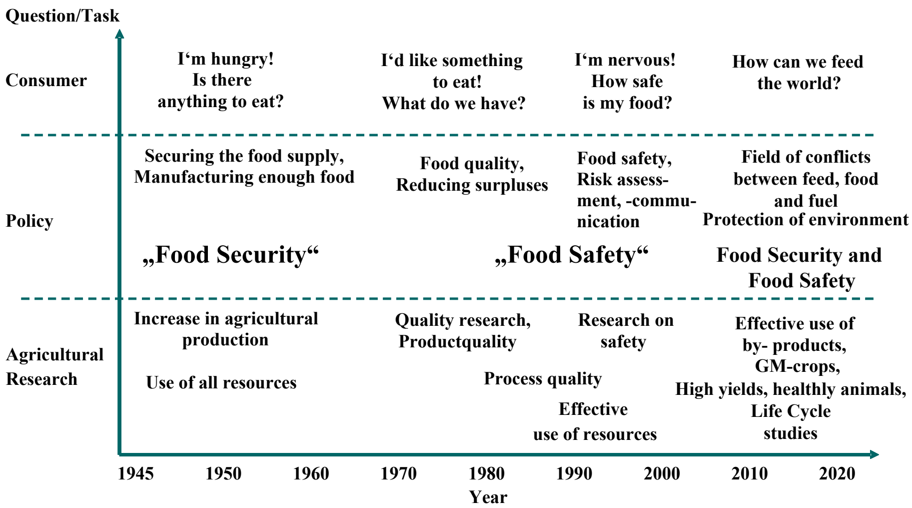


Figure 2:
Dominating questions of society as well as tasks of policy and agricultural research after the 2nd World War in Europe, presently and in future

and limitations of animal nutrition in efficient resource utilization, food quality and safety as well as environmental aspects. In this contribution, the following challenges for animal nutritionists will be considered more in detail:

- Energy and nutrient requirements of food producing animals,
- Food security and safety,
- Nutrient economy/feed resources,
- Environmental aspects.

## 2 Energy and nutrient requirements, feed additives

The most important prerequisite for healthy animals, efficient feed conversion and environmental friendly keeping of food producing animals is to meet the energy and nutrient requirements of the animals. 20 years ago some national committees still existed (e.g. Australia, France, Germany, the Netherlands, UK, USA) and updated the energy and nutrient requirements of animals. Presently such committees exist in the USA (NRC; National Research Council) and in Germany (AfBN of GfE; Ausschuß für Bedarfsnormen der Gesellschaft für Ernährungsphysiologie). They analyse the current references and update the feeding standards.

Table 1 summarizes some of the recent activities of the German committee. Unfortunately most of the booklets are published in German, but some (e.g. goats, pigs in preparation) are translated into English. New scientific knowledge was transferred to the farmers in this way. The farmers will be more and more able to precisely meet the animals' requirements. Animal breeders will develop animals with higher growth rates or more yields incl. genetically modified animals (transgenic animals). The nutritionists have to study the demands of such animals and to derive their energy and nutrient requirements in the future.

It is a real challenge for animal nutritionists to meet the requirements for energy and essential nutrients on the point, but also to deal with feed additives. Modified or protected essential feed additives (e.g. amino acids, trace elements, vitamins) and non essential substances (e.g. enzymes, prebiotics, phytogenic, substances etc.) may contribute to a more efficient conversion of feed into food of animal origin. Reasons for using and potentials of feed additives are summarized in Figure 3.

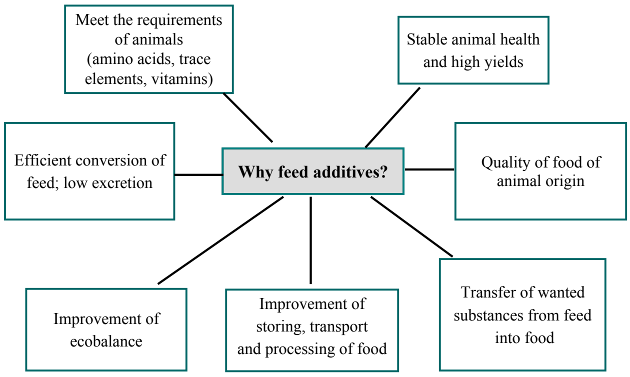


Figure 3:

Reasons and potentials of feed additives in animal nutrition (see Pape, 2006)

Table 1:

Recommendations of the AfBN of the GfE during the last few years and future tasks to meet the energy and nutrient requirements of food producing animals

| | | Parameters | | | | |
|---|---|---|---|---|---|---|
| Title[1)] | Reference | Energy | Protein, Amino acids | Major and Trace elements | Vitamins | Further aspects |
| Energy and nutrient requirements 5. Horses | DLG-Verlag 1995, 120 p. | x | x | x | x | – |
| Energy and nutrient requirements 6. Beef cattle | DLG-Verlag 1995, 85 p. | x | x | x | x | – |
| Energy requirements of sheep | Proc. Soc. Nutr. Physiol. 1996; 5: 149-152 | x | – | – | – | – |
| Energy and nutrient requirements 7. Laying hens and boilers | DLG-Verlag 1999, 185 p. | x | x | x | x | – |
| Energy and nutrient requirements 8. Dairy cows and heifers | DLG-Verlag 2001, 136 p. | x | x | x | x | Structure of feed |
| Energy and nutrient requirements 9. Recommendations for the supply of energy and nutrients to goats | DLG-Verlag 2003, 121 p. | x | x | x | x | Food selection, water |
| Energy and nutrient requirements of growing and fattening turkeys | Proc. Soc. Nutr. Physiol. 2004; 13: 195-233 | x | x | x | x | - |
| Energy and nutrient requirements 10. pigs | DLG-Verlag 2006, 247 p. | x | x | x | x | Species specific nutrition, water |

1) In preparation: Recommendation for horses, sheep; Planned: Revision dairy cows/heifers, beef cattle

In the future one may expect the following developments in the field of feed additives:

- Supply of further amino acids and analogues,
- Rumen protected substances (amino acids, vitamins),
- More efficient trace elements and vitamins,
- More efficient enzymes and probiotics,
- Efficient phytogenic substances (essential oils),
- Influence on rumen metabolism,
  - Efficient utilization of fibre fractions
  - Lignin degradation
  - Degradation/inactivation of antinutritive substances
  - Reduction of energy losses (methane) in the rumen
  - Probably genetically modified microorganisms
- More efficient antioxidative substances, influence on food quality,
- Antibodies, immunomodulators,
- Products from nanotechnology.

## 3 Food security and food safety/quality

Food security and food safety are the key elements of human health and well being. Food security seems to be more important than food safety. First of all the people ask for food ("I am hungry", see Figure 2), but unsafe food is dangerous and may influence human health and life time. Therefore food security and food safety should be considered as two sides of the medal "Human health and well being" (Figure 4).

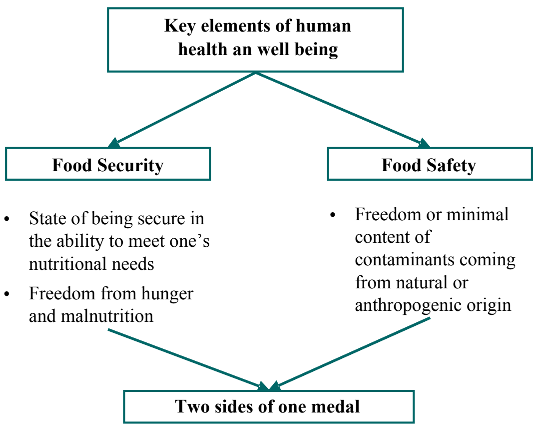


Figure 4:

Food security and food safety as elements of health and well being (Flachowsky and Dänicke, 2005)

Food security and safety include fair distribution of available food, increased food production in deficit regions (»Helping them to help themselves«), application of current scientific knowledge and investment in research to secure food for a growing world population. Increasing demand for high quality animal-based protein should be taken into account as a reality (Wennemer et al., 2005).

Safety means a minimum or the lowest practical relevant content in undesirable/anti-nutritive substances incl. microorganisms, but it means also a content of essential nutrients, so that tolerable upper levels in human nutrition not to be exceeded if people consume higher amounts of certain food. Food of animal origin may contribute to avoiding deficiencies in some trace nutrients (e.g., iodine, selenium, vitamins A, D) which are characterized by the so-called supply category 1, but the tolerable upper level of some nutrients is only 3 to 5 times higher than the human need (Table 2).

Table 2:

Supply and risk categories for trace elements and vitamins of men under consideration of intake and requirements

| Supply category | Criterion |
|---|---|
| 1 | High risk of deficiency |
| 2 | Possible risk of deficiency |
| 3 | Sufficient intake |
| 4 | Intake above recommendations |
| **Risk category** | |
| High | Low difference between requirements and upper level (Factor < 5) |
| Medium | Factor between 5 and 100 |
| Low | No upper level or factor > 100 |

Table 3:

Supply and risk categories for various trace elements and vitamins under consideration of intake and requirements in humans (by BfR, 2004; EFSA, 2006; Gassmann, 2006)

| Nutrient | Supply category | Risk category |
|---|---|---|
| Cu | 3 | high |
| Fe | 1 / 2 | high |
| I | 1 | high |
| Se | 1 / 2 | medium - high |
| Zn | 2 | high |
| Vit. A | 2 / 3 | high |
| Vit. D | 1 | high |
| Vit. E | 2 / 3 | medium |
| Vit. $B_6$ | 4 | medium |
| Folic acid | 1 / 2 | medium |
| Niacin | 3 / 4 | medium |

For this reason such micronutrients as I, Se, vitamins A and D are grouped to the risk category "High" (Table 3). Therefore, for reasons of preventive consumer protection, animal nutritionists reduced the upper levels for some nutrients (e.g., iodine, see Table 14; vitamin A) which are characterized by high transfer rates (from 10 to 30 % for iodine in milk and eggs) from feed into food of animal origin (Table 4). Food of animal origin with high concentrations of single nutrients must be labelled to know the specific parameters. Then they may be considered as functional food with special properties.

Table 4:

Influence of animal nutrition on selected nutrients in food of animal origin

| Food Nutrient | Milk | Meat | Eggs |
|---|---|---|---|
| Protein/Amino acids | (+) | - | - |
| Fat/Fatty acids | +++ | ++ | ++ |
| Major elements | | | |
| Calcium | - | - | - |
| Phosphorus | - | - | - |
| Trace elements | | | |
| Copper | - | (Liver: +++) | (+) |
| Iodine | +++ | (+) | +++ |
| Selenium | ++ | ++ | ++ |
| Zinc | + | + | + |
| Vitamins | | | |
| A | (+) | (Liver:+++) | + |
| D | + | + | + |
| E | (+) | (+) | +++ |
| B-Vitamins | + (if rumen protected) | - to + | - to + |

+++ very strong influence, transfer of supplement into food of animal origin > 10 %
++ strong influence possible, transfer 5 - 10 %
+ influence, transfer 1 - 5 %
(+) low influence, transfer < 1 %
- no influence

## 4 Nutrient economy – Feed resources

Nutrient economy deals with the conversion of feeds/nutrients into food of animal origin. Feed of plant origin is the base for animal nutrition. Much more feed is consumed by animals than by humans (Table 5).

Table 5:

Estimated dry matter (DM) consumption by humans and farm animals

| Species | Number (billions) FAO STAT (2006) | Consumption (DM) (kg/day) | Consumption (DM) (billion t/year) |
|---|---|---|---|
| Humans | 6.3 | 0.45 | 1.0 |
| Cattle, buffaloes, horses, camels | 1.6 | 10 | 5.8 |
| Sheep, goats | 1.9 | 1 | 0.7 |
| Pigs | 0.95 | 1 | 0.35 |
| Poultry | 18.5 | 0.07 | 0.45 |
| Total (animals) | | | 7.3 |

Plant breeding and cultivation are the starting points for feed and food security during the next years. The perspectives mentioned before are real challenges for plant breeders all over the world. The most important objectives for plant breeders can be summarized as followed:

- High yields with low external inputs (low input varieties) such as water, phosphorus, fuel, plant protection substances etc.
- Lower concentrations of toxic substances such as secondary plant ingredients, mycotoxins from toxin-developing fungi, toxins from anthropogenic activities or geogenic givens etc.
- Lower concentrations of substances that influence the use or bioavailability of nutrient such as lignin, phytate, enzyme inhibitors, tannin etc.
- Higher concentrations of the feed value determining components such as nutrient precursors, nutrients, enzymes, prebiotics, essential oils etc.

From the global view of feed and food security low input varieties with high yields have the highest priority. Undesirable substances cannot be removed from feedstuffs, or can only be removed with great effort (Flachowsky, 2006). From the perspective of animal nutrition, this goal is of major significance for the improvement of the percentage of value-determining components of feedstuffs under European conditions, because of the availability of various feed additives on the market. An increase of essential nutrients (e.g. amino acids, vitamins, trace elements etc.) could be very favourable in some other regions of the world.

It is possible to fulfil the objectives mentioned above by conventional plant breeding. But in the future methods of biotechnology may be more flexible, more potent and faster. Presently we are in the starting phase of this technology. Therefore genetical engineering of plants seems to be a technology with a high potential to contribute to the solution of global problems. Of course the technique needs further improvements and more public acceptance as presently. Taking these aspects and further developments (e.g. climate change, by-products of bioenergy) into consideration, we can expect the following new or modified feeds and have to do nutritional and safety assessments:

- Results from plant breeding,
  - Lower content of antinutritive substances
  - Higher concentration of valuable ingredients
- Consequences of climate change/higher $CO_2$-concentration,
  - Higher concentration of carbohydrates
  - Lower content of protein/amino acids and micronutrients

- By-products of bioenergy,
  - Oil seed cake, extracted oil meal
  - (Row) Glycerine
  - Distillated grain solubles
- More efficient use of further (old) feeds
  - Grassland
  - By-products of agriculture and food industry (incl. animal by-products).

*4.1 Feeds from genetically modified plants (GMP)*

The cultivation of GMP increased worldwide from 1.7 (1996) to 102 million ha (≈ 7 % of arable land, James, 2006). Currently, soybeans (60), corn (24), cotton (11) and canola (5 % of global GM area) are the most important GM-crops. They are modified mainly for agronomic traits. Such plants are characterized by so-called input traits (GMP of the first generation) without substantial changes in composition or nutritive value.

GMP of the second generation (with output traits) should contain more special nutrients (e.g. amino acids, fatty acids, vitamins, enzymes etc.) or less antinutritive substances (e.g. mycotoxins, inhibitors, allergens etc.).

Most of the area under GMP is cultivated with plants of the first generation. Numerous scientific associations and expert panels proposed guidelines for the nutritional and safety assessment of feeds from first generation (e.g., EFSA, 2004, ILSI, 2003). Based on the recommendations, nutritional studies with first generation of GMP-feeds have been undertaken worldwide.

Since 1997, 16 studies were performed at the Institute of Animal Nutrition of the German Federal Agricultural Research Centre (FAL) in Braunschweig to determine the effect of first generation GMP-feeds on the nutrition of dairy cows, growing bulls, growing and finishing pigs, laying hens, broiler, as well as with growing and laying characteristics of quails. This research was recently summarized by Flachowsky et al. (2007). The majority of feeds tested in the studies (e.g., Bt-maize, Pat-maize, Pat sugar beet) were grown under similar conditions to their isogenic counterparts in the experimental fields at FAL. The composition of feeds was analysed, and animal studies were used to assess nutritional qualities, including parameters such as digestibility, feed intake, health and performance of target animal species, and effects on food quality derived from the animals. Reproduction was also considered in generation studies with quails (see Figure 5) and laying hens (4 generations, Halle et al., 2006).

Both chemical analyses and the animal studies reveal no biologically relevant differences between GMP feeds and their isogenic counterparts and hence strongly support their substantial equivalence. Our results agree with more than 100 studies published in the literature and reviewed recently (Table 6).

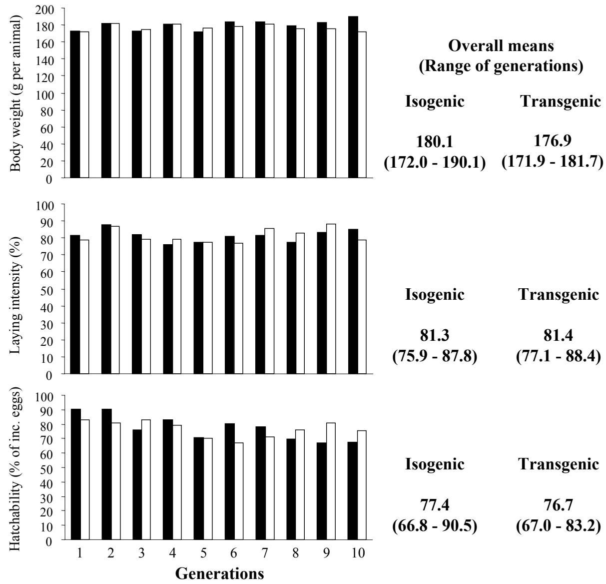


Figure 5:

A) Body weight of female quails (age: 6 weeks), (B) laying intensity and (C) hatchability of quails fed with isogenic (■) and transgenic (Bt, □) corn in a 10 generations experiment (Flachowsky et al., 2005b)

Table 6:

Experiments comparing first generation GM feeds with isogenic counterparts (adapted by Flachowsky et al., 2005a)

| Animal (Species/categories) | Number of experiments | Nutritional assessment |
|---|---|---|
| Ruminants | | No unintended effects in composition (except lower mycotoxins concentration in Bt plants) |
| Dairy cows | 23 | |
| Beef cattle | 14 | |
| Others | 10 | |
| Pigs | 21 | No significant differences in digestibility and animal health as well as no unintended effects on performances of animals and composition of food of animal origin |
| Poultry | | |
| Laying hens | 3 | |
| Broilers | 28 | |
| Others | | |
| (Fish, rabbits etc.) | 8 | |

Mycotoxin contamination of some GMcrops is lower than in non-GM which may be one exception to their substantial equivalence. For example, Bt maize is less severely attacked and weakened by the corn borer and might have a greater resistance to field infections, particularly *Fusarium* fungi, which produce mycotoxins. Evidence of reduced mycotoxin contaminated in GMcrops has been demonstrated in some but not all cases, as summarized by Fachowsky et al. (2005a). In long-term studies, numerous researchers investigated the influence of levels of corn borer infestation of isogenic and Bt hybrids on mycotoxin contamination.

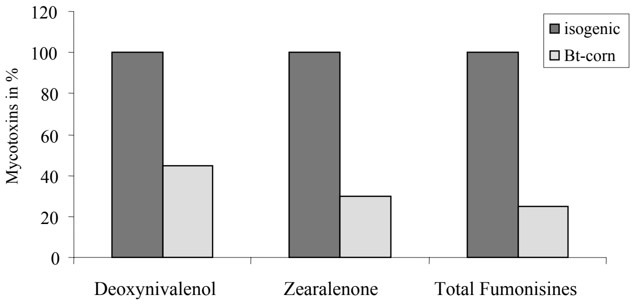


Figure 6:

Mycotoxins in isogenic (100 %) and Bt-corn (% of isogenic corn; data from some references, see Flachowsky et al., 2005a)

Most researchers concluded that a lower level of mycotoxin contamination was observed in the transgenic hybrids, despite the considerable geographical and temporal variation observed (Figure 6).

Nutritional and safety assessment of feeds from GMP of the second generation is a real challenge for animal nutritionists. First recommendations for study designs are given by Flachowsky and Böhme (2005), EFSA (2007) and ILSI (2007).

*4.2 Climate change, by-products and further potentials*

The increase of $CO_2$ in the air may influence plant yields and composition as shown in studies at our Research Centre (Table 7). $CO_2$ is a nutrient for plants and yields of barley and wheat increased, the protein content was decreased.

Table 7:

Influence of $CO_2$ (555 ppm compared with 360 ppm) and various N-fertilizer on yield and protein content in barley and wheat (Effect with 360 ppm ≙ 100 %, changes in %; Weigel and Manderscheid, 2005)

| | N-supply (kg/ha) | |
|---|---|---|
| | 132 | 264 |
| Winter barley | | |
| Yield | + 13,0 | + 12,0 |
| Protein content | - 12,1 | - 13,0 |
| Winter wheat | | |
| Yield | + 7,8 | + 15,6 |
| Protein content | - 11,2 | - 4,5 |

Low protein cereals (Table 7) need a supplementation with amino acids and/or a combination with feeds rich in protein for animal feeding.

Many by-products from bio-fuel industry are richer in protein than the original sources (cereals, sugar beets, rapeseed etc.) and would be acceptable feeds. But on the other side starch and other nutrients (e.g. fat) are used for energetic purposes. Therefore more protein (N) and less energy could be available for animal nutrition in the future. This is a real challenge for animal nutritionists under consideration of optimal diet composition, animal health, quality of food of animal origin and environmental aspects.

Table 8:

Composition of seeds and by-products after bio-fuel production (data from some references)

| Seeds/ | Selected nutrients (g/kg DM) | | | |
|---|---|---|---|---|
| Byproducts | Protein | Lysin | Fat | Starch |
| Wheat | 140 | 3.8 | 20 | 670 |
| Dist. Grain solubles | 370 | 8.5 | 70 | 35 |
| Barley | 120 | 4.2 | 30 | 600 |
| Dist. Grain solubles | 320 | 9.0 | 80 | 30 |
| Corn | 100 | 2.8 | 45 | 700 |
| Dist. Grain solubles | 300 | 7.5 | 120 | 80 |
| Rapeseed | 230 | 12.5 | 440 | 25 |
| Cake | 360 | 19,5 | 100 | 35 |
| Extr. Oil meal | 400 | 21,0 | 25 | 40 |

Other challenges for animal nutritionists are a more efficient use of the global resource grassland (Table 9) and the high amounts of lingo-cellulolytic by-products as cereal straw (Figure 7). About two third of the agricultural area are grassland, its better utilization in combination with a better feed reserves management and feeding of ruminants is an important task for the future.

Table 9:

"Forgotten" potential grassland

| Continent | Area Mill. ha | Percentage of agricultural area % |
|---|---|---|
| Africa | 792 | 79 |
| Asian | 533 | 53 |
| Europe | 464 | 55 |
| Oceania | 466 | 91 |
| North and Central America | 353 | 56 |
| South America | 395 | 81 |
| World, total 1) | ≈ 3 Bill. | 67 |

1) Arable land, global; 1.5 billion ha

Cereal by-products as straw are a real global feed potential. Simple methods should be developed and applied in the tropics/subtropics to increase the nutritive value and to use the enormous potential of microbial fermentation in the rumen of ruminants. Edible mushrooms could be an interesting and successful way for double utilization (mushrooms and feed) of straw (Zadrazil et al., 1996, Figure 7).

Table 10:

Influence of the yield level of plants, the performance level of animals, the ratio of protein from meat and milk, and the level of consumption of protein of animal origin on land area needs ($m^2$ per capita and year, basal data by Flachowsky, 2002)

| Consumption (g protein/day) | 10 | | 20 | | 40 | | 60 | |
|---|---|---|---|---|---|---|---|---|
| Yield level | A[1)] | B[2)] | A | B | A | B | A | B |
| Ratio between protein from meat[3)] and milk (% of protein) | | | | | | | | |
| 70 : 30 | 260 | 105 | 520 | 210 | 1050 | 420 | 1560 | 630 |
| 50 : 50 | 225 | 95 | 450 | 190 | 900 | 380 | 1350 | 570 |
| 30 : 70 | 190 | 85 | 380 | 170 | 760 | 340 | 1140 | 510 |

[1)] Yield level A per hectare: 4 t DM of cereals, 10 t DM of forage; performance level A per day: 15 kg milk; live weight gain: beef cattle: 600 g; pigs: 400 g; poultry: 30 g
[2)] Yield level B per hectare: 8 t DM of cereals, 15 t DM of forage; performance level B per day: 30 kg milk, live weight gain: beef cattle: 1200 g; pigs: 800 g; poultry: 60 g
[3)] Ratio between protein from beef, pork and poultry (in %): ≈ 15 : 60 : 25

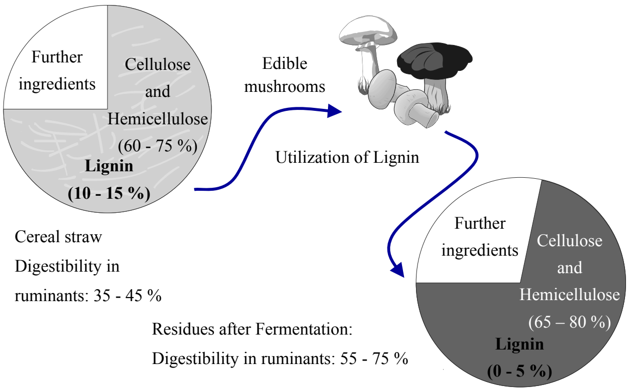


Figure 7:

Challenge: Utilization of lingo-cellulolytic by-products

The limited agricultural area and the higher demand of food of animal origin need a certain level of intensity of plant and animal production. Lower plant yields and lower animal performance require more land to produce a certain amount of food resp. protein of animal origin. The land area needed per inhabitant and year is calculated in Table 10 under consideration of plant and animal performances, the ratio of protein from meat and milk, and the level of consumption of protein of animal origin.

## 5 Environmental aspects

The conversion losses in food production from animal sources are a main point of criticism from the public. On the one hand, these losses contribute to considerable resource consumption (e.g., 3 - 5 kg grain to produce one kg pork), on the other hand to the excretion of nutrients that pollute the environment (Flachowsky and Lebzien, 2006; Verstegen and Tamminga, 2006). As shown in Table 11, protein production via milk and eggs is more efficient and has a lower N and P excretion than via pork and beef. As the feed conversion into food improves, the excretion decreases with higher animal performance (s. Table 11).

Table 11:

Excretions per kg edible protein of animal origin by various animal protein sources

| Protein source | Production per day | Excretion (kg/kg edible protein) N | P | $CH_4$ |
|---|---|---|---|---|
| Milk | 10 kg | 0.65 | 0.10 | 1.0 |
| | 20 kg | 0.44 | 0.06 | 0.6 |
| | 40 kg | 0.24 | 0.04 | 0.4 |
| Beef | 1000 g | 1.3 | 0.18 | 1.5 |
| | 1500 g | 1.0 | 0.14 | 1.2 |
| Pork | 700 g | 0.7 | 0.10 | 0.08 |
| | 900 g | 0.55 | 0.08 | 0.05 |
| Broilers | 40 g | 0.35 | 0.04 | 0.01 |
| | 60 g | 0.25 | 0.03 | 0.01 |
| Eggs | 70 % | 0.4 | 0.07 | 0.02 |
| | 90 % | 0.3 | 0.05 | 0.02 |

But ruminants emit considerable amounts of methane (20 - 30 g $CH_4$ per kg DM-intake) because of the microbial fermentation in the rumen. Methane has a much higher global warming potential than $CO_2$ (Table 12). Therefore more research activities are necessary to reduce the $CH_4$-emission from the rumen (Flachowsky and Brade, 2007).

Table 12:

Local and global environmental aspects

| Substances | Significance local/ regional | global (Global warming potential) |
|---|---|---|
| Nitrogen (N) | x | $N_2O$ Laughing gas, nitrous oxide (310 x as $CO_2$)[1)] |
| Phosphorus (P) | x | - |
| Methan ($CH_4$) | - | x (23 x as $CO_2$)[1)] |
| Trace elements (e.g. Cu, Zn) | x | - |

1) According to ICCP (2006)

As mentioned before higher animal performances increase excretion per animal, but reduce excretions per animal product (Figure 8).

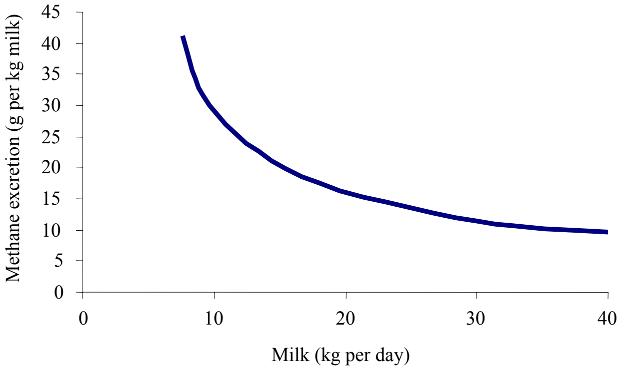


Figure 8:

Methane excretion per kg milk in dependence of daily milk yield of cows

In the future we will have various possibilities for an environmental friendly animal production, as exemplarily shown for phosphorus (Table 13). The nutritionists would be able to meet the animal requirements more precisely.

Table 13:

Possibilities for P-supply of nonruminants under consideration of various scientific fields

| Scientific field | Possibility (References) |
|---|---|
| Animal Nutrition | - Anorganic P-sources (GfE, 1999; 2006) |
| | - Phytase as feed additive (Düngelhoff and Rodehutscord, 1995; GfE, 1999, 2006) |
| Plant Breeding | - Reduction of phytate content (Mendoza, 2002; Spencer et al., 2000a,b) |
| | - Higher phytase content in plants (ILSI, 2003) |
| Animal Breeding | Transgen expression of phytase in saliva and other digestive liquids of pigs (Golovan et al., 2001, Cho et al., 2006) |

Recently the upper levels (UL) for some trace elements in animal feedingstuffs in the EU were reduced for various reasons (Table 14). The Cu- and Zn-upper levels were restricted because of environmental aspects. In the future further restrictions could be expected.

Table 14:

Requirements for food producing animals, upper levels in feedingstuffs and reasons for upper levels for some trace elements

| Trace elements | Cu | I | Se | Zn |
|---|---|---|---|---|
| Requirements (mg/kg DM) | 4 - 10 | 0.15 - 0.5 | 0.1 - 0.3 | 40 - 100 |
| Upper level in feedingstuffs (mg/kg DM) | 15 - 35 | 5 (Dairy cows, laying hens) 10 (Others) | 0.5 | 150 |
| Reasons for UL | Environment, Reduction of excretion | High transfer (Consumer protection) | Animal-health | Environment, Reduction of excretion |

Based on the present knowledge the following potentials to reduce the excretions of N, P, $CH_4$ and trace elements can be mentioned:

- More precise nutrient requirements of animals (e.g. prececal digestible amino acids and P in nonruminants, better understanding of processes in rumen and utilization of potentials)
- Avoid excesses in nutrient supply (N, P, trace elements); meet the requirements of animals
- Use rapid analyses for N-, P- and trace element determination in feed and consider native contents of feeds under consideration of bioavailability of nutrients.
- Using knowledge on rumen metabolisms to optimize N-utilization in ruminants (see Flachowsky and Lebzien, 2006)
- Adding crystalline amino acids to the diet if necessary, using phase-feeding depending on age; calculating amino acid requirements on the basis of praecaecal digestible amino acids (see GfE, 2006) or on the basis of P-availability of P and trace elements in nonruminants.
- Some activities (e.g., high propionate production by ration, fat supplementation, addition of propionate precursors or other feed additives) may decrease methane emissions, but not more than by 20 - 30 % (e.g., from 20 - 25 g to 15 - 20 g $CH_4$ per kg DM-intake, see Flachowsky and Brade, 2007)
- Higher yields of animals, lower animal numbers
- Shorter rearing time for young animals (heifers etc.)
- Improve of animal health, reduce animal losses
- Feeding systems, animal keeping, excrement management (avoid $NH_3$ - losses etc.).

**References**


BfR (2004) Teil I: Verwendung von Vitaminen in Lebensmitteln. Teil II: Verwendung von Mineralstoffen in Lebensmitteln. Toxikologische und ernährungsphysiologische Aspekte. Berlin : BfR-Pressestelle

Cho J, Choi K, Darden T, Reynolds PR, Petitte JN, Shears SB (2006) Avian multiple inositol polyphosphate phosphatase is an active phytase that can be engineered to help ameliorate the planet's "phosphate crisis". J Biotechnol 126(2):248-259

Delgado C, Rosegrant M, Steinfeld H, Ekui S, Courbois C (1999) Livestock to 2020 : the next food revolution. Food Agric Environ Discuss Paper 28

Düngelhof M, Rodehutscord M (1995) Wirkung von Phytasen auf die Verdaulichkeit des Phosphors beim Schwein. Übers Tierernährung 23:135-157

EFSA (European Food Safety Autority) (2004) Guidance document of the scientific panel on genetically modified organisms for the risk assessment of genetically modified plants and derived food and feed. EFSA J 99:1-93

EFSA (European Food Safety Autority) (2006) Tolerable upper intake levels for vitamins and minerals [online]. Zu finden in <http://ec.europa.eu/comm./food/fs/scf/outcome>

EFSA (European Food Safety Autority) (2007) Safety and nutritional assessment of GM plant derived Foods/Feed : the role of animal feeding trials. Draft (in preparation)

FAOSTAT (2006) FAO Statistics, Roma

Flachowsky G (2002) Efficiency of energy and nutrient use in the production of edible protein of animal origin. J Appl Anim Res 22(1):1-24

Flachowsky G (ed) (2006) Möglichkeiten der Dekontamination von ‚Unerwünschten Stoffen nach Anlage 5 der Futtermittelverordnung (2006)'. Braunschweig : FAL, 294 p, Landbauforsch Völkenrode SH 294

Flachowsky G, Aulrich K, Böhme H, Halle I (2007) Studies on feeds from genetically modified plants (GMP) - contributions to nutritional and safety assessment. Anim Feed Sci Technol 133(1-2): 2-30

Flachowsky G, Böhme H (2005) Proposals for nutritional assessments of feeds from genetically modified plants. J Anim Feed Sci, 14(Suppl. 1):49-70

Flachowsky G, Brade W (2007) Potenziale zur Reduzierung der Methan-Emissionen bei Wiederkäuern. Züchtungskd 79(6):417-465

Flachowsky G, Chesson A, Aulrich K (2005a) Animal nutrition with feeds from genetically modified plants. Arch Anim Nutr 59(1): 1-40

Flachowsky G, Dänicke S (2005) From feed to safe food : contributions of animal nutrition to the safety of food. In: Riley AP (ed) New developments in food policy, control, and research. New York : Nova Science, pp 65-95

Flachowsky G, Halle I, Aulrich K (2005b) Long term feeding of Bt-corn - a ten generation study with quails. Arch Anim Nutr 59(6):449-451

Flachowsky G, Lebzien P (2006) Possibilities for reduction of Nitrogen (N) excretion from ruminants and the need for further research – a review. Landbauforsch Völkenrode 56(1-2):19-30

Gassmann B (2006) Zum Festlegen von Höchst- und Mindestmengen an Vitaminen und Mineralstoffen in Lebensmitteln. Ernährungs-Umschau 53:336-343

GfE (1999) Empfehlungen zur Energie- und Nährstoffversorgung der Legehennen und Masthühner (Broiler). Frankfurt a M : DLG-Verl, Energie- und Nährstoffbedarf landwirtschaftlicher Nutztiere 7

GfE (2006) Empfehlungen zur Energie- und Nährstoffversorgung von Schweinen 2006. Frankfurt a M : DLG-Verl., 247 p, Energie- und Nährstoffbedarf landwirtschaftlicher Nutztiere 10

Golovan SP, Meidinger RG, Ajakaiye A, Cottrill M, Wiederkehr MZ, Barney D, Plante C, Pollard J, Fan MZ, Hayes MA, Laursen J, Hjorth JP, Hacker RR, Phillips JP, Forsberg CW (2001) Pigs expressing salivary phytase produce low phosphorus manure. Nat Biotechnol 19:741-745

Halle I, Aulrich K, Flachowsky G (2006) Four generations feeding GMO-corn to laying hens. Proc Soc Nutr Physiol 15:114 [Abstract]

ILSI (2003) Best practices for the conduct of animal studies to evaluate crops genetically modified for input traits [online]. Zu finden in <http//www.ilsi.org/file/bestpracticescas.pdf> [zitiert am 11.10.2007]

ILSI (2007) Best practices for the conduct of animal studies to evaluate crops genetically modified for output traits. Washington : Int Life Sci Inst, (in press)

IPCC - Intergovernmental Panel on Climate Change (2006) 2006 IPCC guidelines for national greenhouse gas inventories : Volume 4: Agriculture, forestry and other land use [online]. Zu finden in <http://www.ipcc-nggip.iges.or.jp/public/2006gl/vol4.htm> [zitiert am 11.10.2007]

James C (2006) Global status of commercialised Biotech/GM crops: 2006 [online]. Zu finden in <http://www.isaaa.org/resources/publications/briefs/35/highlights/default.html> [zitiert am 11.10.2007

Keyzer MA, Merbis MD, Pavel LFPW, van Wesenbeck CFA (2005) Diets shifts towards meat and the effect on cereal use : can we feed the animals in 2030. Ecol Econ 55:187-202

Mendoza C (2002) Effect of genetically modified low phytic acid plants on mineral absorption. Int J Food Sci Technol 37:759-762

Pape H-C (ed) (2006) Futtermittelzusatzstoffe : Technologie und Anwendung. Bergen : AgrimMedia, 304 p, Mischfutter-Bibliothek.

Spencer JD, Allee GL, Sauber TE (2000a) Phosphorus bioavailability and digestibility of normal and genetically modified low-phytate corn for pigs. J Anim Sci 78: 675-681

Spencer JD, Allee GL, Sauber TE (2000b) Growing-finishing performance and carcass characteristics of pigs fed normal and genetically modified low-phytate corn. J Anim Sci 78: 1529-1536

Steinfeld H, Gerber P, Wassenaar T, Castel V, Rosales M, de Haan C (2006) Livestock's long shadow : environmental issues and options [online]. Zu finden in <http://www.virtualcentre.org/en/library/key_pub/longshad/A0701E00.pdf> [zitiert am 02.10.2007]

Verstegen M, Tamminga S (2006) Feed composition and environmental pollution. In: Garnsworthy PC, Wiseman J (eds) Recent developments in non-ruminant nutrition. Nottingham : Nottingham Univ Press, pp 453-465

Weigel H-J, Manderscheid R (2004) CO2 enrichment effects on forage and grain nitrogen content of pasture and cereal plants. J Crop Improvement, 13:73-89

Wennemer H, Flachowsky G, Hoffmann V (eds) (2005) Protein, population, politics : how protein can be supplied sustainably in the 21st century. Frankfurt a M : Plexus, 160 p

Zadrazil F, Kamra DN, Isikhnemhen OS, Schuchardt F, Flachowsky G (1996) Bioconversion feed with white rot fungi : review of work done at FAL Braunschweig. J Appl Anim Res 10:105-124