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Feed-efficient ruminant production: opportunities and challenges

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ABSTRACT. Feed-efficient ruminant production is a key topic in the further development of ruminant husbandry all over the world. Ruminants contribute substantially to human nutrition by production of milk and meat. They are also extremely useful for mankind by providing other important products and labour, such as skins, clothing, bones, dung, heating material, and working as draft animals, etc. The microorganisms in the rumen of ruminants are able to process lignocellulose from low quality roughage into volatile fatty acids and energy, to transfer non-protein nitrogen, such as urea, into microbial protein, and to synthesize B vitamins. Therefore, ruminants are able to produce food of animal origin without competition for feed with non-ruminants and man. On the other hand, gas methane (CH_4) with a high greenhouse gas potential is an unavoidable by-product of rumen fermentation. Furthermore, growing ruminants are characterized by a low growing potential (daily yield in edible protein < 0.05% of body weight). The objectives of ruminant breeding, nutrition and keeping/management should, therefore, be to maximize/optimize the advantages of ruminants and to minimize their disadvantages. Feed-efficient ruminant production is viewed as a complex system starting with plant and animal breeding. More systemic approaches are considered necessary to understand interactions and to find acceptable solutions for complex relationships in the context of food security, resource efficiency, as well environmental, social and economic aspects.

Introduction

Recent decades have been characterized by growth of the global population and higher demand for more and better food and other products providing an improved standard of living. In late October 2011, the world's population reached seven billion. Sustainability in feed and food production is a key challenge for agriculture, as summarized recently in many papers and books (e.g., Fedoroff et al., 2010; Godfray et al., 2010; Pardue, 2010; Foley et al., 2011; Giovannucci et al., 2012; Potthast and Meisch, 2012; HLPE, 2012a, 2013; Flachowsky et al., 2013; Kebreab, 2013; Windisch et al., 2013). In the future there will be strong competition for arable land and non-renewable resources such as fossil carbon fuels, water (e.g., Renault and Wallender, 2000; Hoekstra and Champaign, 2007; Schlink et al., 2010; Deikman et al., 2012), some minerals (such as phosphorus; Hall and Hall, 1984; Scholz and Wellmer, 2013), as well as between feed/food, fuel, fibre, flower and fan (Aerts, 2012) and areas for settlements and natural protected areas. According to the FAO (2009a,b) the global human population will increase from the current 7 billion to more than 9 billion people in 2050, but the output of ruminant meat and dairy products is estimated to increase by about 70% (Alexandratos and Bruinsma, 2012; HLPE, 2013). Therefore, optimization of feed use efficiency in ruminant production systems is a real challenge for feed production and ruminant feeding (Makkar and Beever, 2013).

These developments lead to the following question: is there any need for food of animal origin? As vegans demonstrate, there is no essential need for food of animal origin, but the consumption of meat, fish, milk and eggs may contribute significantly to meeting humans' requirements for amino acids (e.g., Young et al., 1989; WHO et al., 2007; D`Mello, 2011; Pillai and Kurpad, 2011), some important trace nutrients (such as Ca, P, Zn, Fe, I, Se, vitamins A, D, E, B_{12}, etc.), especially for children and juveniles as well as for pregnant and lactating women (Wennemer et al., 2006). Human nutritionists (e.g., Waterlow, 1999; Jackson, 2007) recommend that about one third of the daily protein requirement 0.66–1 g non fat per kg body weight (e.g., Rand et al., 2003; Jackson, 2007; WHO et al., 2007) should originate from protein of animal origin. That means that about 20 g of a daily intake of about 60 g should base on protein of animal origin, which is lower than the present average consumption throughout the world. Currently, the average consumption of protein of animal origin is 23.9 g per person per day (without fish), and ranges between 1.7 (Burundi) to 60.0 g (USA; FAO, 2009a). Eating food of animal origin, esp. meat, is not only a reflection of nutritional needs, but it is also determined by taste, odour and texture, as well as by geographical area, culture, ethics and wealth (Keyzer et al., 2005; Breustedt and Qaim, 2012).

Table 1 summarizes data about animal species/categories and the performance of animals on their expected yield of edible protein (see last two columns). The edible protein yield per kilogram body weight and day characterizes the potential of protein synthesis per kilogram body weight and could be a parameter of resource efficiency. Edible protein of animal origin will be considered in the paper as the main objective of animal husbandry.

Table 1. Influence of animal species, categories and performances on yield of edible protein (Flachowsky, 2002; Flachowsky and Kamphues, 2012, Flachowsky et al., 2013)

Protein source BW	Performance per day	Dry matter intake, kg · day^{-1}	Roughage to concentrate ratio, on DM base, %	Edible fraction, % of product or body mass	Protein in edible fraction, g · kg^{-1} fresh matter	Edible protein, g · day^{-1}	Edible protein g · kg^{-1} BW · day^{-1}
Dairy cow	2 kg milk	8	100			67	0.1
650 kg	5 kg milk	10	95/5			163	0.25
	10 kg milk	12	90/10	95	34	323	0.5
	20 kg milk	16	75/25			646	1.0
	40 kg milk	25	50/50			1292	2.0
Dairy goat	0.5 kg milk	1	100			17	0.3
60 kg	1 kg milk	1.5	90/10	95	36	34	0.55
	2 kg milk	2	80/20			68	1.1
Beef cattle	200 g DWG	6.0	100			19	0.05
350 kg	500 g DWG	6.5	95/5			48	0.14
	1000 g DWG	7.0	85/15	50	190	95	0.27
	1500 g DWG	7.5	70/30			143	0.41
Growing/fattening	200 g DWG	1.5	30/70			18	0.22
pig	500 g DWG	1.8	20/80			45	0.56
80 kg	700 g DWG	2	10/90	60	150	63	0.8
	1000 g DWG	2.2	0/100			90	1.1
Broiler	20 g DWG	0.06	15/85			2.4	1.6
1.5 kg	40 g DWG	0.07	10/90	60	200	4.8	3.2
	60 g DWG	0.08	0/100			7.2	4.8
Laying hen	20% LP	0.09	30/70			1.4	0.8
1.8 kg	50% LP	0.10	20/80			3.4	1.9
	70% LP	0.11	10/90	95	120	4.8	2.7
	90% LP	0.12	0/100			6.2	3.4

BW – body weight, DWG – daily weight gain, LP – laying performance

Furthermore, it is also easier to compare the animal yields of various types of animal production on the basis of animal protein yield (De Vries and de Boer, 2010; Flachowsky and Kamphues, 2012). Based on the present situation, the objective of the paper is to review some important opportunities and challenges for more efficient production of edible protein by ruminants, esp. cattle.

Ruminants in the food chain

Global animal numbers and production of food of animal origin are updated by FAOSTAT (2012) yearly. Large (including cattle and buffalo) and small (such as sheep and goats) ruminants are a very important part of the human food chain. In comparison with pigs and poultry, ruminants are characterized by some specific advantages and disadvantages (Table 2).

Table 2. Lights/opportunities and shadows/challenges of ruminants as important parts of the food chain

Lights/opportunities	Shadows/challenges
Utilization of lingnocellulose and co-products of agriculture, food and fuel industry	Methane-emission from the microbial fermentation (4–10% of gross energy as losses; Table 4)
Microbial synthesis of protein from non-protein nitrogen (NPN)	Low growth potential (< 1% of body weight) and low protein yield of growing ruminants (Table 1)
Microbial synthesis of B-vitamins	Low energy and nutrient efficiency in growing ruminants
No or low food/feed competition to human and non-ruminants (Tables 1 and 3)	

Ruminants need little or no arable land for feed production. They are able to produce milk and meat from grassland (Table 3) because of their symbiosis with microorganisms in the rumen. For higher performance, they need some concentrates that can also be replaced in part by co-products from the food or biofuel industries (Makkar, 2012).

On the basis of the data in Tables 1 and 3, the land requirement (arable land, grassland) per person per year, taking into account the amounts and sources of consumed protein of animal origin, can be calculated (Flachowsky and Kamphues, 2012). These calculations show a clear dependence of land requirement on animal species/categories as protein sources, as well animal and plant yields.

Apart from the demand for resources, feed/food production causes emissions with a certain greenhouse gas potential, such as carbon dioxide (CO_2) from fossil fuel, methane (CH_4; greenhouse gas factor (GHF) about 23; IPCC, 2006) from enteric fermentation, esp. in ruminants, and from excrement management, as well as nitrogen compounds (NH_3, N_2O: GHF about 300; IPCC, 2006) from the protein metabolism of animals (e.g., DEFRA, 2006; Flachowsky and Hachenberg, 2009; FAO, 2010; Godfray et al., 2010; Grünberg et al., 2010; Leip et al., 2010; Flachowsky et al., 2011; FAOSTAT, 2012; Hristov et al., 2013; Table 4). Apart from the low input of limited resources along the food chain (Figure 1), a low output of greenhouse gases (CO_2, CH_4, and N_2O; referred to collectively in terms of their greenhouse gas effects as Carbon Footprints or CO_2-equivalents; CO_{2eq}; Flachowsky et al., 2011), and minerals such as phosphorus (Table 4) and some trace elements during feed/food production are very important aims of sustainable agriculture. Presently, about 15% of total global emissions (CO_{2eq}) should come from crop and livestock production (HLPE, 2012a).

Higher milk yield results in higher methane emission per cow or goat, but significantly lower methane and Carbon Footprints per kilogram of milk (Tables 4 and 7; FAO, 2010). On the other hand, higher milk yields result in fewer dairy cows and, therefore, beef cows are required to produce a certain amount of meat. So-called allocations (Cederberg and Stadig, 2003; Feitz et al., 2007; Thomassen et al., 2008; Flysjö et al., 2011; Zehetmeier et al., 2011) are necessary to assess CFs for milk and beef production. For example, Zehetmeier et al. (2011) made such an economic allocation of GHG-emissions in dairy husbandry (milk and beef) on the basis of 6 000; 8 000 or 10 000 kg milk per cow per year and asked for the same amount of beef with increased milk yields. The total GHG-emission for milk production on a farm decreased from 1.06, 0.93 to 0.89 kg $CO_{2eq} \cdot kg^{-1}$ milk; those of beef increased from 10.75 *via* 13.13 to 16.24 kg $CO_{2eq} \cdot kg^{-1}$ beef. These and similar calculations (e.g., on the basis of 1 kg edible protein) are recommended to assess emissions for milk/meat of various production intensities (Flachowsky and Kamphues, 2012).

Improvement of feed efficiency of animal production is a very important topic of agriculture. This is not only a research project for intensive animal production. It is a much larger challenge for all forms of animal keeping. About 85% of farmers, i.e. around 2 billion people, are producing on farms below 2 ha in area (HPLE, 2012b). Those small holders partially living from and with ruminants must be also considered in future developments.

Therefore, a further objective of this report is to summarize the aspects of feed-efficient ruminant production under consideration of various production conditions and to deduce future challenges.

Table 3. Calculations for land need per kg edible protein in dependence on animal species/categories; plant yields and animal performances (roughage to concentrate ratio see Table 1; all concentrates from arable land, no co-products in feeding considered; Flachowsky et al., 2013)

Protein source	Animal yield per day	Edible protein yield, $g \cdot day^{-1}$	Grassland or perennial crops, $m^2 \cdot kg^{-1}$*		Arable land or cultivated crops, $m^2 \cdot kg^{-1}$*	
			A	B	A	B
Cow milk, kg	2	67	300	120		0
	5	163	120	60	15	6
	10	323	65	35	18	8
	20	646	40	18	30	12
	40	1292	20	10	50	20
Goat milk, kg	0.5	17	150	60	0	
	1	34	100	40	22	9
	2	68	60	25	29	12
Beef, g DWG	200	19	650	320	0	
	500	48	275	130	35	15
	1000	95	190	60	55	22
	1500	143	75	40	80	30
Pork, g DWG	200	18	60	25	260	110
	500	45	20	10	160	65
	700	63	8	4	140	55
	1000	90	0		120	50
Poultry, g DWG	20	2.4	10	4	110	40
	40	4.8	4	2	65	25
	60	7.2	0		55	22
Eggs, % LP	20	1.4	50	20	220	90
	50	3.4	15	6	120	50
	70	4.8	6	2	100	40
	90	6.2	0		100	40

DWG, LP – see Table 1; * plant yields: level A: 5 t dry matter roughage (grassland), 2 t dry matter grain $\cdot$ ha^{-1} (arable land), level B: 10 t dry matter roughage, 5 t dry matter grain $\cdot$ ha^{-1}

Table 4. Effects of animal species, categories and performances on some emissions (Flachowsky, 2002, 2011; Flachowsky et al., 2011)

Protein source BW	Performance per day	Nitrogen excretion, % of intake	Methane emission, g per day*	Emissions, $kg \cdot kg^{-1}$ edible protein			
				P	N	CH_4	CO_{2eq}**
Dairy cow	10 kg milk	75	310	0.10	0.65	1.0	30
650 kg	20 kg milk	70	380	0.06	0.44	0.6	16
	40 kg milk	65	520	0.04	0.24	0.4	12
Dairy goat	2 kg milk	75	50	0.08	0.5	0.8	20
60 kg	5 kg milk	65	60	0.04	0.2	0.4	10
Beef cattle	500 g DWG	90	170	0.30	2.3	3.5	110
350 kg	1000 g DWG	84	175	0.18	1.3	1.7	55
	1500 g DWG	80	180	0.14	1.0	1.2	35
Growing/fattening pig	500 g DWG	85	5	0.20	1.0	0.12	16
80 kg	700 g DWG	80	5	0.12	0.7	0.08	12
	900 g DWG	75	5	0.09	0.55	0.05	10
Broilers	40 g DWG	70	Traces	0.04	0.35	0.01	4
1.5 kg	60 g DWG	60		0.03	0.25	0.01	3
Laying hen	50 % LP	80	Traces	0.12	0.6	0.03	7
1.8 kg	70 % LP	65		0.07	0.4	0.02	5
	90 % LP	55		0.05	0.3	0.02	3

BW, DWG, LP – see Table 1; * CH_4– emission depending on composition of diet; ** adequate to Carbon Footprints (CF – sum of greenhouse gas)

Feed-efficient ruminant production

The traditional and simplest way to assess feed use efficiency by animals is by calculating the feed conversion rate (FCR) or FC efficiency (FCE). Both parameters are very important measurements in assessing the conversion of feed into animal products such as milk or meat. More details for calculation of FCR or FCE are given by Colman et al. (2011). Recent calculations try to consider not only the conversion of feed into food of animal origin, but also include some or all inputs of non-renewable resources such as water, fuel, energy, arable land, etc., and outputs such as methane, N-compounds, or CF along the whole food chain (Figure 1; Huhtanen and Hristov, 2009; Gerber et al., 2011; Powell et al., 2012, 2013; Windisch et al., 2013). Therefore, some of these relationships will be considered in the following text.

Resource efficiency along the entire food chain

Calculations incorporating important inputs along the food chain (Figure 1) enable a more complex assessment of the production of food of animal origin. Such calculations allow conclusions concerning the need for limited resources (Table 3 for land need). Lack of data makes it difficult to carry out such calculations. The challenges arising in the 21st century require new tools for such calculations (Peters et al., 2007). There is a need for data on how human food consumption patterns influence the need for resources along the food chain and which environmental consequences should be expected.

De Vries and de Boer (2010) summarized references concerning land use and energy input per kilogram weight gain, milk, or eggs, but only some authors have calculated inputs and emissions per kilogram edible proteins of pork (e.g., Zhu and van Ierland, 2004).

On the basis of data from Tables 1, 3 and 4, as well some references (see footnotes), various resources introduced into the food chain and some emissions to produce 1 kg edible protein from milk or beef are summarized in Table 5.

Such calculations (Table 5) along the food chain demonstrate a higher need for arable land to produce one kilogram of edible protein in milk or beef more intensively, but the need for fossil fuel and the emissions are lower in this case. More data are necessary for the use of water in plant production. The FCR and the greenhouse gas emissions per food production seems to be useful and necessary to identify real resource costs and weaknesses along the entire food chain.

Opportunities and challenges

About two thirds of the agricultural area are grasslands or can be considered areas of perennial crops (about 3.3 billion ha; FAO, 2009a) with extremely varying yields. The use of this biomass for food production is a very important opportunity for ruminants (Taube et al., 2013). Only these animals are able to produce valuable food of animal origin on the basis of feed very rich in lignocellulosic substances as described above (Table 2). Apart from food of animal origin, ruminants also have other important tasks for the community, esp. for small holder farmers, including working as draft animals (esp. cattle, buffalo), providing leather for clothes, manure for soil fertility, as heating material for biogas; and they are considered to offer food and social security. Plant and animal breeding are the starting points for a sustainable and feed efficient ruminant production (Flachowsky et al., 2013).

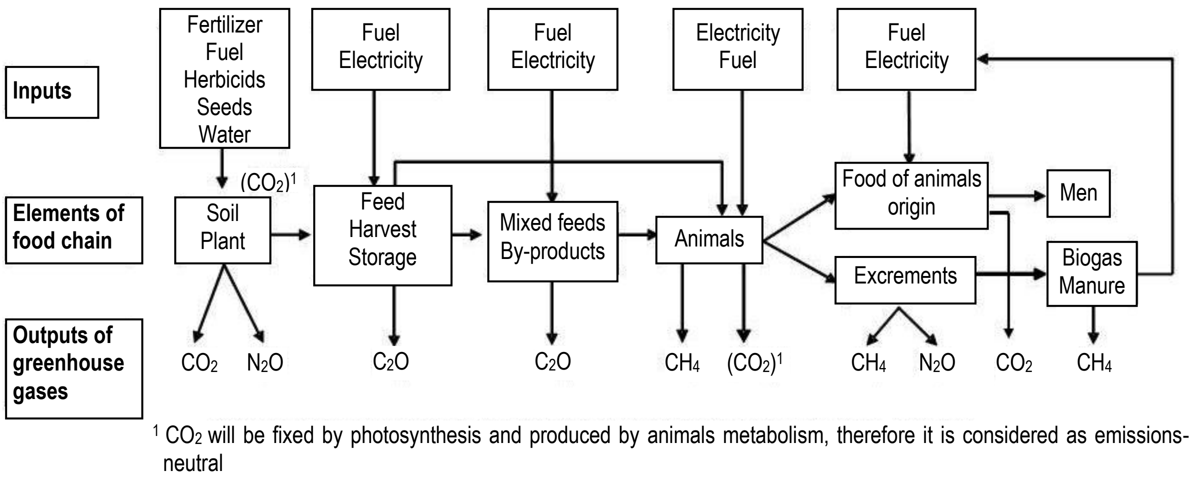

Figure 1. Substantial elements of the whole food chain 'soil – plants – animals – food of animal origin' to produce food of animal origin as well as selected inputs of limited resources and outputs of greenhouse gases (Flachowsky and Hachenberg, 2009)

Table 5. Model calculations for resource need and emissions to produce 1 kg edible protein *via* milk or beef under consideration of the whole food chain (see Tables 1, 3 and 4)

	Animal yield, kg · day^{-1}*	Protein yield, g · day^{-1}	Days to produce 1 kg of protein	Virtual water need, m^3· kg^{-1}**	Total area, m^2 · kg^{-1}***	Arable land, m^2 · kg^{-1}***	Fossil fuel, MJ · kg^{-1}****	FCR, kg DM · kg^{-1} protein	CF, kg CO_{2eq} · kg^{-1}
Milk	5	160	6.2	40	66	6	120	62	60
	20	640	1.6	30	30	12	75	25	16
Beef	0.5	48	20.8	140	140	15	500	135	110
	1.0	95	10.5	80	82	22	200	74	55

* DM intake and roughage: concentrate ratio according to Table 1; ** calculation on the base of data by Hoeckstra and Champaign (2007); *** plant yield according to level B in Table 3; **** calculation on the base by de Vries and de Boer (2010)

Based on the opportunities, the following paragraphs characterize present and future challenges of plant and animal breeding for resource-efficient production of food of ruminant origin. Finally, the consequences of present and future developments for ruminant nutrition will be taken under considerations.

Plant breeding

Increasing feed/food demands require higher and stable plant yields and/or more areas for production. Because of limited resources, low input plants are an important prerequisite for solving future problems and for establishing sustainable agriculture. Such plants should be very efficient in their use of water, mineral nutrients (including N), fuel, and arable land (high yields), but they should also be able to more efficiently use of solar energy and unlimited plant nutrients from the air (such as N_2 and CO_2; Table 6). Non-legumes should also be able to use N from the air for N-fixing symbiosis. Furthermore, the genetic pool available in plants, animals and microorganisms should contribute to optimizing plants and animals for more efficient conversion of limited resources into feed and food. Maintaining the biodiversity of the available genetic pool is also a very important aspect of sustainable agriculture. Losses of biodiversity may have dramatic consequences for plant breeding, including plant biotechnology, in the future (Serageldin, 1999; Tester and Langridge, 2010; HLPE, 2012a; Tillie et al., 2013).

Resource productivity and/or resource efficiency measures are key challenges for feed-efficient and sustainable ruminant production in the future. Plant breeding and cultivation could be considered the key elements and starting points for feed and food security in the next century (Flachowsky, 2008, 2013; SCAR, 2008; The Royal Society, 2009). The most important objectives for plant breeders from the view of animal nutrition and food security can be summarized as follows (also Table 6):

– high and stable yields with low external inputs of non-renewable resources (low input varieties) such as water, arable land, fossil fuel, minerals, plant protection substances, etc.;
– maximal use of natural unlimited resources such as sunlight, nitrogen, and carbon dioxide from the air;
– higher resistance against biotic and abiotic stressors and adaptation to potential climate changes;
– optimization of the genetic potential of plants for highly efficient photosynthesis;
– lower concentrations of toxic substances such as secondary plant ingredients, mycotoxins from toxin-producing fungi, toxins from anthropogenic activities or geogenic origin;
– lower concentrations of substances that influence the use or bioavailability of nutrients such as lignin, phytate, enzyme inhibitors, tannins, etc.;
– higher concentrations of the components determining nutritive value, such as nutrient precursors, nutrients, enzymes, pro- and prebiotics, essential oils, etc.

The conditions for and challenges to producing high amounts of phytogenic biomass are summarized in Table 6.

Arable land and water are considered to be the greatest challenges on the supply side for food production. Dobbs et al. (2011) estimate that in 2030 there will be a 30% higher need for water (an additional 1850 km^3) and between 140 and 175 million ha (about 10% of the present area) deforestation.

Table 6. Potentials to produce phytogenic biomass and their availability per inhabitant under consideration of the increase of population (The Royal Society, 2009; Flachowsky, 2010)

Plant nutrients in the air (N_2, CO_2)	↑↔
Solar energy	↔
Agricultural area	↓
Water	↓
Fossil energy	↓
Mineral plant nutrients	↓
Variation of genetic pool	↑

↑ increase, ↓ decrease, ↔ no important influence

Furthermore, the genetic pool available in plants, animals and microorganisms could also contribute to optimizing plants and animals for more efficient conversion of limited resources into feed and food (Table 6).

From the global perspective of feed and food security, plants with low inputs of non-renewable resources and high and stable yields should have the highest priority in plant breeding. In addition, low losses on the field, during harvest and storage are also important aspects of feed/food security (Schwerin et al., 2012). Furthermore, undesirable substances can often not be removed from feedstuffs, or can only be removed with great effort (e.g., Flachowsky, 2006; Fink-Gremmels, 2012; Verstraete, 2013). Therefore, a decrease of undesirable substances in plants, esp. under tropical and subtropical conditions, is also an important objective of plant breeding.

More attention must be focused on grassland, as recently proposed in the concept of sustainable grassland intensification, described by Taube et al. (2013) in detail. Intensification of grassland should be understood as ‘environmental factor productivity’ or eco-efficiency.

Furthermore, potential aspects of climate changes (HLPE, 2012a; IPCC, 2012) should be considered by plant breeders and ‘new’ plants should be adapted to such changes (e.g., Reynolds, 2010; Newman et al., 2011; Potthast and Meisch, 2012).

Possible climate change may also be an additional challenge for feed producers, feed conservation, and animal feeding (Schwerin et al., 2012; Windisch et al., 2013). Some authors (e.g., Easterling et al., 2007; Reynolds, 2010) predict a 15%–20% fall in global agricultural production by 2080 as a consequence of the expected climate change. The following climate change-related problems can be expected (Whitford et al., 2010):

- adaption to greater extremes in climate conditions and higher temperatures;
- the water supply may become limited or more variable; better adaption of plants to drought-resistance (e.g., Deikman et al., 2012);
- increasing of salt content in soils, better adaptation of plants;
- higher rates of disease infections and pest infestations (e.g., Mettenleiter and Behle, 2008; Wally and Punja, 2010).

A rapidly changing climate will require rapid development of new plant varieties. The negative effects of climate change could be greater than the possible solutions by conventional plant breeding. Therefore, the magnitude of the ‘technology gap’ between solutions by conventional breeding and need for adaptation to climate change will determine if plant yields are adequate or not (Whitford et al., 2010).

Animal breeding and feed conversion

Similar challenges can be formulated for animal breeders, feed producers, animal feeders and veterinarians. The breeding of domestic animals has a long-standing and successful history, starting with domestication several thousand years ago. Some aspects for more efficient feed conversion are considered in the simple model calculations in the next paragraph.

Feed conversion can be influenced on the feed side (feed quality) and on the animal side. Highly digestible feed and a high feed intake may contribute to a higher energy and nutrient intake and thus improve the ratio between energy available for performance and needed for maintenance, as demonstrated for dairy cows in Table 7. For example, the energy portion required for maintenance is reduced from 54% of total energy intake in the case of 10 kg milk per day to 18% if 30 kg of milk are produced.

Table 7. Model calculation to show the influence of dry matter intake (dry matter intake: 7.0 MJ net energy lactation (NEL) per kg DM) of dairy cows (body weight: 650 kg; 4% milk fat; GfE 2001) on energy intake, percentage of maintenance, milk yield, energy per kg of milk as well as emissions per kg of milk (Niemann et al., 2011)

Dry matter intake, kg · day^{-1}	10	15	20	25	30
Energy intake, MJ NEL · day^{-1}	70	105	140	175	210
Maintenance, 37.7 MJ NEL per cow per day, % of total NEL intake	53.9	35.9	26.9	21.5	18.0
Milk yield, 3.3 MJ NEL per kg	9.8	20.4	31.0	41.6	52.2
Net energy per kg milk, MJ NEL per kg milk	7.1	5.1	4.5	4.2	4.0
Methane emission*					
g · day^{-1}	240	360	480	600	720
g · kg^{-1} milk	24.5	17.6	15.5	14.4	13.8
Carbon footprint, g CO_{2eq} · kg^{-1} milk**	825	605	530	495	475

* according to Flachowsky and Brade (2007): 24 g CH_4 per kg DMI for all diets; ** calculated on the base of the greenhouse potential of CH_4 (x 23) and the calculations by Daemmgen and Haenel (2008)

Another way for a more efficient conversion of feed into food of animal origin could be energy and nutrient requirements for maintaining animals. These requirements depend on animal species, production category, body composition and other factors. The energy requirements are usually given per kilogram metabolic body size (kg $BW^{0.75}$; e.g., 0.293 MJ NEL · kg^{-1} $BW^{0.75}$ for dairy cows; GfE, 2001). Similar values were deduced by other energy evaluation systems (e.g., 0.272 or 0.335 MJ NEL · kg^{-1} $BW^{0.75}$ for beef or dairy cattle by the NRC, 2001). All of the values are characterized by large variation among individuals. Lower maintenance requirements save energy/nutrients and more energy/nutrients are available for animal yield, with consequences for lower methane emission and Carbon Footprints per unit product (Table 8).

Table 8. Model calculation to show the influence of various energy maintenance requirements on milk yield of lactating cows (body weight: 650 kg per cow, dry matter intake: 20 kg per day; net energy content of feed: 7.0 MJ NEL per kg DM; Niemann et al., 2011)

Maintenance requirements for energy					
MJ NEL per kg $BW^{0.75}$	0.20	0.25	0.30	0.35	0.40
MJ NEL per cow per day	25.7	32.2	38.6	45.0	51.5
Energy intake, MJ NEL per cow per day	140	140	140	140	140
Maintenance in % of NEL- intake	18.4	23.0	27.6	32.1	36.8
Milk yield, kg per cow per day	34.6	32.7	30.7	28.8	26.8
Methane emission					
g per cow per day	480	480	480	480	480
g per kg milk	13.9	14.7	15.6	16.7	17.9
Carbon footprints, g CO_{2eq} per kg milk	480	505	535	575	615

During anaerobic microbial fermentation, some feed energy is lost *via* methane (e.g., Baldwin, 1995; Kebreab et al., 2006; Martin et al., 2010). Methane losses vary between 4% and 10% of the gross energy intake of ruminants (e.g., Flachowsky and Brade, 2007; Tamminga et al., 2007) and increase with increasing fibre content of the rations (e.g., Kirchgessner et al., 1995; Hindrichsen et al., 2005; Ellis et al., 2010). The consequences of lower methane emission on the yield and emissions of dairy cows are shown in Table 9 and described in many papers (e.g., Flachowsky and Brade, 2007; Beauchemin et al., 2008; Fievez et al., 2010; Flachowsky et al., 2011; for more details see: Greenhouse Gas in Animal Agriculture – Finding a Balance between Food and Emissions. Anim. Feed Sci. Tech. 2011, 166–167, 1–796). Some breeding parameters (e.g., Beever et al., 2001; Hegarty et al., 2005; Brade et al., 2008) may also influence the methane emissions of ruminants.

Table 9. Model calculation to show the influence of methane reduction on the energy available for dairy cows and milk yields (conditions for calculation: dry matter intake: 20 kg per cow per day; body weight: 650 kg per cow, 7 MJ NEL per kg DM with 20 g CH_4-emission; Niemann et al., 2011)

Methane production				
g per kg DMI	30	25	20	15
g per cow per day	600	500	400	300
Energy intake, MJ NEL per day	130	135	140	145
Milk yield, kg per day	28.0	29.5	31.0	32.5
Methane emission, g per kg milk	21.4	17.0	12.9	9.2
Carbon footprint, g CO_{2eq} per kg milk	735	585	440	315

Apart from those aspects mentioned above, there are some other possibilities of achieving more efficient conversion of feed, such as:

- lower fat content in food of animal origin (e.g., meat, milk, eggs);
- higher protein content in products (e.g., milk);
- lower lactose content in milk (e.g., from about 48 g · l^{-1} to below 40 g · l^{-1}) to relieve metabolism (liver) by lower gluconeogenesis;
- higher resistance of animals against biotic and abiotic stressors;
- stabile animal health, lower animal losses (lower mortality).

Further details on the current stage of achieving more sustainable animal production and efficient feed conversion are described by Robi et al. (2007), Laible (2009) and Niemann et al. (2011). The forecasted climate change will also have an important impact on feed and animal production, animal health and feed conversion, as recently discussed by Schwerin et al. (2012).

Furthermore, efficient feed production and conservation, optimal diet composition to meet the requirements for all essential nutrients, taking into consideration animal species, categories, and their yields, efficient use of feed resources and by-products of the agricultural, food and biofuel industries, as well as the supply of sufficiently high quality water for drinking, are further important prerequisites for healthy animals and the efficient production of high quality food with and from ruminants.

Conclusions

Human population growth, limited arable land, fresh water and fuel, as well possible climate changes require a radical rethinking of agriculture for the 21st century to meet humans' demands for the 6F's (feed, food, fibre, fuel, flower and fan) while reducing the environmental impact of their production. Development of plants taking into account the resources necessary to produce them may be considered a long-term challenge for plant breeders. More public investments are needed and new and imaginative public-private collaboration can also make plant and animal breeding beneficial for developing countries. More systemic approaches are necessary to understand interactions and to find acceptable solutions for complex connections in terms of food security, resource efficiency, as well environmental, social and economic aspects.

Ruminants are able to utilize lignocellulose, non-protein nitrogen and co-products of the food and biofuel industries into food of animal origin without any feed competition with non-ruminants and man. It is also known, however, that 1 kg of beef or 1 kg of edible protein from growing cattle has the highest greenhouse gas potential and uses the most land, albeit, mainly grassland. Mono-causal considerations are not able to solve global problems in the field of food security.

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