Nutritional economic and ecological aspects in the production of edible protein of animal origin at different performance levels of farm livestock

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1. Introduction

The continued growth of the world's population and the increasing demand for foods of animal origin make efficient resource management an overriding necessity. Particular attention and critical debate are focused on the losses which occur during conversion of plant products into foods of animal origin. The fundamental issues are the need for and the extent of the provision of foods of animal origin.

Animal products are needed in human nutrition primarily to provide proteins and amino acids, especially for children and adolescents, pregnant and nursing women and other groups of people. The daily protein requirement is 0.75 to 1 g per kg bodyweight (DGE, 1989) and it has been estimated that if one-third of this is supplied by animal protein, the risk of an amino acid deficit can be largely avoided. Consequently, the recommended daily intake of animal protein is in the region of 20 g per person. But meat, milk and eggs also contain nutrients other than amino acids, such as varying amounts of macro- and trace elements (e. g. Ca, P, Fe, Cu, Zn, Se, J) and vitamins (Vitamin A, E, B_1, B_2, B_6, B_{12} etc.), which can become deficient if animal products are absent from the human diet. The pleasure of eating foods of animal origin must also be mentioned. In many parts of the world far more than the recommended 20 g per person and day is supplied and consumed (Table 1).

Table 1: Provision of foods of animal origin in various regions of the world (FAO, 1997)

Region	Food of animal origin per person and year					
	Meat		Milk		Eggs	
	kg	g*	kg	g*	kg	g*
World	37.3	18.4	95.2	8.3	7.5	2.5
- North America	93.2	46.0	195.2	16.7	14.1	4.6
- Europe	58.5	28.8	219.6	19.2	9.2	3.0
- Asia	24.4	12.0	37.9	3.3	6.5	2.1
- Africa	12.6	6.2	30.4	2.7	2.3	0.8

* Edible protein

The total amount of edible protein of animal origin currently produced worldwide would be sufficient to provide on average 20 g of edible protein per person and day (Table 2). As many as 8000 million people could theoretically be supplied with sufficient protein. The problem we face currently is therefore not one of production but of distribution. This situation will change if the populations of entire regions should in future eat or wish to eat more protein of animal origin. This is almost certain to happen so that the variants designated as scenarios 2 and 3 in Table 2 indicate future trends and average supply situations.

These figures indicate the necessity to increase the supply of foods of animal origin in a sustainable manner. This issue has been addressed by several authors in recent years (e. g. FLACHOWSKY,1999; JAHREIS and GUNSTHEIMER,1998; KIRCHGESSNER et al., 1991).

Table 2: Calculations of the supply of edible protein of animal origin under different scenarios (FLACHOWSKY, 2000)

Consumption of animal protein/person and day	No. of people 6000 million	8000 million
Scenario 1 20 g per person	130 %*	95 %*
Scenario 2 60 g for 2000 million people and 20 g for 4000 or 6000 million people	80 %	65 %
Scenario 3 60 g for 2000 million people and 40 g for 4000 or 6000 million people	55 %	45 %

* Possible supply in % based on current production of protein of animal origin: ~10 kg /person per year

The present work attempts to present nutritional and ecological aspects in the production of edible protein of animal origin from agricultural livestock in relation to different production types and yields. This paper is not concerned with possibilities for the production of protein from aquaculture, insects, moluscs etc. For a review of these aspects we refer to JAHREIS and GUNSTHEIMER (1998). For the purpose of our calculations, protein production is based on the input of crude protein and dietary energy. Other resources which are available in limited quantities and also needed and utilised in the production of feedingstuffs and food such as arable land or technical energy, are left out of account. Such considerations exceed the scope of our work and have already featured in previous investigations (e. g. BICKEL et al., 1979; FLACHOWSKY, 1992; FLACHOWSKY et al., 1982; KRUMMEL and DRITSCHILO, 1977; PIMENTEL et al., 1975; VANDENHAAR, 1998; WERSCHNITZKY, 1979).

2. Materials and methods

2.1 Edible protein as reference basis

In selecting edible protein as a reference basis for our calculations we considered its advantages as the deciding factor while being fully aware of its inherent limitations:

Advantages

- Main objective in the production of foods of animal origin
- Comparison of different protein sources and production types becomes possible.

Limitations

- Difficulties in conversion to animal product
- Formulation of some definitions (e. g. proportion of edible fractions, protein content in edible fractions, etc.)
- Ignores the energy content of foods (which can be very important for meeting human energy requirements).

The amount of edible protein produced daily with reference to animal species, livestock category and yield is based on experimental data from feeding and slaughter trials. Key sources used in our calculations of the daily production of edible protein are shown in Table 3. The fluctuations in the protein content of a protein source vary little between different authors. Defining the edible protein content poses greater problems because views differ widely between authors and cultures (e.g. use of giblets, tripe, blood etc.). The data can also be used as a basis for further calculations, for example of the protein production per cow or laying hen and year, etc.

Table 3: Assumptions in the production of edible protein of animal origin

Protein source		Production per day	Edible fraction (%)	Protein content in the edible fraction (g/kg fresh substance)	Edible protein (g/day)
Milk[1)]		5 kg	95	32	152
		10 kg			304
		20 kg			608
		40 kg			1216
Beef[2)]		500 g LWG*	50	190	48
		1000 g LWG			95
		1500 g LWG			143
Pork[3)]		300 g LWG*	60	150	27
		500 g LWG			45
		700 g LWG			63
		900 g LWG			81
Poultry meat[4)]		20 g LWG*	60	200	2.4
		40 g LWG			4.8
		60 g LWG			7.2
Eggs[5)]	30 % LP**	20 g EM***	95	120	2.3
	50 % LP	32 g EM			3.6
	70 % LP	45 g EM			5.1
	90 % LP	58 g EM			6.6

* Liveweight gain, ** Laying performance in %; *** Egg mass
1) GfE (2000), 2) GfE (1995), 3) GfE (1987), 4) GfE (1999), 5) GfE (1999) [GfE = German Nutrition Society]

2.2 Use of feedingstuff and nutrients

The amount and the composition of the feedingstuff and nutrients used have a significant impact on the results of nutritional and ecological calculations. The determination of feed intake in relation to animal species, livestock category and yield was based on feeding trials and statistics by the German Nutrition Society, GfE (1987, 1995, 1999, 2000). The decision which natural reference standard to use for nutritional calculations poses greater difficulties. Potential candidates are dry matter and/or organic substance, gross energy or conventional measures of energy for the various species (digestible, metabolisable or net energy) and crude protein or other parameters of protein use (digestible crude protein, major amino acids). For practical reasons we have used gross energy and crude protein as the basis for the calculations in this paper, while being fully aware that both lack precision. For example, the use of gross energy for such calculations ignores ruminants, whose diets are usually richer in cell-wall constituents (lignin) than those of non-ruminants. On the other hand, the amount of initial feedingstuff produced was to be the reference basis and consideration of other parameters would interfere with these comparisons.

A question that arises frequently in connection with nutritional calculations is whether humans and animals are in competition for food. As with estimations of edible fractions (cf. Table 3), it is necessary to make assumptions about the proportion of concentrate that could be used directly in human nutrition. This involves not only estimating the amount, but also assessing whether concentrates should be regarded as by-products (e. g. extracted soybean meal, by-products of grain processing (FLACHOWSKY and KAMPHUES, 1996)) or can be used directly in human nutrition. The proportion of by-products used in animal nutrition has not only nutritional implications but it also affects the results of calculations on land use (VANDENHAAR, 1998) and the use of technical energy and CO_2 output in food production (BOCKISCH, 2000). Table 4 contains data on the proportion of concentrate that could also be used directly in human nutrition.

Table 4: Feed consumption for selected production types and yields

Protein source		Daily yield	Feed intake (kg DM/ head/ day)[2)]	Proportion of concentrate[1)]	Crude protein (g/head and day)
Milk		5 kg	8	0	1000
		10 kg	12	0	1400
		20 kg	17	(20)	2200
		40 kg	24	(40)	3300
Beef		500 g LWG*	6	0	720
		1000 g LWG	7	(20)	850
		1500 g LWG	8	(30)	1000
Pork		300 g LWG*	1.5	(20)	280
		500 g LWG	1.8	(40)	330
		700 g LWG	2.1	(65)	380
		900 g LWG	2.3	(80)	430
Poultry meat		20 g LWG*	0.06	(20)	12
		40 g LWG	0.07	(50)	16
		60 g LWG	0.09	(80)	20
Eggs	30 % LP**	20 g EM***	0.09	(20)	15
	50 % LP	32 g EM	0.10	(35)	16.5
	70 % LP	45 g EM	0.11	(50)	18
	90 % LP	58 g EM	0.12	(70)	19.5

1) Concentrates that can be consumed directly by humans (= competition for food between animals and humans)
2) Gross energy content of the feed in relation to fat and ash content (17 to 20 MJ/kg DM)
* Liveweight gain; ** Laying performance in %; *** Egg mass

2.3 Emissions

Emissions of N, P and methane per kg of edible protein are taken into account in the calculations.

2.4 Reference parameters

The calculation methods for input, efficiency and emissions are presented below.

Parameters for nutritional and ecological calculations:

$$\text{Input (per kg)} = \frac{\text{Intake (energy/nutrient)}}{\text{Edible protein produced (in kg)}}$$

$$\text{Efficiency (\%)} = \frac{\text{Retention (energy/nutrient, edible protein)}}{\text{Intake (energy/nutrient)}} \times 100$$

$$\text{Emissions per kg of edible protein} = \frac{\text{Emissions (N, P, } CH_4\text{)}}{\text{Edible protein produced (in kg)}}$$

The weak points of nutritional and ecological calculations for the production of edible protein include the following:

Uncertainty of data

- Variations in feed use and consumption by animals
- Variations in the nutrient content of the feed and the animal product
- Effect of performance level
- Consideration of the contribution of rearing and parent stock.

Assumptions (definition of different scenarios)

- Size of edible fractions and their protein content
- Competition between animals and humans for food (e.g. classification of individual feedingstuffs).

This paper is mainly concerned with comparisons based on yield and between different livestock species and categories. Specific techniques available to animal nutritionists for increasing the efficiency of feed conversion (e. g. ration design, use of amino acids, enzymes, antibiotics, microorganisms, etc.) are not considered here. The potential of sustainable resource management as a discipline has been discussed elsewhere (FLACHOWSKY and SOUFFRANT, 2000).

3. Nutritional economic evaluation of different protein sources

The elementary prerequisite for growth, reproduction, lactation and egg production is to secure a sufficient supply of energy and nutrients to meet the animals' requirement for maintenance. Any surplus energy and nutrients over and above the maintenance requirement are available for growth, milk and egg production. It follows that the efficiency of nutrient utilisation for the production of edible protein in animals without a measurable output is zero; at low yields it is relatively low and the input very high because the burden of the "unproductive" maintenance requirement is proportionately higher at low yields and low levels of protein production.

Figure 1 illustrates this development using the energy required for the production of edible milk protein in relation to milk yield as an example. Similar graphs can be constructed for crude protein or other nutrients, as shown for egg production in Figure 2. Despite an increasing crude protein requirement, the efficiency of crude protein utilisation improves at higher yields, thus reducing the crude protein required for the production of edible egg protein.

The result of a more efficient utilisation and a reduced feed input is that more nutrients per product remain in the animal

Figure 1: Effect of milk yield and protein production on the maintenance and production requirement of energy in growing cattle (liveweight: 650 kg) and on the energy input per kg of edible protein (GfE 2000)

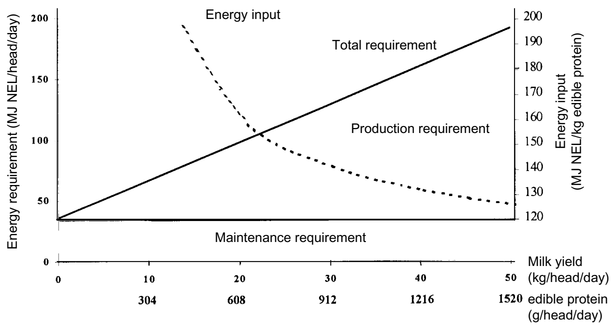
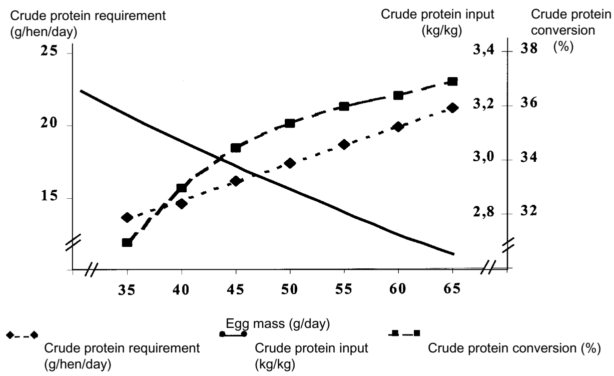


Figure 2: Effect of daily egg mass production on the crude protein requirement of laying hens (liveweight: 1.8 kg/hen, from 32 weeks of age) and on crude protein input and crude protein utilisation per g of edible protein produced (GfE 2000)



or in the animal product and fewer nutrients are excreted (e. g. N, P) and thus are not available for polluting the environment.

These fundamental trends imply that as productivity increases feed ingredients are converted more effectively into edible animal products, resulting in lower emissions per end product, which would ultimately make the production of foods of animal origin more sustainable and environmentally compatible. This statement cannot be extrapolated indefinitely because at higher yields the competition for food with humans usually increases (Table 4) and the consumption of technical energy for feed production tends to rise (ABEL, 1996; FLACHOWSKY, 1992; KRUMMEL and DRITSCHILO, 1977).

3.1 Milk

Nutritional economic and ecological calculations for the production of milk protein are relatively simple to carry out if the calf rearing phase is disregarded. The amount of energy and crude protein required for the production of 1 kg milk protein declines with increasing milk yield, whereas the required amount of concentrate increases markedly in absolute terms and slightly in relative terms (Fig. 1, Table 5). At higher yields the effect of the diminishing input of energy and crude protein becomes progressively less apparent because the high absolute milk yield means that the relative share of the maintenance requirement becomes smaller (GfE 2000). This statement also applies to the level of emissions (N, P, CH_4) per animal product (cf. Table 18).

Table 5: Effect of milk yield on selected nutritional parameters in the production of 1 kg milk protein (excluding allowances for rearing and dry period)

Average milk yield		Input per kg of edible protein			
		Gross energy	Gross energy from concentrate	Crude protein	Crude protein from concentrate
(kg/day)	(kg/year)	(GJ)	(GJ)	(kg)	(kg)
2	500	1.6	0	10.0	0
5	1500	0.85	0	6.0	0
10	3000	0.65	0	4.6	0
20	6000	0.48	(0.1)	3.7	(0.7)
30	9000	0.38	(0.12)	3.4	(1.0)
40	12000	0.34	(0.14)	3.2	(1.3)

Resource management during the rearing period and the productive life of cows have a significant influence on the results of nutritional and ecological calculations (Table 6).

Table 6: Criteria for nutritional calculations in milk production allowing for the intensity of the rearing period and the productive life of dairy cows

Inputs in relation to age at first calving			
	Age at first calving (months)		
Criterion	24	30	36
Dry matter intake (t/head)	4.0	4.8	5.3
Gross energy intake (GJ/head)	68	82	90
Crude protein intake (kg/head)	520	620	680

Protein yield of dairy cows at slaughter in relation to their productive life	Productive life (years)			
	1	2	4	6
Protein yield (kg/cow/year)*	50	25	12	8.5

* Assumptions: 600 kg liveweight, 50 % edible fraction, 17 % protein in the edible fraction

A young age at first calving and a long productive lifespan of cows can both contribute to making protein production more efficient nutritionally as well as ecologically (Table 7).

3.2 Beef

Beef can be produced from calves born to dairy cows or from suckler cows. When calves are considered a "by-product of milk production" (costs incurred during the dry period are included in the dairy cow calculations) the allocation of the feed input is relatively clear-cut. In beef cattle the input per kg of edible protein is determined primarily by liveweight gains (Table 8).

Table 7: Effect of the length of the rearing period (age at first calving) und the productive life of cows on selected nutritional parameters in the production of 1 kg milk protein*

Age at first calving (months)	24			30		
Productive life (years)	2	4	6	2	4	6
Milk yield (kg/cow/year)	Input per kg of edible protein Gross energy (GJ)					
4000	0.75	0.70	0.66	0.80	0.72	0.68
8000	0.50	0.46	0.44	0.53	0.47	0.45
12000	0.40	0.38	0.36	0.43	0.39	0.37
	Crude protein (kg)					
4000	5.4	5.0	4.8	5.7	5.1	4.9
8000	4.2	3.9	3.8	4.4	4.0	3.9
12000	3.8	3.6	3.5	3.9	3.6	3.5

* (Lactation yield: 4000, 8000 or 12000 kg/year, 32 g protein/kg; carcass weight of the cows: 600 kg/cow)

Table 8: Effect of liveweight gain on selected nutritional parameters in the production of edible protein as beef*

	Input per kg of edible protein			
Average liveweight gain (g/head and day)	Gross energy (GJ)	Gross energy from concentrate (GJ)	Crude protein (kg)	Crude protein from concentrate (kg)
200	4.0	0	30	0
500	2.1	0	15	0
1000	1.2	(0.25)	9	(1.5)
1500	0.9	(0.3)	7.5	(2.2)

* Calf as by-product of milk production

In suckler cow management the results of nutritional economic and ecological calculations are influenced by liveweight gain, age at first calving, calving interval and productive life of the suckler cows (Table 9), with liveweight gain being the dominant factor.

Table 9: Effect of age at first calving and productive life of suckler cows on selected nutritional parameters in the production of 1 kg edible protein as beef in relation to liveweight gains (LWG)*

Age at first calving (months)	27		36	
Productive life of the cows (years)	3	6	3	6
LWG (g/head/day)	Input per kg of edible protein Gross energy (GJ)			
500	2.4	2.3	2.5	2.4
1000	1.7	1.6	1.8	1.7
1500	1.5	1.4	1.6	1.5
	Crude protein (kg)			
500	19	18	20	19
1000	13	12	12	11
1500	11	10	12	11

* Slaughter weight of the cows: 600 kg (50 % edible fraction; 17 % protein in the edible fraction); 1 calf/year; growth period: 50-350 kg (50 % edible fraction; 19 % protein in the edible fraction)

On the other hand, it is undeniable that suckler cows can utilise grazing areas which would otherwise be unsuitable for food production, or only usable to a limited extent. From an economic point of view milk and beef production must be considered as a unit. If the milk yield increases, each cow will supply more people with milk; emissions of N, P and methane per kg milk or per person supplied with milk will decline accordingly. (Table 10).

Table 10: Calculation of N, P and methane emissions by dairy cows in relation to milk yield and milk consumption (≈350 l/head/year, DGE 1996)

Milk yield (kg/cow and year)	Quantity sufficient for No. of people/year	Emissions by dairy cows per person (kg/year) N	P	CH_4
6000	17.1	5.1	1.2	7.7
8000	22.9	4.6	1.05	6.0
10000	28.6	4.2	0.9	5.0
12000	34.3	4.0	0.8	4.2

On the other hand, at higher milk yields fewer dairy cows are needed to supply the population. Although beef consumption in Germany has fallen in recent years (≈10 kg/person per year), the amount of meat produced by slaughtering cows and their beef calves is no longer sufficient to supply the population. It is therefore necessary to produce beef from suckler cows and their calves (or to meet the demand through imports). These less effective forms of utilising fodder plants and the resulting higher emissions per animal product mean that at higher milk yields, per capita N, P und CH_4 emissions can rise again (cf. Tables 10 and 11).

Table 11: Calculation of N, P and methane emissions by cows and beef cattle in relation to milk yield and consumption of milk (≈ 350 l/ head/year) and beef (≈ 10 kg /head/year)

Milk yield (kg/cow and year)	Sufficient for No. of people/year Milk	Meat[1)]	Emissions by cows and beef cattle per person (kg/year) N	P	CH_4
6000	17.1	20	7.0	1.5	10.4
8000	22.9	20[2)]	6.8	1.4	9.4
10000	28.6	20[2)]	7.0	1.4	9.3
12000	34.4	20[2)]	7.4	1.5	10.2

1) Calculation of meat yield: cows with 3 years productive life; 600 kg carcass mass; 50 % meat yield (100 kg meat/cow and year); 1 calf/cow and year, 50 % to finishing, 1000 g daily gains, 50 % meat yield (100 kg meat/beef cattle and year)

2) Beef production from suckler cows necessary

3.3 Pork

As for milk and beef production, daily liveweight gain is the main factor affecting nutritional economic and ecological parameters in the production of protein from pork (Table 12). The amount of energy and crude protein required per kg of edible protein declines with rising liveweight gains whereas the proportion accounted for by concentrates and the competition for food with humans increases. Along with the rate of liveweight gains by fattening pigs, other factors affecting nutritional parameters are the rearing period of gilts, the productive lifespan of sows and above all the number of weaned piglets per sow.

Table 12: Effect of liveweight gain on selected nutritional parameters in the production of edible protein from pig meat

Mean liveweight gain (g/pig and day)	Input per kg of edible protein: Gross energy (GJ)	Gross energy from concentrate (GJ)	Crude protein (kg)	Crude protein from concentrate (kg)
300	0.9	(0.2)	10	(2)
500	0.7	(0.3)	7.5	(3)
700	0.6	(0.5)	6	(4)
900	0.6	(0.4)	5	(4)

3.4 Poultry meat

The nutritional parameters for the production of broiler meat are lower (Table 13) than the data reported for beef and pork (Table 8, 9 and 12). The differences are due to the high protein synthesis capacity of growing chickens, which substantially exceeds that of growing pigs or cattle per kg liveweight (≈ 8 g, 1.5 g and 0.8 g/kg LW respectively for broilers, fattening pigs and beef cattle with 50, 800 and 1200 g liveweight gains/day, respectively). As in other growing animals, the amount of liveweight gain has a significant effect on the measured data.

Table 13: Effect of liveweight gain (fattening period) on selected nutritional parameters in the production of edible protein from broiler meat

Average liveweight gain (g/broiler/day) (Fattening period in days to 1540 g finishing weight)	Input per kg of edible protein: Gross energy (GJ)	Gross energy from concentrate (GJ)	Crude protein (kg)	Crude protein from concentrate (kg)
20 (73)	0.45	(0.10)	5	(1.0)
30 (50)	0.32	(0.12)	3.5	(1.2)
40 (38)	0.26	(0.13)	3	(1.5)
50 (30)	0.22	(0.14)	2.5	(1.8)

* Excluding resources used for broiler parent stock

3.5 Eggs

The amount of energy and protein required for the production of protein from laying hens is heavily dependent on egg laying performance (Fig. 2, Table 14) and at high production levels approximately comparable with data for dairy cows (≈ 30-40 kg milk/day, Table 5).

Table 14: Effect of laying performance on selected nutritional parameters in the production of edible protein from hens' eggs

Average laying performance in % (Egg mass in g per day)	Input per kg of edible protein: Gross energy (GJ)	Gross energy from concentrate (GJ)	Crude protein (kg)	Crude protein from concentrate (kg)
30 (20)	0.70	(0.15)	6.0	(1.2)
50 (32)	0.48	(0.16)	4.0	(1.4)
70 (45)	0.36	(0.18)	3.3	(1.6)
90 (58)	0.30	(0.21)	3.0	(2.0)

Compared with the impact of egg laying performance, the number of chicks reared per pullet and the duration of the pullet rearing period have a relatively minor influence on resource consumption data (Table 15).

Table 15: Effect of breeding hen performance, intensity of pullet rearing and laying performance on selected nutritional parameters in the production of 1 kg edible protein from hens' eggs*

Chicks reared per breeding hen	50		200	
Rearing period (weeks)	20	25	20	25
	Input per kg of edible protein			
Laying performance	Gross energy (GJ)			
30 %	0.60	0.65	0.58	0.62
90 %	0.40	0.42	0.38	0.40
	Crude protein (kg)			
50 %	5.0	5.2	4.8	5.0
90 %	3.6	3.8	3.5	3.0

* Carcass weight of the hens: 1.5 kg

3.6 Other protein sources

The trend outlined for the different forms of edible protein production described above, according to which fewer resources of energy and protein are needed at higher yields, thus making their conversion more efficient, also applies to other sectors of milk (e. g. goats, sheep etc.), meat (sheep, rabbits, turkeys, ducks, geese, etc.) and egg production (quails etc.). Table 16 illustrates this point with data for the production of rabbit meat.

Table 16: Effect of feeding intensity on selected nutritional parameters in the production of edible protein from rabbit meat (after SEMISCH et al., 1995)

Feeding intensity	Input per kg of edible protein: Gross energy (GJ)	Gross energy from concentrate (GJ)	Crude protein (kg)	Crude protein from concentrate (kg)
Intensive fattening (45 g LWG/head/day)	0.7	(0.25)	7.5	(2.0)
Intensive fattening and reproduction (48 young rabbits/year, 45 g LWG/head/day)	0.85	(0.3)	9.0	(2.0)
Extensive fattening (20 g LWG/head/day)	0.95	(0.2)	10.0	(2.0)

3.7 Comparative assessment

The different livestock species and categories used for the production of dietary proteins vary widely with regard to the amount of energy and crude protein required and emissions of N, P and methane per kg of edible protein (Tables 17 und 18). The production of milk, egg protein and broiler meat was least demanding on resources.

The production of protein from growing pigs and cattle requires considerably more resources and causes higher N and P emissions per kg of dietary protein. Beef production is additionally associated with the formation of methane in the rumen. In all forms of protein production, input and emissions per kg of protein decline with increasing yields. In addition to yields, the reported data are also influenced by the feed intake, the composition of the diet (e. g. crude protein, energy and P content), the proportion of edible protein in the animal product and any allowances for energy and nutrients needed for rearing and reproduction.

When other factors are taken into consideration (e. g. technical energy, competition for food with humans), higher yields and accurate feeding of agricultural livestock are crucial for ensuring that the production of foods of animal origin is managed in a sustainable and environmentally compatible manner.

Table 17: Comparison of nutritional parameters in the production of edible protein from different protein sources and at different yield levels

Protein source	Yield	Input per kg of edible protein: Gross energy (GJ)	Crude protein (kg)
Milk	5 kg/day	0.85	6
	10 kg /day	0.65	4.6
	20 kg/day	0.48	3.7
	40 kg/day	0.34	3.2
Beef	500 g LWG/day	2.1	15
	1000 g LWG/day	1.2	9
Pork	300 g LWG/day	0.9	10
	700 g LWG/day	0.6	6
Poultry meat	20 g LWG/day	0.45	5
	40 g LWG/day	0.26	3
Eggs	50 % LP	0.5	4
	90 % LP	0.3	3

Table 18: Estimated values for levels of N, P and CH_4 generated in the production of 1 kg edible protein of animal origin

Protein source	Yield	Emissions by farm animals per kg of edible protein: N (kg)	P (g)	CH_4 (kg)
Milk	5 kg/day	0.9	140	1.5
	10 kg/day	0.6	100	1.0
	20 kg/day	0.4	60	0.6
	40 kg/day	0.3	40	0.4
Beef	500 g LWG/day	2.0	300	2.5
	1000 g LWG/day	1.2	180	1.5
Pork	300 g LWG/day	1.5	200	-
	700 g LWG/day	0.8	120	-
Poultry meat	20 g LWG/day	0.6	80	-
	40 g LWG/day	0.3	40	-
Eggs	50 % LP	0.8	90	-
	90 % LP	0.3	50	-

4. Conclusions

The conclusions to be drawn from these calculations are as follows:

- Nutritional calculations based on edible protein permit comparisons between livestock species and categories but have a number of weak points (e. g. definition of the edible fraction).
- Dietary protein from poultry meat and eggs, followed by cow's milk and pork, can be produced with the lowest input of gross energy and crude protein.
- Increases in N and P emissions per kg of edible protein follow the same ranking order.
- Nutritional parameters (input data, feed conversion) improve with rising yields due to the relatively smaller proportion required for maintenance. The yield therefore has a significant impact on the ranking order of livestock species and categories with regard to the efficiency of feed conversion.
- For sophisticated nutritional/economic analyses, the rearing period (e. g. young cattle, pullets) and resource consumption for parent stock (suckler cows, sows, broiler parent flocks etc.) must also be taken into consideration.
- As yields rise, competition for food with humans increases. It is greater for poultry and pigs than for ruminants but depends in all species on the amount of by-products used in the ration.
- Ruminants, especially in the tropics and subtropics, are of overriding importance for the protein supply of the human population because of natural conditions (grassland) and the advantages of microbial digestive processes in the forestomachs.
- From a nutritional and ecological viewpoint and addressing the issue on a global level, the following possibilities have been identified for improving the supply of protein of animal origin in the tropics and subtropics:
  - Reduction of livestock numbers (especially of ruminants in the tropics and subtropics because 70 % of livestock herds kept in these regions produce only about 30 % of the world's total dietary protein)
  - Raising yields
  - Development of a feed stockpiling system including use of by-products in the tropics and subtropics
  - Increasing the fodder value of inferior feedingstuffs.

5. Summary

The production of edible protein of animal origin as the principal objective of livestock husbandry served as the basis for the nutritional and ecological calculations undertaken here. The nutritional parameters calculated were the amount of gross energy and crude protein required per kg of dietary protein from milk, beef, pork, poultry meat, rabbit meat and eggs. The competition for food between farm animals and humans was assessed by determining the amount of concentrate required per kg of edible protein. Emissions of N, P and methane per kg of dietary protein formed the basis for ecological considerations.

The results of nutritional and ecological calculations for different livestock species and categories are determined primarily by yields. As yields increase the proportion of the maintenance requirement allocated to the product or unit of edible protein becomes relatively smaller; this reduces the amount of energy and protein required and increases their conversion efficiency. At daily yields of 30 kg milk, 1000 g gains in beef catte, 700 g in pigs, 40 g in broilers and a laying performance of 80 %, the production of 1 kg edible protein from milk, beef, pork, poultry meat or eggs requires a gross energy of about 0.4; 1.2; 0.6; 0.25 and 0.35 GJ respectively and 3.4; 9.0; 6.0; 3.0 and 3.5 kg of crude protein respectively. N emissions per kg of edible protein for the five protein sources amount to about 0.35; 1.2; 0.8; 0.3 and 0.4 kg; calculated P emissions were about 50, 180, 120, 40 and 60 g respectively.

At the stated yield levels, protein production from milk, poultry meat or eggs is therefore more efficient both nutritionally and ecologically than that from pork and beef. Competition for food with humans is greater in the production of protein from non-ruminants (pigs, poultry) than ruminants; this parameter is also dependent on the proportion of by-products from agriculture and food production in the daily ration and on the animals' yields.

The global aim of a sustainable and ecologically acceptable production of protein of animal origin can be achieved by reducing livestock herds, increasing animal performance and utilising feedingstuffs in animal nutrition that are unsuitable for direct consumption by humans.

6. Literature

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