A Review on Environmental Impacts of Nutritional Strategies in Ruminants[1]

S. Tamminga

Department of Animal Nutrition, Wageningen Institute of Animal Sciences, WIAS, Wageningen, The Netherlands

ABSTRACT: Primary (plant), secondary (animal), and tertiary (human) biological systems are driven by energy, either fossil or renewable energy in biomass. Their ratio shifts from about 10:90 in primary, via 25:75 in secondary, to 90:10 in tertiary systems. Energy input in ruminant production is mainly as plants and plant parts from primary production, and the amount needed per unit product (milk, meat) primarily depends on its digestibility. This is high in young, leafy, whole plants, in roots and tubers, and in reproductive organs (whole seeds) or organ parts (by-products) of mature plants. Use of fossil energy per kilogram of DM for primary production ranges from 1 to 3 MJ in forage to over 8 MJ in concentrate feeds, whereas input per kilogram of milk is 1 to 10 MJ. Biomass energy used in ruminant production contains nitrogen (N), phosphorus (P), and potassium (K), but in a ratio rarely balanced to the animals requirements. In secondary systems, energy is partitioned between foods of animal origin and waste. The latter contains OM, N, P, K, and gases (CO_2, CH_4), which may cause environmental problems. Losses per kilograms of milk vary and are 10 to 45 g for N, 0 to 3 g for P, and 2 to 20 g for K. Environmental impacts of animal production can be reduced by varying the use of inorganic fertilizer and changing the forage to concentrate ratio. Digestibilities can be improved by proper harvest management. Level and ratio of dietary N, P, and K can be adjusted to requirements by selecting proper ingredients, reducing their loss in waste. Limited scope exists to reduce losses in respiration and fermentation gases.

Key Words: Environment, Nutrition, Ruminants, Waste

J. Anim. Sci. 1996. 74:3112–3124

Introduction

Biological systems fall apart in primary, secondary, and tertiary systems. In primary systems biomass is produced as a result of photosynthesis, which in turn is driven by solar energy to produce combinations of elements C, H, O, N, S, and P into complicated compounds. These are primarily known as carbohydrates, proteins, and lipids. Animal production is a secondary production system and the output of the primary system is used as its input. The complex organic compounds are broken down to the level of monomers (sugars or short-chain organic acids, amino acids, long-chain fatty acids), which pass the wall of the digestive tract, a barrier between the outside and the inside of the animal. Subsequently they are either used as fuel or as precursors for their resynthesis to proteins, lipids, and carbohydrates. The tertiary system, i.e., the human population, resembles the secondary system, except that a significant part of the input originates from the secondary (animal) system. A further distinction between the three systems is that they increasingly depend on the input of fossil energy. A rough estimate reveals that the fossil:renewable energy in biomass ratio shifts from about 10:90 in primary via 25:75 in secondary to 90:10 in tertiary systems (Meadows et al., 1992).

There is a growing awareness worldwide of the necessity to protect the environment (Brundland, 1986; Meadows et al., 1992), preventing the contamination of air with carbon dioxide, methane, ammonia, and nitrogen oxides and other gases that contribute to the greenhouse effect. In addition, interest exists in preventing the contamination of soil and water with excessive amounts of phosphorus (P), nitrogen (N), and potassium (K).

Like all other human activities, development and use of intensive animal production systems, including those with ruminants, contribute to environmental pollution due to the output of waste. In intensive ruminant production systems, energy-containing

[1]Presented at a symposium titled "Ruminant Nutrition from an Environmental Perspective" at the ASAS 87th Annu. Mtg., July 1995, Orlando, FL.

Received October 12, 1995.
Accepted June 14, 1996.

compounds produced as biomass in primary plant production are converted to desired animal products such as meat and milk and into less desirable waste products. Waste comprises fecal and urinary output as well as the fermentation and respiration gases carbon dioxide (CO_2) and methane (CH_4). Apart from the renewable energy deposited in biomass, considerable amounts of fossil energy are used, also resulting in a loss of CO_2. In the slurry (mixture of feces and urine), usually high amounts of water, N, P, and K are excreted. In areas with a technologically highly developed and intensive animal production, an efficient re-utilization of N, P, and K in primary (plant) production may become impossible by the limited area of available land. The high water content of waste prevents its transport over large distances and often much more N, P, and K are produced than can be taken up by primary plant production systems within the area that can be reached economically.

Animal production is primarily driven by the input of energy, either energy in biomass or fossil energy. With that energy varying amounts of N, P, and K are transported through the soil-plant-animal system. Transportation through the soil-plant-animal system does not mean that N, P, and K play a passive role in the system. On the contrary, their role is very essential, active, and often catalytic. To make or keep the soil-plant-animal system ecologically sustainable, the three components (soil, plants, animals) of the systems should be balanced with each other so that losses of CO_2, CH_4 N, P, and K are kept to a minimum. Within the animal component, the flow of energy and its containing elements is primarily determined by nutritional strategies. This paper discusses the impact of variation in nutritional strategies on the prevention of environmental pollution, with emphasis on intensive ruminant animal production systems.

Environmental Pollution Caused by Animal Production

As indicated earlier, environmental pollution by animal production systems is caused by two imbalances. The intensity of the nutrient flux through the animal part of the soil-plant-animal system often exceeds the capacity of the other components of the system to efficiently utilize the elements C, N, P, and K. Besides, the ratio between C, N, P, and K required in animal production differs from the ratio that can be efficiently handled by the soil and plant components of the system. Apart from deposition on the soil, the imbalances also cause the escape of C, N, P, and K to two other components essential for the system, the atmosphere and subsoil and surface water.

The physical appearance of the four elements differs. This not only influences their availability as a nutrient for plants and animals but is also important for the ease with which they may become dispersed in the environment. Availability in the different compartments of the soil-plant-animal system is influenced by many different factors and interactions. Nutrient availability in the soil is beyond the scope of this paper, and discussion here is restricted to some aspects of dispersion in the environment. The elements C and N appear in solid, solute, and gaseous forms, whereas only solid and solute forms of P and K are known to occur in nature. Dispersion of solid forms are least difficult to control, solute forms cause more problems, and controlling the dispersion of gaseous forms is almost impossible.

In their solid form, C and N are important components of biomass, generated by photosynthesis and deposited in above- and below-ground plant parts. The significance of the latter should not be ignored because it can vary with soil type and type of vegetation. For instance, under grazing conditions, sandy soil below intensively cultivated grassland may contain pools of >100 t/ha of C and >6 t/ha of N. These figures are roughly 20 times as much as that extracted from the same soil by harvesting vegetative growth above ground. Figures for loam soils under grazing were 40% lower. Under mowing conditions, figures were some 10% lower than under grazing conditions for both soil types (Hassink and Neeteson, 1991). Wolf and Jansen (1991) calculated figures of 34, 75, and 52 t of C for arable land, grass, and forested land, respectively.

A continuous exchange of C from solid through solute to gaseous forms and vice versa takes place through photosynthetic, respiratory, and fermentative processes occurring in the soil simultaneously. Comparable, but more complicated, conversions take place with N through processes known as N-fixation, ammonification, nitrification, and denitrification. The ammonification of urea, excreted onto the soil as urine, causes ammonia to escape into the air followed by deposition and nitrification to NO_3^-, which easily leaks into subsoil water reservoirs. Alternatively, the denitrification of nitrate may cause the escape of nitrous oxides (NO_x). Ammonia is believed to contribute to the acid deposition, and nitrous oxides are known for their harmful effects on the ozone layer.

A special situation occurs in ruminants when C is converted into methane (CH_4). Methane is also considered harmful to the ozone layer as well as contributing to the greenhouse effect (Tamminga, 1992a). Methane escapes to the air in relatively small quantities, because of its much higher intensity of infrared energy absorption than CO_2, and CH_4's contribution to the greenhouse effect per gram is around 30 times higher than that of CO_2 (Johnson et al., 1991). Less desired effects of CO_2 from animal production are restricted to those resulting from the use of fossil energy.

Phosphorus is an important nutrient in primary production. This element often starts its entry in the soil-plant-animal system as an ingredient of the feed, particularly when a high concentrate to milk ratio is applied. It is more serious for concentrate feeds if they are based on by-product ingredients. Such ingredients have a relatively high P content, of which a relatively small proportion is absorbed and retained from it by ruminants, and a major part is excreted in feces. When this is subsequently used to fertilize the soil, less P is leaving the system in animal products than enters the system with imported (concentrate) feed ingredients. In the long run this may make P accumulate in the soil until the soil becomes saturated, after which P will filter into groundwater or remain in surface water.

The element K is highly soluble in water. Compared with those of animals, K requirements of plants are relatively high and again concentrate ingredients may contain high amounts, much higher than the animal can efficiently use. Accumulation in the soil does occur only to a limited extent and excess K leaves the system in ground and surface water. Although maximum values of 12 mg K/L are used for drinking water, harmful effects are not well documented. Many foods contain much higher levels; for instance, milk contains 1,500 mg K/L (Van Boheemen et al., 1991).

Table 1. Input of fossil energy (FE) during production and gross (GE) and net energy (NE) in animals feeds

Feedstuff	Energy content, MJ/kg DM		
	FE[a]	GE[b]	NE[b]
Fresh grass	3.1	18.7	7.2
Fresh grass	1.6	18.2	6.9
Lucerne (alfalfa)	1.6	17.8	5.3
Corn silage	2.7	18.3	6.3
Grass silage	2.7	18.3	6.3
Lucerne silage	2.0	17.4	4.7
Grass hay	1.5	18.1	5.4
Lucerne hay	1.5	17.9	4.8
Straw	1.2	18.0	3.5
Corn	9.0	18.4	8.4
Barley	9.0	18.1	7.8
Wheat	9.0	18.2	8.5
Whole cottonseed	10.0	23.0	7.9
Soybeans	10.0	23.2	10.4
Beet pulp	13.7	17.3	7.0
Citrus pulp	14.6	17.2	7.4
Corn gluten feed	6.1	18.4	7.5
Soybean meal	6.8	20.0	7.9
Sunflower seed	6.8	19.6	5.6
Cottonseed meal	6.8	19.9	5.9
Lucerne meal	2.5	18.0	5.1

[a]Hageman and Mandersloot (1994).
[b]Dutch Feeding Table.

Nutritional Strategies

In ruminant production systems nutritional regimens can be differentiated into short-, medium-, or long-term strategies. Feeding strategies not only differ with regard to their time length, but to some extent they also depend on external conditions such as grazing or indoor feeding that may or may not be dictated by seasonal climatic conditions.

Short-term feeding strategies are those that take place within a matter of days and include changes in forage quantity and quality, forage to concentrate ratio, concentrate composition, the use of additives and the sequence and frequency of feed allocation to the animals. Medium-term strategies take place over a period ranging from several weeks to several months and include stocking rate, ad libitum vs restricted intake, flat feeding (i.e., feeding a constant quantity of feed of a constant quality during a certain period) vs feeding following requirements, adaptation of feeding to seasonal patterns, and (various ways of) grazing vs feeding in confined environments, or grazing alternated with confinement. Long-term feeding strategies cover a lifetime and are primarily executed at herd (system), rather than at animal, level. These strategies include growing and harvesting feed and attempts to influence product quantity per area, product (milk, meat) quality, reproduction efficiency, enhancing longevity, and so on.

Obviously, feeding strategies as mentioned above are not strictly separated, but each strategy has impacts on the quantity and quality of the desired products as well as on waste unavoidably associated with the desired production.

Energy Input and Distribution in Feeds

Feed production in modern agriculture requires the input of high amounts of fossil energy. Table 1 gives some estimated figures for a number of feeds frequently used in cattle nutrition. The figures for the input of fossil energy (Hageman and Mandersloot, 1994) should be treated with caution. In the case of the by-product listed it is difficult to decide which part of the total energy input should be attributed to the by-product residue itself and which part to the desired product (starch, oil, sugar) extracted from it. In addition, the figures may have local rather than general significance, because in the figures presented here, the energy needed to transport the feed from the production site to the site of feed manufacturing industry and the energy cost of pelleting is included.

A curvilinear relation seems to exist between net energy content of the feed and the input of fossil energy (Figure 1). The figure shows three groups of feeds, low, medium, and high energy input feeds. The latter group comprises products that had to undergo

Table 2. Content of carbon, nitrogen, phosphorus, and potassium in feedstuffs

Feedstuff	Concentration, g/kg DM				Percentage of C concentration			
	C[a]	N[b]	P	K	C	N	P	K
Fresh grass	431	36	4.2	40	100	8.3	.97	9.3
Fresh grass	431	24	3.8	30	100	5.6	.88	7.0
Lucerne (alfalfa)	413	29	3.0	33	100	7.0	.73	8.0
Corn silage	444	14	2.0	13	100	3.1	.45	2.9
Grass silage	423	32	3.9	33	100	7.6	.92	7.8
Lucerne silage	403	27	3.0	33	100	6.7	.74	8.2
Grass hay	422	23	3.0	25	100	5.5	.71	5.9
Lucerne hay	413	29	3.0	27	100	7.1	.73	6.5
Straw	423	6	1.1	15	100	1.3	.26	3.6
Corn	461	16	3.3	4.1	100	3.5	.72	.9
Barley	451	20	4.2	5.5	100	4.4	.93	1.2
Wheat	454	22	3.9	4.9	100	4.9	.86	1.1
Cottonseed	505	36	7.4	12.0	100	7.2	1.47	2.4
Soybeans	504	64	6.1	19.9	100	12.8	1.21	3.9
Beet pulp	418	16	1.1	8.1	100	3.8	.26	1.9
Citrus pulp	421	11	1.2	10.4	100	2.6	.28	2.5
Corn gluten feed	440	32	9.8	13.8	100	7.3	2.23	3.1
Soybean meal	444	82	7.3	24.8	100	18.6	1.64	5.6
Sunflower seed	438	59	12.7	14.8	100	13.5	2.90	3.4
Cottonseed meal	445	65	11.3	16.9	100	14.6	2.54	3.8
Lucerne meal	413	30	2.8	31.8	100	7.2	.68	7.7
Carcass	537	64	12	4.0	100	11.9	2.06	1.0
Milk	481	46	7.5	11	100	9.6	1.55	5.3

[a]Calculated from chemical composition.
[b]From CVB Feeding Table (CVB, 1994).

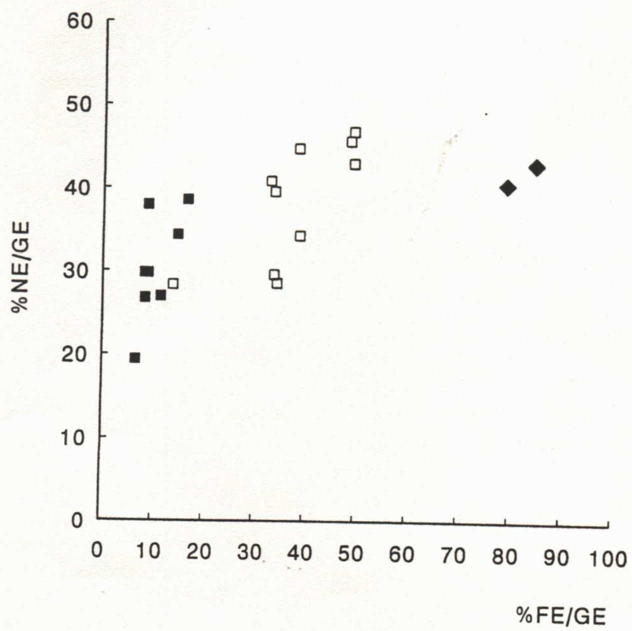

Figure 1. Fossil energy input and feed quality of forages (■), concentrates (□), and artificially dried products (♦).

artificial drying as part of the manufacturing process. Examples are dried sugarbeet pulp and citrus pulp. The low energy input group are roughages. The figure shows that in this group in particular, the proportion of net energy within gross energy can be raised considerably, with an increased input of fossil energy. In practice this increased input of fossil energy is to a large extent due to the high use of inorganic fertilizer, the manufacturing of which requires 39 MJ/kg N (Hageman and Mandersloot, 1994, 1995).

Distribution of C, N, P, and K in Nutrients and Feeds

As is typical of all organic material, animal feeds contain the elements C, H, O, N, S, and P, of which N and P currently receive most attention in the relation of animal production and environmental problems. Elements in the ash fraction of animal feeds that cause concern are K, Cu, occasionally Zn, and heavy metals such as Pb. Discussion in this paper is restricted to C, N, P, and K, elements that are present in animal feeds in various proportions. The basal components of animal feeds are lipids, proteins, and carbohydrates, which contain 750, 500, and 450 g C/kg. Proteins also contain 160 g/kg of N and due to the presence of nucleic acids 2 g/kg of P. Based on the

Table 3. Input and output of potassium and potassium content in homegrown feeds on Dutch dairy farms

	83/86	89/90	90/91	91/92	92/93
Input, kg/ha					
Concentrates	71	56	56	57	—
Roughages	27	14	13	15	—
Fertilizers	22	21	17	19	—
Others	7	17	17	19	—
Total input	127	108	103	101	—
Output, kg/ha					
Cattle	1	1	1	1	—
Milk	18	18	18	18	—
Roughage	1	9	–1	–5	—
Others	0	4	3	3	—
Total output	20	32	21	17	—
Surplus	107	76	82	84	—
Content, g/kg DM					
Grass	33.0	34.9	36.8	35.9	37.7
Grass silage	30.7	30.6	32.8	33.2	36.2
Corn silage	—	—	—	13.3	12.8

chemical composition of their basal components, and their contents of P and K, the distribution of C, N, P, and K in animal feeds can be calculated (Table 2). The variation in C content in the different feeds is relatively small, and variation largely depends on the fat content, but the results show a wide variation in the ratio between the different elements. The C:N:P:K ratio differs between different feeds. The C:N:P:K ratio present in feeds also shows substantial differences from that present in animal products (meat, milk). A surplus in the feed, usually occurring with K, will be excreted, whereas a deficiency (sometimes observed with P), has to be supplemented to the feed. Because the most important route for C excretion is through CO_2 in respiration and CH_4 in eructation, a relative accumulation of P in feces and K in urine occurs, respectively.

Feeding Strategies and Excretion of Waste

Excretion of waste in animal production has quantitative as well as qualitative aspects. An example of quantitative aspects are CO_2 excretion, particularly that resulting from the input of fossil energy, CH_4 release, and total production of feces and urine. More qualitative aspects are the moisture content of feces, the ratio between feces and urine, the urea or total N content of the urine, the P content of the feces, and the presence of residues of feed and other additives. Excessive animal waste usually results from either a high stocking density or from feeding considerably more of the nutrients N, P, and K than is required by the animals.

Feeding strategies are to some extent dependent on the farming system. Between 1950 and 1985, dairy farming has intensified heavily in The Netherlands. Nitrogen input per kilogram of N excreted in milk increased from 2.2 in 1950 to 6.4 in 1985 (Ketelaars and Van de Ven, 1992). This intensification was possible by growing more feed on the farm through an increased N fertilization or by buying more concentrates grown or produced elsewhere. Increasing the amount of milk produced per hectare from 8,700 to 20,500 sharply increased the surplus of N, P, and K, per hectare from 376, 24, and 72 in 1950 to 650, 54, and 201 kg in 1985 for N, P, and K, respectively (Korevaar, 1992). At the same time, when expressed on a per kilogram of milk basis, surplus N decreased by 25%, whereas surplus P remained constant and surplus K increased by 15%. When increasing the production of home-grown fodder by increasing N fertilization, but at the same time maintaining a constant milk production per cow and per hectare by a decreased use of concentrates, there was an enhanced surplus of N, P, and K, per hectare and per kilogram of milk. Because the necessary input of fossil energy is lower for roughages than for concentrates, the latter way of intensifying will reduce the necessary input of fossil energy directly related to the feed.

Energy Losses

With the animal as the basic unit, the cost of maintenance is considered an important source of waste. With regard to energy input, a long-term feeding strategy aimed at increasing production per animal usually reduces the input of energy from biomass per kilogram of desired product, but not necessarily the total energy input. Higher productions need better-quality feeds, which often means a higher input of fossil energy. Increasing lifetime production per animal will however reduce energy input per kilogram of product needed for replacement. In the

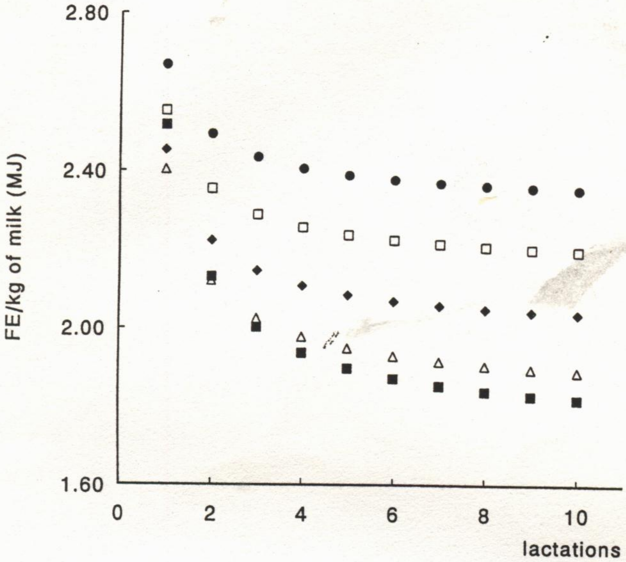

Figure 2. The effect of annual milk yield (■:5,000 kg; △:7,500 kg; ◆:10,000 kg; □:12,500 kg; ●:15,000 kg) and number of lactations on the input of fossil energy (FE) per kilogram of milk.

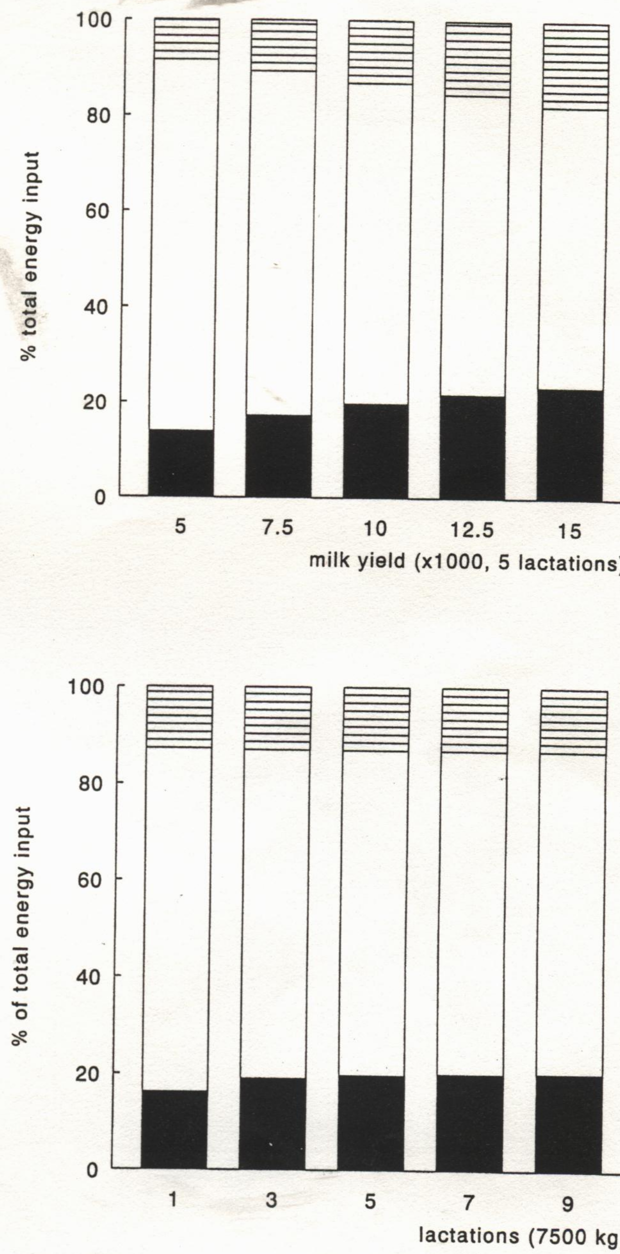

Figure 3. (Top panel) The effect of annual milk yield on net energy (solid area), fossil energy (hatched area), and waste energy (blank area) as proportion of total energy input in dairy cows. (Bottom panel) The effect of number of lactations on net energy (solid area), fossil energy (hatched area), and waste energy (open area) as proportion of total energy input in dairy cows.

case of beef cattle production, energy costs of replacement can be considered as being restricted to the costs of fetal development, which are almost negligible compared with costs of maintenance needed to produce a carcass of approximately 400 kg in a period of up to 18 mo. With milk-producing animals, the situation is more complicated. The loss of energy per kilogram of milk produced depends on annual production as well as on number of lactations (i.e., lifetime production) (Figure 2).

Calculations were made on the distribution of total energy input over net energy, waste from fossil energy, and waste from energy in biomass. Assumptions were an energy input of 12.5 gigajoules (GJ) of NE for maintenance up to 24 mo of age, a deposition in the carcass (360 kg) of 9 GJ of NE, and a requirement for milk production of 3.3 GJ/ton of FPCM (milk corrected for fat and protein content deviating from 4.0 and 3.4, respectively). Raising the animal was assumed on the basis of an average roughage, 5.8 MJ of NE/kg of DM. With increasing levels of milk production forage quality was assumed to gradually increase from 5.5 MJ of NE/kg at 5,000 kg/yr to 6.9 MJ of NE at 15,000 kg, whereas the ratio between NE from forage to NE from concentrate was increased from 85:15 at 7,500 kg to 40:60 at 15,000 kg. Results are shown in Figure 3.

From Figure 3 it may be concluded that with increasing milk production the output/input ratio increases, but also that part of the increase is counterbalanced by the necessary increased input of fossil energy, which is entirely lost as CO_2. Increasing the number of lactations has a much less profound effect. Similar calculations are possible for beef cattle. Because animal breed, growth rate, feeding intensity, and carcass composition is much more variable than that of milk in dairy cattle, no attempt to do so was made.

Part of the energy losses are caused by the eructation of CH_4. Not only is it a loss of energy, but

CH_4 losses also contribute to the global warming or greenhouse effect (Johnson et al., 1991). Methane production by ruminants has been found to be influenced by animal size, dry matter intake, intake of (digestible) carbohydrates and other digestible dietary components (Wilkerson et al., 1994). In dairy cows, body weight, milk yield, and type of roughage influence CH_4 production (Kirchgessner et al., 1994). Moe and Tyrrell (1979) observed CH_4 losses per kilogram of carbohydrates digested of 1.14, 2.14, and 5.83 MJ/kg for soluble residue, hemicellulose, and cellulose, respectively. The inclusion of fat in diets for ruminants causes negative effects on CH_4 losses (Kirchgessner et al., 1994), whereas the inclusion of ionophores or halogenated (Cl, Br) methane analogues also causes reductions in CH_4 losses (Van Nevel and Demeyer, 1988). These specific losses do not always seem to be consistent (Johnson et al., 1991).

In dairy cows, Van der Honing et al. (1981, 1983) observed a positive effect of DM intake on CH_4 loss. In addition, these authors calculated a negative effect of fat on CH_4 loss of −1.91 (SE .76) MJ/kg fat. In grass-fed dairy cows, it was observed that increasing the N content decreased CH_4 losses (Tamminga, 1992a). This phenomenon does not seem to have general applicability; Kirchgessner et al. (1994) observed a positive relationship between CP intake and CH_4 emission. From results above, it may be concluded that CH_4 losses can be controlled by manipulation of dietary composition.

Calculations by Kirchgessner et al. (1994) showed that a considerable amount of CH_4 (216 g/d) seems to be released independently of milk production. Calculating this amount as a proportion of total energy input per kilogram of milk at annual production levels of 5,000 and 15,000 kg, respectively, this would account for .044 and .028% of total energy input. Fossil energy input, resulting in increased CO_2 output, increased from 8.4 to 17.2% of total energy input (Figure 3, top panel). Even when the 30 times higher contribution to global warming is taken into account, reduction in CH_4 release by increasing milk yield would account for only about 5% of the effect of the increased release of CO_2 due to a higher fossil energy input.

Nitrogen Losses

Nitrogen losses occur at various sites in cattle (Tamminga, 1992b). Ruminal losses result mainly from an imbalance between the quantity of carbohydrates and protein degraded in the rumen. An asynchrony between the rate at which carbohydrates and proteins are degraded may also contribute to N losses from the rumen (Stern et al., 1994). Postruminal N losses occur as endogenous losses in the digestive tract and also comprise N losses occurring in organs and tissues after absorption from the small intestine. Important causes of endogenous losses in ruminants are protein entering the small intestine and neutral detergent fiber (NDF) passing the small intestine (Van Bruchem et al., 1997). Major causes of post-absorptive losses seem to be an imbalance between the availability of net energy and amino acids at the tissue level (Hof et al., 1994; Subnel et al., 1994).

Ruminal degradation often results in a net loss of protein, due to an imbalance between protein and carbohydrates, because of microbial synthesis. Crude protein in feed is also partly converted to CP in microbes. Although the amino acid composition of microbial true protein is superior to that of true protein in most feeds, this advantage is offset by the fact that 15 to 20% of microbial CP is nucleic acids, which in cattle is not available for metabolism (Chen et al., 1990). Ruminal losses occur as NH_3, which, after conversion into urea in the liver, is excreted in the urine.

Dairy farming on the basis of grassland products, as is common in northwestern Europe, has a relatively low N efficiency. Ruminal N losses are particularly important under grazing conditions because cattle select for high-quality, leafy grass with a high CP content. Besides, the intensive use of inorganic N as a fertilizer has made it possible to have high-quality, young, leafy forage available almost during the entire growing season. Surplus forage grown during parts of the growing season can be conserved and fed during the winter period. The rapid degradation of CP of immature grass is not synchronized with the degradation of carbohydrates; which creates an imbalance (Van Vuuren et al., 1991). Based on in situ data Van Vuuren (1993) calculated for CP in grass a linear relationship between CP content and ruminal N losses. Above a CP content of 155 g/kg DM, almost 80% of the extra CP gets lost from the rumen.

Feed selection can to some extent be limited by the method of grazing, such as continuous vs rotational vs zero-grazing systems. Continuous grazing has certain advantages over rotational grazing. The tiller density remains high, which prevents the invasion or even overgrowing by less desired forage species. At high stocking densities continuous grazing guarantees a constant high quality (Lantinga, 1985).

Grass growth shows seasonal fluctuation that is easier to manage with rotational than with continuous grazing. Continuous grazing needs a regular adjustment of stocking density to growing conditions. A low stocking density allows the animals to select but also allows the standing material to age and to deteriorate in quality. As a result, feed intake and even more important, nutrient density, in the ingested feed is reduced and, consequently, production of either meat or milk is impaired. At the same time, total N losses are likely to be reduced and the importance of N losses shifts from the rumen to endogenous losses in feces and urine. High stocking densities will keep the pasture short but may lead to overgrazing. Various ways exist to balance stocking density to available forage under continuous grazing. Adjusting the number of animals is one way, varying the size of the continuously grazed area another. Restriction of grazing time combined with supplementation is also an option. In the latter case either conserved forage or concentrates can be used as supplement.

Because selection can be eliminated, control of ruminal N losses is easiest achieved in zero grazing systems. If necessary, imbalances between energy and protein can be smoothed away by supplementing the grass. Options are supplementation with low-protein roughages such as corn silage or with low-protein concentrates (Van Vuuren et al., 1992b), either high in starch, present in most grains, or high in rapidly degradable structural carbohydrates such as beet pulp. A disadvantage of feeding these concentrates as a supplement is the extra input of fossil energy associated with their production, a disadvantage that is less important with corn silage. Besides, grazing is considered a natural habit of cattle and therefore has a positive influence on the animal's welfare. Although zero-grazing will reduce the total loss of N, at the same time a shift will occur and relatively more N is lost as NH_3 in the air and less as NO_3^- leaching to soil and water (Ketelaars and Van de Ven, 1992).

The main external input factors for N into ruminant production systems are inorganic fertilizer and concentrates. Of these, input through N fertilizer is often more important than input through concentrates. Nitrogen fertilization has different effects. Dry matter (DM) yield per hectare is increased in a curvilinear way, whereas CP yield is increased linearly (Kemp et al., 1979). The effect of N fertilization on CP content of forage is twofold (Van Vuuren, 1993): it increases the DM yield and N content at a fixed number of days after N application (vertical effect) and it reduces the number of days to reach a particular stage of growth (horizontal effect).

Forage quality can be widely manipulated by grassland management, of which N fertilization and time of harvesting (grazing or cutting) are the most powerful tools. Other ways of manipulation are grass species or cultivars, soil type, and season (Kemp et al., 1979). At a yield of 2,000 kg/ha, Van Vuuren (1993) calculated a horizontal effect of 5 g N/kg DM per 100 kg extra N·ha^{-1}·yr^{-1}. Days of regrowth to the same yield after the previous cut were reduced from 68 at zero N application to 30 d at 700 kg N·ha^{-1}·yr^{-1}. Kemp et al. (1979) observed a similar pattern, but with an increased N content of about 3 g/kg DM. During the second half of the growing season differences in N content in grass due to N fertilization became much smaller, possibly because the N application in each cut was reduced. After cutting, N content initially increases to reach a peak after about 2 wk and then rapidly decreases in the following weeks (Wilman, 1975). Depending on the level of N fertilization, height of the peak varied between 40 and 60 g N/kg DM, but the decline was around 10 g·kg^{-} DM·wk^{-1}, regardless of the level of N application. Nitrogen fertilization increases N content of grass and also influences the nature of the N. Increasing N application increases the proportion of nonprotein N (**NPN**) from around 15% at no fertilization to almost 35% at an application rate of 1,000 kg N·ha^{-1}·yr^{-1} (Goswami and Willcox, 1979). Because the majority of NPN is water-soluble, this will increase N losses from the rumen.

High N fertilization of predominantly perennial ryegrass (*Lolium perenne*) enhanced ruminal N losses. Grass fertilized with 275 and 500 kg of N/ha resulted in CP contents of 171 and 204 g/kg DM, respectively. When this grass was fed to dairy cows, the lower fertilized grass showed ruminal N losses of 21.5%, increasing to 33% after feeding the highly fertilized grass (Van Vuuren et al., 1992a). Manipulation of N content in forages also affects the other components. Cell wall (NDF) content and(or) soluble sugars decrease with an increasing N content, whereas lipid content increases. Extension of the time of harvesting reduces N content and increases NDF content with a concomitant reduction in NDF digestibility, probably resulting in an impaired feed intake, but certainly resulting in a decreased nutrient density.

Under conditions of zero-grazing outside the growing season feeding strategy depends on the application of conserved feeds, either forages conserved by ensiling or forages and concentrates conserved by drying. Selection can be largely excluded by feeding totally mixed rations (TMR) that are carefully balanced in such a way that ruminal losses are eliminated and endogenous losses kept to a minimum. As an alternative, the concentrate part of the diet can be fed frequently in small portions using a computer-controlled dispensing system. With high-concentrate diets, scope also exists for manipulation of site of digestion as well as influencing the fermentation pattern in the rumen. The ratio in which aminogenic, glucogenic, and ketogenic energy is supplied can be manipulated, through which the partitioning between organs and tissues as well as the composition of the production (milk, meat) can be influenced (De Visser, 1993).

A second important site of N losses is the small intestine where endogenous protein is excreted in digestive enzymes, bile, desquamated epithelial cells, and mucus (Tamminga et al., 1995). As indicated earlier, causes of increased endogenous losses in ruminants are primarily protein entering the small intestine, NDF passing the small intestine (Van Bruchem et al., 1995), or infection with parasites (MacRae, 1993). In sheep, approximately 10 g of extra endogenous N was passing the end of the ileum per kilogram of NDF passing through the small intestine (Lammers-Wienhoven et al., 1995). Reabsorption does occur to a significant extent and varies between 50 and 75% (Van Bruchem et al., 1995). This would suggest that a minimum of 125 g CP (the equivalent of 20 g of N) has to be resynthesized. Assuming that endogenous N passing the ileum is completely lost and that the resynthesis takes place with an efficiency of 75% (Tamminga et al., 1995), each kilogram of undigested NDF would be at the expense of the loss of approximately 100 g of endogenous CP. In reality, CP losses may be lower, because an as yet unknown proportion of endogenous CP seems to be nonprotein N.

A third important group of N losses is postabsorptive losses, primarily caused by an imbalance between the availability at tissue level of (net) energy and amino acids (Hof et al., 1994; Subnel et al., 1994), and to a lesser extent due to an imbalanced amino acid profile (Armentano, 1994). The nature and source of these losses is not clear, but liver and mammary gland are usually responsible (Reynolds et al., 1994). In cattle, liver tissue constitutes less than 5% of total body tissue, but it is responsible for 12 to 25% of the whole-body oxygen consumption and energy expenditure (Kelly et al., 1993), and amino acids seem to be an important substrate (Müller, 1995). Efficiency of utilization of amino acids absorbed from the blood by the mammary gland is high, and for the majority of essential amino acids >90% of what is extracted from the blood is excreted in milk (Baldwin and Kim, 1993).

Similar calculations that were performed at animal level for energy can be made for protein by using the recently developed Dutch protein evaluation system, the DVE/OEB system (Tamminga et al., 1994). Feeding dairy cows according to requirements showed that the lifetime efficiency of N utilization under standard feeding conditions (DVE/CP ratio of .55) remains relatively low and reaches a maximum of just below 30% at annual productions of some 10,000 kg (Figure 4, top panel). Unless the animals are used for less than 3 lactations, increasing annual milk per animal above 10,000 kg does not further increase the efficiency of protein utilization.

Increasing the number of lactations to above five, only marginally improves efficiency of utilization up to an annual milk yield of 10,000 kg (Figure 4, bottom panel). Quite significant improvements seem possible by increasing the DVE/CP ratio (Figure 5). The most effective option is to improve the ruminal and total digestibility of the OM. This provides more substrate for microbial protein synthesis on the one hand with a simultaneous reduction of DM passing through the small intestine, which will reduce endogenous losses on the other. It should be realized, however, that of each gram of N captured in microbial protein, about

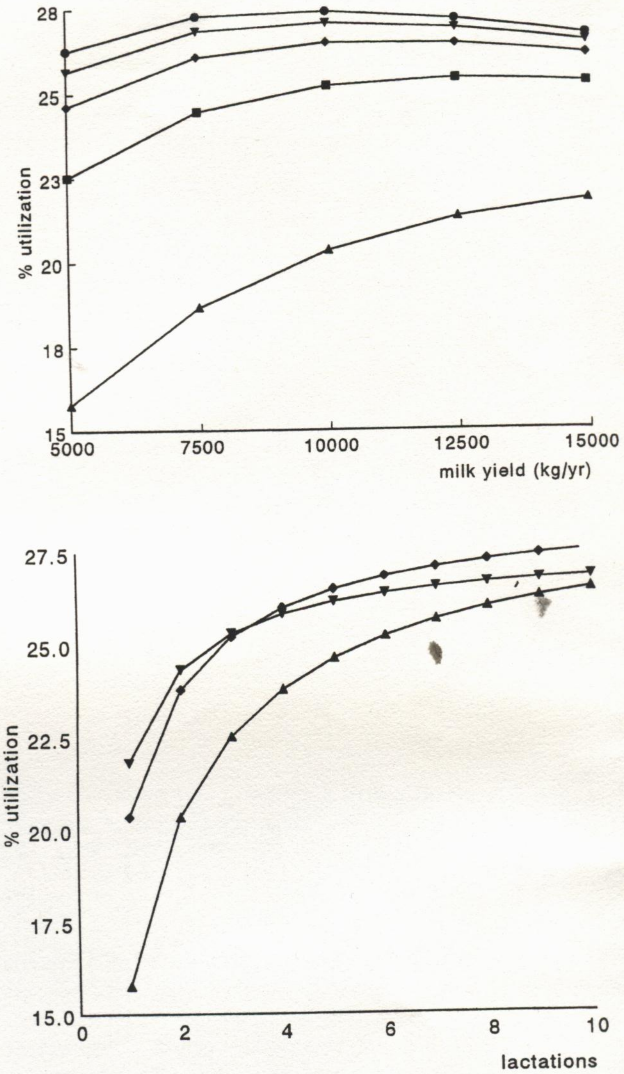

Figure 4. (Top panel) The effect of milk yield on N utilization in dairy cows differing in number of lactations. (▲:1; ■:3; ♦:5; ▼:7, and ●:9 lactations). (Bottom panel) The effect of number of lactations on N utilization in dairy cows at different milk yields. (▲=5,000 kg; ♦=10,000 kg; ▼=15,000 kg).

one-third is lost either in the fecal excretion of undigested N or in the urinary excretion of purine derivatives originating from microbial nucleic acids (Chen et al., 1990). A second option is to decrease ruminal degradability of protein. Feed processing through heat treatment, chemical treatment, extrusion, or expander cooking has been proven to be quite effective means in that respect (Satter, 1986; VanBelle et al., 1989; Broderick et al., 1991). Heat treatment and chemical treatment have the danger of causing an impaired intestinal digestion (Van Straalen and Tamminga, 1990). Unfortunately, both approaches necessitate an increased input of fossil

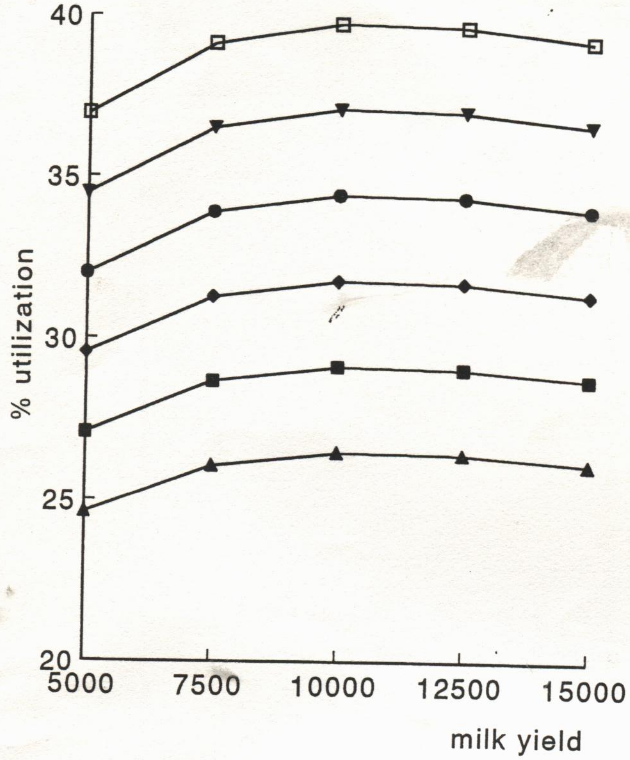

Figure 5. The effect of increasing the DVE/CP ratio N utilization in dairy cows at differenet levels of milk yield (▲ = .50; ■ = .55; ♦ = .60; ▼ = .70; □ = .75).

energy with a concomitant increased loss of CO_2 from that fossil energy. Reducing the dietary DVE/NE_l ratio also has potential. When this is realized by a reduction in CP input, this will almost automatically lead to an increase in DVE/CP ratio. To what extent this can be done without impairing microbial fermentation in the rumen needs further investigation.

Reducing the DVE input to about 80% of current recommendations did improve the efficiency of utilization of DVE from 65 to 75% without dramatic negative effects on milk production and milk protein content (Hof et al., 1994). No signs of an impaired feed intake due to a shortage of ruminally degradable protein was observed, but DVE/CP ratio in these experiments were relatively low and ranged only between .46 and .59 (Hof and Tamminga, 1994).

Phosphorus Losses

In ruminants, P is ingested with the feed and a varying proportion is excreted in the feces. The proportion not excreted in feces is termed available P. By correcting fecal excretion for P of endogenous origin, true availability of P can be estimated. By far the most important endogenous source is P in saliva, which in sheep, depending on the rumination activity, was shown to vary from one to six times the amount consumed with the feed (Yano et al., 1991). Daily secretion ranges between 5 and 10 g of P in sheep and between 30 and 60 g in cattle (Breves and Schröder, 1991). An amount of 60 g would provide enough P to cover maintenance and the production of 20 kg of milk. A second important source of endogenous P is bile.

Metabolism of P in ruminants is complicated by the fact that a significant amount of P is incorporated into microbial biomass as a component of nucleic acids and phospholipids. The ratio of N:P in microbial biomass ranges between 6 and 7 (Durand and Kawashima, 1980) and approaches that in milk. The proportion of feed P incorporated into microbial biomass is not known. Recycling of P through saliva is substantial in ruminants and may exceed fecal excretion 5- to 10-fold (Symonds and Forbes, 1994). Dependent on pH, P in saliva is present as $H_2PO_4^-$, HPO_4^{2-}, or PO_4^{3-}. One may therefore assume incorporation of P in microbes to be easier from P in saliva than from P in feed. This explains differences observed in absorptive efficiency between saliva P (75 to 85%), inorganic P supplements (80 to 90%) and P in feed (50 to 60%) (Yano et al., 1991). Although transport of P across the ruminal wall seems possible, the ruminal wall is not considered a major site of P absorption (Breves and Schröder, 1991). In ruminants, apparent absorption of P occurs in the small intestine, and its magnitude is regulated by the requirements of the animal. The uptake of P may be impaired by infections (MacRae, 1993). Phosphorus is required for (skeletal) growth, as a milk component (10 g/kg), and to replace P endogenously excreted in the digestive tract. Also, the dietary Ca/P ratio may influence the efficiency of absorption.

In early lactation more P is needed for excretion in milk than is provided by the diet and the animal will mobilize body reserves, which are repleted later in lactation. The capacity of cattle to mobilize and replete P is not well documented, but estimates suggest up to 1.5 kg (Benzie et al., 1959), the equivalent of what is excreted in 150 kg of milk. This is considerably less than the amount of milk that can be produced from body energy stores. Because dairy diets are largely based on grass products and concentrates produced from by-product ingredients, dietary P levels are usually adequate, except when large amounts of corn silage or full grains are included in the diet. Under the latter conditions it may be necessary to supplement the diet with inorganic P.

Unlike N, the main source of P input in dairy systems is with concentrates rather than through fertilizers (Hermans and Vereijken, 1995). A significant part of P in feed is present as phytic acid, a form in which P is not available for monogastric farm animals, because they lack the enzyme phytase. Although 85% of P in forages may also be present as phytate, in the rumen it is completely hydrolyzed. For ruminants, true availability of P in forages is therefore usually high and between .65 and 1.0 (Minson, 1990). Virtually all P that is lost in excreta in ruminants is voided with the feces, either in nucleic acids or phospholipids.

Because in practice P metabolism and fecal P excretion are largely regulated by P intake, the easiest way to reduce P loss is to reduce P input with the concentrate part of the diet. This would require the inclusion of ingredients low in P in dairy concentrates, which normally contain between 5 and 6 g of P/kg DM. The best option would be to include more grains in concentrates for ruminants, but these are also suitable for monogastric animals and human consumption. Besides, the inclusion of high amounts of grain may interfere with the fiber needs of dairy cows. Because internal inputs do not constitute any burden for the system or the environment, home-grown feeds, such as corn silage or fodder beets, have been recommended for dairy diets. Nowadays the development of such integrated farming systems receive much attention. Estimates suggest possible improvements in the efficiency of utilization of N and P at the animal level from 17 to 26% for N and from 23 to 31% for P. At the farm level, improvements would be even more spectacular and efficiencies of utilization could be raised from 15 to 39% for N and from 31 to 100% for P (Aarts et al., 1992). Besides being internal inputs they have the advantage of being low in P and to some extent able to replace part of the externally purchased concentrates. Fodder beets have the disadvantage of a limited intake and a high substitution rate (Meijer et al., 1994). Besides, they cannot be cultivated in all soils. Corn silage and products derived from it, such as corn cob mix, seem to have more potential and are already being used in practice.

Potassium Losses

Table 3 shows the changes in in- and output of K per hectare of grassland in The Netherlands in the last decade (CVB, 1994). The results show that concentrates are by far the most important source of input. Input with fertilizer has been drastically reduced in recent years, and the surplus seems to stabilize at around 80 kg/ha. Despite this, the K content in grass-based feeds has increased by around 25% in the last few years. This is believed to be caused by the changes in manure application methods due to legislation imposed upon farmers to reduce NH_3 losses from manure. In recent years, the application of manure has only been allowed by soil injection rather than by spreading. Application is restricted to the growing season, which is one of the reasons K in manure is taken up by the plant very rapidly and efficiently and accumulates in the plant. As a consequence, absorption of Mg is impaired and becomes very low, probably below 5%, which may lead to hypomagnesemia. Incidence of hypomagnesemia has indeed increased.

An apparent advantage of the high K levels in forages is that it dilutes urine, resulting in lower urinary N levels (Ketelaars and Van de Ven, 1992), which is considered an advantage. Frequency distribution of N concentrations in urine spots showed 10 to 12 g/L as the most frequent concentration, resulting in a fertilization equivalent of up to 600 kg $N \cdot ha^{-1} \cdot yr^{-1}$. Potassium levels of >25 g/kg DM in forage reduced urinary N concentration by up to 30%, thus reducing the fertilization equivalent to some 400 kg $N \cdot ha^{-1} \cdot yr^{-1}$ (Ketelaars and Van de Ven, 1992), a level at which N can efficiently be taken up by the plants. The dilution therefore reduces the conversion of urea into NH_3, and high dietary K levels also reduce the N concentrations in the soil where cows urinate during grazing.

If considered necessary, K inputs in dairy diets can be easily reduced by excluding a limited number of ingredients from mixed concentrate dairy feeds. Of the approximately 150 ingredients for concentrate feeds listed in the Dutch feeding tables (CVB, 1993) over 85% have a K content of below 20 g/kg and almost 95% remain below 30 g/kg.

Economic Perspectives

The introduction of measures to reduce losses of energy, N, P, and K will have significant economic consequences. Studies on the effects of the implementation of manure legislation (Berentsen et al., 1992) showed that improved animal manure management combined with reduced application of inorganic N fertilizer could drastically reduce N losses, without much effect on the losses of P and K. However, calculated effects on labor income were even more dramatic and reductions of up to 70% were calculated.

Reducing NH_3 losses seemed about 10 times more expensive than reducing other N losses, such as nitrate leaching. For reducing NH_3 losses, a price of between Hfl. 10, and Hfl. 26, (the equivalent of approximately $US 8, to 15,) per kilogram of N reduction was calculated, whereas reducing other N losses was only at the expense of Hfl. 1, to Hfl. 2.50 per kilogram of N reduction (Berentsen and Giessen, 1994).

The environmental and economic consequences of the introduction of a new protein evaluation system for the dairy industry in The Netherlands (the DVE system) was also studied (Berentsen et al., 1993). The authors concluded that without further regulations with respect to ruminal N losses, the DVE system will not lead to reductions in N losses and environmental and economic effects are expected to be insignificant. Putting restrictions on ruminal N losses must lead to extensification of land use by lowering the application rate of fertilizer. To maintain production, higher amounts of concentrates are necessary. Not only will this lead to higher costs and a reduction in farmers' income, the loss of fossil energy will also be enhanced. Effects on surplus P and K were not taken into account, but they may increase. A more attractive option could be the use of home-grown, low-N concentrate replacers.

Implications

Animal production is inevitably associated with the production of waste and therefore some degree of environmental pollution seems unavoidable. Various feeding strategies are available or can be developed to minimize environmental pollution. A complicating factor is that the various forms of pollution may oppose each other. To find optimal feeding strategies, trade-off values of the different forms of pollution have to be determined. To reduce pollution to acceptable levels, mixed and integrated farming systems, an increased use of home-grown feeds and in some cases extensification of animal production systems are recommended.

Literature Cited

Aarts, H.F.M., E. E. Biewenga, and H. Van Keulen. 1992. Dairy farming systems based on efficient nutrient management. Neth. J. Agric. Sci. 40:285.

Armentano, L. E. 1994. Impact of metabolism by extragastrointestinal tissues on secretory rate of milk protein. J. Dairy Sci. 77: 2809.

Baldwin, R. L., and W. Y. Kim. 1993. Lactation. In: J.M. Forbes and J. France (Ed.) Quantitative Aspects of Ruminant Digestion and Metabolism. p 433. CAB International, Wallingford, U.K.

Benzie, D., A. W. Boyne, A. C. Dalgarno, J. Duckworth, and R. Hill. 1959. Studies of the skeleton of sheep. III. The relationship between phosphorus intake and resorption and repair of the skeleton in pregnancy and lactation. J. Agric. Sci. 52:1.

Berentsen, P.B.M., and G.W.J. Giessen. 1994. Economic and environmental consequences of different governmental policies to reduce N losses on dairy farms. In: E. A. Huisman, J.W.M. Osse, D. Van der Heide, S. Tamminga, B. J. Tolkamp, W.G.P. Schouten, C. E. Hollingworth, and G. L. Van Winkel (Ed.) Biological Basis of Sustainable Animal Production. p 133. Wageningen Pers, Wageningen, The Netherlands.

Berentsen, P.B.M., G.W.J. Giessen, and R. F. Speelman. 1993. Economic and environmental effects of a new protein evaluation system in dairy farming. J. Dairy Sci. 76:2332.

Berentsen, P.B.M., G.W.J. Giessen, and S. C. Verduyn. 1992. Manure legislation effects on income and on N, P and K losses in dairy farming. Livest. Prod. Sci. 31:43.

Breves, G., and B. Schröder. 1991. Comparative aspects of gastrointestinal phosphorus metabolism. Nutr. Res. Rev. 4:125.

Broderick, G. A., R. J. Wallace, and E. R. Orskov. 1991. Control of rate and extent of protein degradation. In: T. Tsuda, Y. Sasaki, and R. Kawashima (Ed.) Physiological Aspects of Digestion and Metabolism in Ruminants. p 541. Academic Press, San Diego, CA.

Brundland, G. H. 1986. Our Common Future. World Commission on Environment and Development. Oxford University Press, Oxford, U.K.

Chen, X. B., F. D. DebHovell, and E. R. Orskov. 1990. Excretion of purine derivatives by ruminants: recycling of allantoin into the rumen via saliva and its fate in the gut. Br. J. Nutr. 63:197.

CVB. 1993. Veevoedertabel. Centraal Veevoeder Bureau, Lelystad, The Netherlands.

CVB. 1994. Kalium, een kopzorg op het melkveebedrijf. Centraal Veevoeder Bureau, Lelystad, The Netherlands.

De Visser, H. 1993. Influence of carbohydrates on feed intake, rumen fermentation and milk performance in high-yielding dairy cows. Ph.D. Thesis. Agricultural University, Wageningen, The Netherlands.

Durand, M., and R. Kawashima. 1980. Influence of minerals in ruminal microbial digestion. In: Y. Ruckebusch and P. Thivend (Ed.) Digestive Physiology and Metabolism in Ruminants. p 375. MTP Press Ltd, Lancaster, U.K.

Goswami, A. K., and J. S. Willcox. 1979. Effect of applying increasing levels of nitrogen to ryegrass. I. Composition of various nitrogenous fractions and free amino acids. J. Sci. Food Agric. 20:592.

Hageman, I. W., and F. Mandersloot. 1994. Model energieverbruik melkveebedrijf. Publikatie nr. 86, Proefstation voor de Rundveehouderij, Schapenhouderij en Paardenhouderij, PR, Lelystad, The Netherlands.

Hageman, I. W., and F. Mandersloot. 1995. Energy use and methods for reduction. In: W. Luten, H. Snoek, S. Schukking, and M. Verboon (Ed.) Applied Research for Sustainable Dairy Farming. p 44. Research Station for Cattle, Sheep and Horse Husbandry, Lelystad, The Netherlands.

Hassink, J., and J. J. Neeteson. 1991. Effect of grassland management on the amounts of soil organic N and C. Neth. J. Agric. Sci. 39:225.

Hermans, C., and P. Vereijken. 1995. Grazing animal husbandry based on sustainable nutrient management. Agric. Ecosyst. Environ. 52:213.

Hof, G., and S. Tamminga. 1994. Feeding management to reduce nitrogen losses in dairy cows. In: E. A. Huisman, J.W.M. Osse, D. Van der Heide, S. Tamminga, B. J. Tolkamp, W.G.P. Schouten, C. E. Hollingworth, and G. L. Van Winkel (Ed.) Biological Basis of Sustainable Animal Production. p 149. Wageningen Pers, Wageningen, The Netherlands.

Hof, G., S. Tamminga, and P. J. Lenaers. 1994. Efficiency of protein utilization in dairy cows. Livest. Prod. Sci. 38:169.

Johnson, D. E., T. M. Hill, B. R. Carmean, M. E. Branine, D. W. Lodman, and G. M. Ward. 1991. New perspectives on ruminant methane emissions. In: C. Wenk and M. Boessinger (Ed.) Energy Metabolism of Farm Animals. p 376. EAAP publication no. 58, Institut für Nutztierwissenschaften, Gruppe Ernährung, ETH, Zurich, Switzerland.

Kelly, J. M., H. Park, M. Summers, and L. P. Milligan. 1993. Interactions between protein and energy metabolism. In: J. M. Forbes, and J. France (Ed.) Quantitative Aspects of Ruminant Digestion and Metabolism. p 341. CAB International, Wallingford, U.K.

Kemp, A., O. J. Hemkes, and T. Van Steenbergen. 1979. The crude protein production of grassland and the utilization by milking cows. Neth. J. Agric. Sci. 27:36.

Ketelaars, J.J.M.H., and G.W.J. Van de Ven. 1992. Stikstofstromen in agro-ecosystemen. In: H. G. Van der Meer and J.H.J. Spiertz (Ed.) Agrobiologische thema's. p 33. CABO-DLO, Wageningen, The Netherlands.

Kirchgessner, M., W. Windisch, and H.-L. Müller. 1994. Methane release from dairy cows and pigs. In: J. F. Aguilera (Ed.) Energy Metabolism of Farm Animals. p 399. EAAP publ. no. 76. C.S.I.C., Publishing Service, Granada, Spain.

Korevaar, H. 1992. The nitrogen balance on intensive Dutch dairy farms: A review. Livest. Prod. Sci. 31:17.

Lammers-Wienhoven, S.C.W., L. Ram, J. Voigt, J. Van Bruchem, J.J.M.H. Ketelaars, and S. Tamminga. 1995. Effect of cell walls on production and re-absorption of endogenous nitrogen along the small intestine of sheep. A pilot study. Neth. J. Agric. Sci. (In press).

Lantinga, E. A. 1985. Productivity of grasslands under continuous and rotational grazing. Ph.D. Thesis. Agricultural University, Wageningen, The Netherlands.

MacRae, J. C. 1993. Metabolic consequences of intestinal parasitism. Proc. Nutr. Soc. 52:121.

Meadows, D. H., D. L. Meadows, and J. Randers. 1992. Beyond the Limits. Earthscan Publications Ltd., London.

Meijer, R., Tj. Boxem, G. Smolders, A. Van der Kamp, and G. H. Wensink. 1994. Voederbieten voor melkvee. Publikatie nr. 88, Proefstation voor de Rundveehouderij, Schapenhouderij en Paardenhouderij, PR, Lelystad, The Netherlands.

Minson, D. J. 1990. Forage in ruminant nutrition. Academic Press, San Diego, CA.

Moe, P. W., and H. F. Tyrrell. 1979. Methane production in dairy cows. J. Dairy Sci. 62:1583.

Müller, M. J. 1995. Hepatic fuel selection. Proc. Nutr. Soc. 54:139.

Reynolds, C. K., D. L. Harmon, and M. J. Cecava. 1994. Absorption and delivery of nutrients for milk protein synthesis by portal drained viscera. J. Dairy Sci. 77:2787.

Satter, L. D. 1986. Protein supply from undegraded dietary protein. J. Dairy Sci. 69:2734.

Stern, M. D., G. A. Varga, J. H. Clark, J. L. Firkins, J. T. Huber, and D. L. Palmquist. 1994. Evaluation of chemical and physical properties of feeds that affect protein metabolism in the rumen. J. Dairy Sci. 77:2762.

Subnel, A.P.J., R.G.M. Meijer, W. M. Van Straalen, and S. Tamminga. 1994. Efficiency of milk protein production in the DVE protein evaluation system. Livest. Prod. Sci. 40:215.

Symonds, H. W., and J. M. Forbes. 1994. Mineral metabolism. In: J. M. Forbes and J. France (Ed.) Quantitative aspects of ruminant digestion and metabolism. p 363. CAB International, Wallingford, U.K.

Tamminga, S. 1992a. Gaseous pollutants by farm animal enterprises. In: C. Phillips and D. Piggins (Ed.) Farm Animals and the Environment. p 345. CAB International, Wallingford, UK.

Tamminga, S. 1992b. Nutrition management of dairy cows as a contribution of pollution control. J. Dairy Sci. 75:345.

Tamminga, S., H. Schulze, J. Van Bruchem, and J. Huisman. 1995. The nutritional significance of endogenous N-losses along the gastro-intestinal tract of farm animals. Arch. Anim. Nutr. 48:9.

Tamminga, S., W. M. Van Straalen, A.P.J. Subnel, R.G.M. Meijer, A. Steg, C.J.G. Wever, and M. C. Blok. 1994. The Dutch protein evaluation system: The DVE/OEB system. Livest. Prod. Sci. 40: 139.

Vanbelle, M., E. Teller, M. Focant, B. Vanabelle, and D. Bruyer. 1989. Improvement of the feed conversion in ruminant livestock production. In: G. Piva, and J. Wiseman (Ed.) Proc. 1st Intl. Feed Prod. Conf. p 1. Editrice Essegivi, Piacenza, Italy.

Van Boheemen, P.J.M., M.E.G. Berghs, F. R. Goossensen, P. Hotsma, and P. C. Meeuwissen. 1991. Milieubelasting in 2000 door kaliumbemesting. In: H.A.C. Verkerk (Ed.) Mest en Milieu in 2000: Visie vanuit het landbouwkundig onderzoek. p 61. Dienst Landbouwkundig Onderzoek, DLO, Wageningen, The Netherlands.

Van Bruchem, J., J. Voigt, S.C.W. Lammers-Wienhoven, U. Schönhusen, J.J.M.H. Ketelaars, and S. Tamminga. 1997. Production and re-absorption of endogenous protein along the small intestine of sheep. Estimates derived from ^{15}N dilution of plasma non-protein-N. Br. J. Nutr. (In press).

Van der Honing, Y., S. Tamminga, B. J. Wieman, A. Steg, B. van Donselaar, and L.G.M. Van Gils. 1983. Further studies on the effect of fat supplementation of concentrates fed to lactating dairy cows. 2. Total digestion and energy utilization. Neth. J. Agric. Sci. 31:27.

Van der Honing, Y., B. J. Wieman, A. Steg, and B. Van Donselaar. 1981. The effect of fat supplementation of concentrates on digestion and utilization of energy by productive dairy cows. Neth. J. Agric. Sci. 29:79.

Van Nevel, C. J., and D. I. Demeyer. 1988. Manipulation of rumen fermentation. In: P. N. Hobson (Ed.) The Rumen Microbial Ecosystem. p 387. Elsevier Applied Science, London.

Van Straalen, W. M., and S. Tamminga. 1990. Protein degradability in ruminant diets. In: J. Wiseman, and D.J.A. Cole (Ed.) Feed Evaluation. p 55. Butterworth, London.

Van Vuuren, A. M. 1993. Digestion and nitrogen metabolism of grass fed dairy cows. Ph.D. Thesis. Agricultural University, Wageningen, The Netherlands.

Van Vuuren, A. M., F. Krol-Kramer, R. A. Van der Lee, and H. Corbijn. 1992a. Protein digestion and intestinal amino acids in dairy cows fed fresh *Lolium perenne* with different nitrogen contents. J. Dairy Sci. 75:2215.

Van Vuuren, A. M., C. J. Van der Koelen, H. Valk, and H. De Visser. 1992b. Effects of partial replacements of ryegrass by low protein feeds on rumen fermentation and nitrogen loss by dairy cows. J. Dairy Sci. 76:2982.

Van Vuuren, A. M., S. Tamminga, and R. S. Ketelaar. 1991. *In sacco* degradation of organic matter and crude protein of fresh grass (*Lolium perenne*) in the rumen of grazing dairy cows. J. Agric. Sci. 116:429.

Wilkerson, V. A., D. P. Casper, D. R. Mertens, and H. F. Tyrrell. 1994. Evaluation of several methane producing equations for dairy cows. In: J. F. Aguilera (Ed.) Energy Metabolism of Farm Animals. p 395. EAAP publ. no. 76. C.S.I.C., Publishing Service, Granada, Spain.

Wilman, D. 1975. Nitrogen and Italian ryegrass. 2. Growth up to 14 weeks: Nitrogen, phosphorus and potassium content and yield. J. Br. Grassl. Soc. 30:243.

Wolf, J., and L.H.J.M. Janssen. 1991. Effects of changing land use in the Netherlands on net carbon fixation. Neth. J. Agric. Sci. 39: 237.

Yano, F., H. Yano, and G. Breves. 1991. Calcium and phosphorus metabolism in ruminants. In: T. Tsuda, Y. Sasaki, and R. Kawashima (Ed.) Physiological Aspects of Digestion and Metabolism in Ruminants. p 277. Academic Press, San Diego, CA.

NEWS AND NOTES

Announcements about meetings, personnel changes and other items of interest to the Society should be sent to the Technical Editor, Journal of Animal Science, 1111 N. Dunlap Ave., Savoy, IL 68174. Approximately 90 days should be allowed from date of submission until receipt of the *Journal* by the membership. These announcements are edited and published in the journal and at our World Wide Web home page (http://www.asas.org) free of charge.

A fourth annual **Frank Baker Beef Improvement Essay Contest** is being sponsored by the Beef Improvement Federation. Students currently enrolled in an advanced degree program at an accredited university in the United States or Canada are eligible. Each winner will be reimbursed for expenses up to $500 to attend the BIF Meeting at Dickinson, ND, May 14–17, 1997. Essays can be contributed on any specific topic concerning genetic improvement in beef cattle. Details for applicants can be obtained from Dr. Larry V. Cundiff, chair of BIF Baker Essay Award Committee, U.S. Meat Animal Research Center, P.O. Box 166, Clay Center, NE 68933. Essays and vitae must be postmarked by February 20, 1997. Winners will be notified by March 20, 1997.

The National Animal Health Monitoring System (NAHMS), a nonregulatory unit within the USDA, is planning to conduct the first-ever **NAHMS equine study** in 1998. The NAHMS program is designed to help meet animal health information needs of U.S. agriculture. They are interested in having those allied with the horse industry help them determine where information gaps are for equine health information, and thus what are good candidates for the study focus. To gather information, an 800 telephone number and Internet access will be established. Dates for the survey are January 1, 1997 to March 15, 1997. To complete the survey by phone, call 800-545-8732 from any touchtone phone in the United States, or log into the Intenet address (http://www.aphis.usda.gov/equine_survey/). Surveys that are sent by mail cannot be processed.

The **Society for Range Management's 50th Anniversary Meeting** will take place February 16–21, 1997, in Rapid City, SD. Deadline for registration for non-members with reduced rates is January 12, 1997. Registration fee includes a 1-year membership in SRM. Conference information and registration forms are available from SRM Headquarters, 1839 York Street, Denver, CO 80206 (phone 303/355-7070; fax 303/355-5059; E-mail srmden@ix.netcom.com).

The 23rd International Conference of the Animal Transportation Association (AATA), **"Business in a New World,"** will be held March 16–19, 1997, in Santiago, Chile. Some of the topics covered are road transportation, security, stocking densities, perishable materials, and container specifications. For more information about AATA or the conference, contact Jim Stafford (U.S.) at 713/443-4595 or Tim Harris (Europe) at +44 (0) 1737 82 22 49.

An **International Conference on Agricultural Production and Nutrition** will be held March 19–21, 1997, in Boston, MA. Organized by Tufts University School of Nutrition Science and Policy and Henry A. Wallace Institute for Alternative Agriculture, the conference will examine all aspects of the relationship between the quality/safety of food and the production system used to raise it. Besides biological and technological aspects, the conference also will deal with consumer attitudes, regulatory issues, and agricultural development strategies. For information contact William Lockeretz, School of Nutrition Science and Policy, Tufts University, Medford, MA 02155 (E-mail wlockeretz@infonet.tufts.edu).

The 5th Easter School in Agricultural Science, **Progress in Pig Science**, will be held at the University of Nottingham Sutton Bonington Campus April 7–12, 1997. This will include aspects of genetics, nutrition, reproductive physiology, meat science, management and the environment that affect the production of pig products. Registration is due by February 28. For more information, call the conference secretary, Sue Golds, at 01159 516066.

The **XVIII International Grassland Congress '97** will be held in Canada. Complete registration packages are available through the IGC Secretariat Office at 403/244-4487 (fax 403/244-2340; E-mail amc@forage.org) or can be viewed on the Internet site http://www.forage.org.

Kansas State University will conduct the **17th International Workshop on Rapid Methods and Automation in Microbiology** July 11–18 in Manhattan, KS. A symposium will occur on July 11 and 12. Contact Daniel Y.C. Fung (phone 913/532-5654; fax 913/532-5681; E-mail danfung@ksu.ksu.edu).

The **30th Annual Meeting of the Society for the Study of Reproduction** will be held August 2–5, 1997, in Portland, OR. Abstracts must be postmarked by February 15, 1997. For information contact Judith Jansen, Executive Secretary, 1603 Monroe Street, Madison, WI 53711-2021 (phone 608/256-2777; fax 608/256-4610; E-mail ssr@ssr.org). For meeting information and updates, visit the SSR web site at http://www.ssr.org/~ssr/ssr.

A **Transgenic Animals in Agriculture Conference** will take place August 24–27, 1997, in Tahoe City, CA. For more information call the Biotechnology Program, UC Davis, at 916/752-3260 (fax 916/752-4125; E-mail tgmeeting@ucdavis.edu). Information is also available on the Internet at http://pubweb.ucdavis.edu/Documents/BIOTECH/biotech1.htm.

(tableau I). Les valeurs de la P3 confirment les résultats obtenus précédemment dans notre Laboratoire (Tisserand *et al*, 1986) et par d'autres chercheurs (Obara et Shimbayashi, 1987; Djajanegara et Doyle, 1989), qui concluent que les ovins sont plus sensibles à la carence azotée que les caprins. Les caprins, grâce sans doute à une meilleure utilisation de l'azote (recyclage de l'urée surtout), réduisent le déficit azoté au niveau du rumen, principalement, et du cæcum dans une moindre mesure, ce qui permet une activité microbienne plus efficace.

Nos résultats mettent aussi en évidence un effet de la nature du complément azoté : l'activité microbienne dans le cæcum semble indépendante de la nature et de la quantité du complément azoté chez les caprins, alors qu'elle est diminuée chez les ovins avec le régime P3 sans complément azoté. Cela confirme les travaux antérieurs qui mettent en évidence un meilleur recyclage de l'N chez les caprins. Toutefois, nos résultats sont à considérer avec prudence car le cæcum ne constitue qu'une partie du gros intestin et le temps de séjour des aliments dans ce compartiment, arbitrairement fixé à 24 h, ne correspond vraisemblablement pas à la durée réelle. En effet, pour ce qui concerne le gros intestin, le temps de séjour apparaît plus élevé chez les caprins que chez les ovins (Alrahmoun, 1985).

En conclusion, et malgré les réserves précédentes, cet essai met en évidence que l'activité cellulolytique dans le cæcum est presque équivalente à celle du rumen et que l'activité cellulolytique du rumen est plus élevée chez les caprins que chez les ovins, surtout avec les régimes pauvres en azote.

Alrahmoun W (1985) Thèse d'état, université de Dijon, 213 p

Demarquilly C, Chenost M (1969) *Ann Zootech* 18, 419-435

Djajanegara A, Doyle PT (1989) *Anim Feed Sci Technol* 27, 31-47

Obara Y, Shimbayashi K (1987) *Jpn J Zootech Sci* 58, 611-617

Tisserand JL, Bellet B, Masson C (1986) *Reprod Nutr Dév* 26, 313-314

Tableau I. Disparition de la MS de la paille après 24 h de séjour dans le rumen puis/ou dans le cæcum (moyenne ± écart type).

Période	*Espèce*	*Rumen (R)*	*Rumen puis cæcum (R + Ce)*	*Cæcum (Ce)*
P1	ovine	25,3 ± 2,1 [a]	42,0 ± 2,5	25,6 ± 3,0 [c]
	caprine	29,8 ± 2,1 [b]	40,8 ± 3,5	22,7 ± 2,6 [d]
P2	ovine	26,8 ± 3,2 [c]	37,6 ± 4,2 [c]	24,3 ± 2,5
	caprine	29,5 ± 4,4 [d]	40,8 ± 2,4 [d]	25,1 ± 1,8
P3	ovine	20,9 ± 1,5 [a]	33,9 ± 1,1 [a]	22,7 ± 2,6
	caprine	26,1 ± 4,0 [b]	37,5 ± 2,7 [b]	22,4 ± 1,7

Pour une même période et un même site, les moyennes indicées diffèrent significativement; [a, b] : $P<0{,}01$; [c, d] : $P<0{,}05$.

MacRae, J. C. 1993. Metabolic consequences of intestinal parasitism. Proc. Nutr. Soc. 52:121.

Meadows, D. H., D. L. Meadows, and J. Randers. 1992. Beyond the Limits. Earthscan Publications Ltd., London.

Meijer, R., Tj. Boxem, G. Smolders, A. Van der Kamp, and G. H. Wensink. 1994. Voederbieten voor melkvee. Publikatie nr. 88, Proefstation voor de Rundveehouderij, Schapenhouderij en Paardenhouderij, PR, Lelystad, The Netherlands.

Minson, D. J. 1990. Forage in ruminant nutrition. Academic Press, San Diego, CA.

Moe, P. W., and H. F. Tyrrell. 1979. Methane production in dairy cows. J. Dairy Sci. 62:1583.

Müller, M. J. 1995. Hepatic fuel selection. Proc. Nutr. Soc. 54:139.

Reynolds, C. K., D. L. Harmon, and M. J. Cecava. 1994. Absorption and delivery of nutrients for milk protein synthesis by portal drained viscera. J. Dairy Sci. 77:2787.

Satter, L. D. 1986. Protein supply from undegraded dietary protein. J. Dairy Sci. 69:2734.

Stern, M. D., G. A. Varga, J. H. Clark, J. L. Firkins, J. T. Huber, and D. L. Palmquist. 1994. Evaluation of chemical and physical properties of feeds that affect protein metabolism in the rumen. J. Dairy Sci. 77:2762.

Subnel, A.P.J., R.G.M. Meijer, W. M. Van Straalen, and S. Tamminga. 1994. Efficiency of milk protein production in the DVE protein evaluation system. Livest. Prod. Sci. 40:215.

Symonds, H. W., and J. M. Forbes. 1994. Mineral metabolism. In: J. M. Forbes and J. France (Ed.) Quantitative aspects of ruminant digestion and metabolism. p 363. CAB International, Wallingford, U.K.

Tamminga, S. 1992a. Gaseous pollutants by farm animal enterprises. In: C. Phillips and D. Piggins (Ed.) Farm Animals and the Environment. p 345. CAB International, Wallingford, UK.

Tamminga, S. 1992b. Nutrition management of dairy cows as a contribution of pollution control. J. Dairy Sci. 75:345.

Tamminga, S., H. Schulze, J. Van Bruchem, and J. Huisman. 1995. The nutritional significance of endogenous N-losses along the gastro-intestinal tract of farm animals. Arch. Anim. Nutr. 48:9.

Tamminga, S., W. M. Van Straalen, A.P.J. Subnel, R.G.M. Meijer, A. Steg, C.J.G. Wever, and M. C. Blok. 1994. The Dutch protein evaluation system: The DVE/OEB system. Livest. Prod. Sci. 40: 139.

Vanbelle, M., E. Teller, M. Focant, B. Vanabelle, and D. Bruyer. 1989. Improvement of the feed conversion in ruminant livestock production. In: G. Piva, and J. Wiseman (Ed.) Proc. 1st Intl. Feed Prod. Conf. p 1. Editrice Essegivi, Piacenza, Italy.

Van Boheemen, P.J.M., M.E.G. Berghs, F. R. Goossensen, P. Hotsma, and P. C. Meeuwissen. 1991. Milieubelasting in 2000 door kaliumbemesting. In: H.A.C. Verkerk (Ed.) Mest en Milieu in 2000: Visie vanuit het landbouwkundig onderzoek. p 61. Dienst Landbouwkundig Onderzoek, DLO, Wageningen, The Netherlands.

Van Bruchem, J., J. Voigt, S.C.W. Lammers-Wienhoven, U. Schönhusen, J.J.M.H. Ketelaars, and S. Tamminga. 1997. Production and re-absorption of endogenous protein along the small intestine of sheep. Estimates derived from ^{15}N dilution of plasma non-protein-N. Br. J. Nutr. (In press).

Van der Honing, Y., S. Tamminga, B. J. Wieman, A. Steg, B. van Donselaar, and L.G.M. Van Gils. 1983. Further studies on the effect of fat supplementation of concentrates fed to lactating dairy cows. 2. Total digestion and energy utilization. Neth. J. Agric. Sci. 31:27.

Van der Honing, Y., B. J. Wieman, A. Steg, and B. Van Donselaar. 1981. The effect of fat supplementation of concentrates on digestion and utilization of energy by productive dairy cows. Neth. J. Agric. Sci. 29:79.

Van Nevel, C. J., and D. I. Demeyer. 1988. Manipulation of rumen fermentation. In: P. N. Hobson (Ed.) The Rumen Microbial Ecosystem. p 387. Elsevier Applied Science, London.

Van Straalen, W. M., and S. Tamminga. 1990. Protein degradability in ruminant diets. In: J. Wiseman, and D.J.A. Cole (Ed.) Feed Evaluation. p 55. Butterworth, London.

Van Vuuren, A. M. 1993. Digestion and nitrogen metabolism of grass fed dairy cows. Ph.D. Thesis. Agricultural University, Wageningen, The Netherlands.

Van Vuuren, A. M., F. Krol-Kramer, R. A. Van der Lee, and H. Corbijn. 1992a. Protein digestion and intestinal amino acids in dairy cows fed fresh *Lolium perenne* with different nitrogen contents. J. Dairy Sci. 75:2215.

Van Vuuren, A. M., C. J. Van der Koelen, H. Valk, and H. De Visser. 1992b. Effects of partial replacements of ryegrass by low protein feeds on rumen fermentation and nitrogen loss by dairy cows. J. Dairy Sci. 76:2982.

Van Vuuren, A. M., S. Tamminga, and R. S. Ketelaar. 1991. *In sacco* degradation of organic matter and crude protein of fresh grass (*Lolium perenne*) in the rumen of grazing dairy cows. J. Agric. Sci. 116:429.

Wilkerson, V. A., D. P. Casper, D. R. Mertens, and H. F. Tyrrell. 1994. Evaluation of several methane producing equations for dairy cows. In: J. F. Aguilera (Ed.) Energy Metabolism of Farm Animals. p 395. EAAP publ. no. 76. C.S.I.C., Publishing Service, Granada, Spain.

Wilman, D. 1975. Nitrogen and Italian ryegrass. 2. Growth up to 14 weeks: Nitrogen, phosphorus and potassium content and yield. J. Br. Grassl. Soc. 30:243.

Wolf, J., and L.H.J.M. Janssen. 1991. Effects of changing land use in the Netherlands on net carbon fixation. Neth. J. Agric. Sci. 39: 237.

Yano, F., H. Yano, and G. Breves. 1991. Calcium and phosphorus metabolism in ruminants. In: T. Tsuda, Y. Sasaki, and R. Kawashima (Ed.) Physiological Aspects of Digestion and Metabolism in Ruminants. p 277. Academic Press, San Diego, CA.