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Environmental Impacts of Beef Cattle

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Abstract

Beef production is to be considered as a system in which the nutrients are cycling through the components soil, plant, animal and waste. During transfer between and within components, nutrients are inevitably lost to the environment. Excessive losses of phosphate (PO_4^{2-}) and nitrate (NO_3^-) may case eutrofication in soil and water. Nutrients that cause concern because of their contribution to global warming of the atmosphere are gaseous forms of C in methane (CH_4) and N in nitrous oxide (N_2O) and its precursor ammonia (NH_3). Loss of N and P to the environment can be limited by feeding animals according to or just below recommended requirements for protein and P. Quantification of nutrient balances on an animal scale is very difficult, notably for grazing animals. The best option is to base feed intake on energy requirements for maintenance and the achieved growth performance.

Loss of CH_4 can be limited by shifting the fermentation pattern in the rumen. Present tools are the use of rumensin, already widely applied in the US, and in future maybe immunisation. A major source of nutrients lost to the environment is that from the feed that is used to maintain the animals. In beef cattle this amount varies between 50 and 75% of the net energy ingested with the feed. Significantly lower nutrient losses can be achieved by shortening the fattening period and the use of faster growing animals. Reducing the number of animals needed for reproduction by improving their longevity and reproduction efficiency can also help.

Introduction

Animal production is part of a production system. Together with plants used as feed, animal waste or excreta and the soil they form a production cycle. A variety of nutrients is cycling through the various compartments of that system. The different compartments may have different capacities to handle these nutrients efficiently. Due to an inefficient storage or utilisation, nutrients may be lost to the environment, notably to water and to the atmosphere. When produced in excessive amounts, a number of soluble and gaseous compounds directly or indirectly originating from animal production, cause concern. They are known to have a negative effect on the environmental components soil, water and atmosphere. Nutrients inevitably lost from animal production into the environment are Nitrogen (N), Phosphorus (P), sometimes potassium (K), and the greenhouse gases methane (CH_4) and nitrous oxide (N_2O) with its precursor ammonia (NH_3). Important contaminants of soil and water are nitrogen as nitrate (NO_3^-) and phosphorus (P). Both originate primarily from N and P in fertiliser and in animal manure, the latter being a mixture of faeces and urine. Although both nutrients are important for soil fertility, excessive levels of them in the soil cause the risk of runoff or leaching to surface and sub-soil water, causing eutrofication. This is particularly true for P. To secure healthy drinking water and to avoid eutrofication with N, in 1991, the EU has accepted the nitrate directive in which member states are required to keep the nitrate content of water in so-called nitrate-sensitive zones below 50 mg L^{-1}.

Greenhouse gases are carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O). They are feared for their potential to contribute to global warming. An overview of the emissions, their change and the contribution of agriculture is presented in Table 1 (IPCC, 2001).

Table 1 Emissions of greenhouse gases, their change and the contribution of agriculture

	CO_2 (ppm)	CH_4 (ppb)	N_2O (ppb)
Pre-industrial	280	700	270
1998	365	1745	314
Change/year	1.5	7.0	0.8
Global warming potential	1	40	330
Contribution of agriculture	5	20	> 50

Emissions of CO_2 are predominantly the result of the use of fossil fuel. The contribution of agriculture in general and animal production in particular to CO_2 emissions is relatively small and even in industrialised countries with highly mechanised animal production systems, this contribution usually does not exceed 5% (Sauerbeck, 2001).

Methane results from the anaerobic decay of organic matter in the sediments of natural marshlands and rice fields. Substantial contributions also come from ruminants, biomass burning, decay of organic matter in landfills, fossil fuel production and leaks in natural gas distribution systems (Crutzen, 1995). Around 20% is believed to come from ruminants and animal wastes. Because of its high global warming potential (GWP), CH_4 contributes some 55% of the GWP of a dairy cow (Johnson et al., 1997). According to EPA estimations (EPA, 2005a), of the methane emissions from beef and dairy enterprises in the US, 58% originate from cow-calf operations, 23% from dairy and 19% from feedlots and stockers.

Nitrous oxide arises from microbial nitrification and/or microbial or chemical denitrification in the soil. Its emission is considered to be on average 1.25% of the amount of N applied to that soil. Addition of nitrogen to the soil via mineral N fertilisers, animal manure, crop residues or sewage waste generally increases the N_2O emission. Nitrous oxide emission is influenced by land use. It was found (Vermoesen et al., 1996) that N_2O emission from mown grassland, grazed grassland and maize fields were distinctly different with 1.7%, 2.9% and 3.6% of the N applied or 2.8, 14.0 and 3.2 kg N_2O/ha/year.

It is now widely accepted that undesired nutrient losses should be avoided or at least kept to a minimum. This needs a combination of technical, legal and mental interventions. Many types of interventions at many sites in the production chain (soil–

plant–animal–manure) are possible (Tamminga, 2003). Important technical tools are a reduction in the use of NPK fertiliser, nutrition and manure management.

Nutrient flows in beef cattle

The ultimate target of animal production is to produce animal products like milk, eggs or meat. In the case of the beef production system as applied in the US, the animal compartment is characterised by different phases among which are cow-calf operations on pasture, growing or stocking animals on pasture, either or not supplemented with extra nutrients and finishing animals in feedlots. Besides, there is a wide variety of breeds, types of animals and fattening systems. In general terms, a beef calf is born at a weight of 40 kg and reaches a weaning weight of 200 kg after 7 months. Under optimum growing conditions slaughter weight can be reached between 15 and 20 months of age. Slaughter weight is quite variable and very much depends on the type and breed of animals.

In animal production in general, nutrients ingested with the feed are deposited in the body as water, fat, protein and minerals or lost to the environment. Organic nutrients ingested by beef cattle are usually expressed as TDN (in % of DM) or Net Energy (NE in Mcal/kg) and Metabolisable Protein (MP in g), whereas inorganic nutrients are more commonly expressed as elemental minerals, for instance as phosphorus (P). Net Energy is the amount of energy present in the feed corrected for inevitable energy losses in faeces (remaining is Digestible Energy or DE), energy losses in urine and methane (remaining is Metabolisable Energy) and energy lost in heat as respiration gases (remaining is Net Energy). Requirements are usually expressed in NE and separated in those for maintenance (NE_m), growth and pregnancy in which NE_m is also lost to the environment. Energy requirements for beef cattle have been calculated and tabulated (NRC, 2000). Next to or rather as part of their energy requirements, beef animals require protein. Nowadays this is expressed as Metabolisable Protein (MP). This is crude protein (Nx6,25) corrected for losses in the rumen (Rumen Degradable Protein or DIP) after correction for N captured in microbial protein, for losses in the intestine (undigested and endogenous protein lost in faecal excretion) and nucleic acids originating from microbial protein synthesized in the rumen and lost in the urine. Requirements for MP are also separated in those for maintenance, growth and pregnancy, but, unlike with energy, no account is given for the losses of N in urine due to an inefficient utilisation of MP during deposition in the body. Apart from the requirements for maintenance and N deposition in the body, ruminants have a requirement for N in rumen degradable protein (RDN or DIP) to keep the rumen microbes working properly.

Animal production aims at the retention of nutrients in the body or excretion in milk. Nutrients lost and considered detrimental to the environment are usually not expressed in terms of energy and protein, but as elements or their oxidized or reduced forms. Examples are carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), ammonia (NH_3) and phosphate (P). Present day feed evaluation systems are therefore not very suitable to estimate the amounts and forms in which nutrients are lost to the environment. Nutrients not deposited in the body are divided between excretion in faeces, excretion in the urine and excretion in fermentation and respiration gases. Nutrients excreted to the environment are often reported in kg of an element per animal per year. Appropriate ways to express them are as C in CO_2 or CH_4, predominantly representing energy, as N that represents protein and as P to represent phosphate.

Deposited fat and protein can also be expressed as deposited C and N. Assuming that fat deposited in beef is equal to tallow, a mix of palmitic, stearic and oleic acid, it can be calculated that fat contains on average 76% of C. The C content of a variety of proteins of animal origin varied between 47 and 53% (Rafecas et al., 1994). Both are higher than the 45% C often found in the organic matter in the feed.

Table 2. Proportion of Net Energy, Metabolisable protein and Phosphorus lost in maintenance

	Age (months)	Weight (kg)	Proportion of nutrient lost in maintenance		
			Energy	Protein	Phoshorus
Stockers	7-15	200-350	0.76	0.71	0.74
Feedlot cattle	16-20	350-533	0.52	0.44	0.40
Replacement heifers	16-24	350-500	0.64	0.65	0,65
Beef cows	> 36	600	0.76	0.71	0.74
Bulls	> 15	300-800	0.55	0.66	0.66

In recent years dynamic models have been developed, at least for dairy cows, that try to predict the excretion of Methane (Mills et al., 2001), Nitrogen (Kebreab et al., 2002), and Phosphorus to the environment (Kebreab et al., 2004). As yet no such models specifically designed for beef cattle exist, although the Cornell Net Carbohydrate and Protein System (CNCPS) model has been evaluated for that purpose with reasonable success (Fox et al., 2004).

In beef cattle usually a larger proportion of the ingested nutrients is lost to the environment than what is deposited in the body. Notably the requirements for maintenance form a major part of the total requirements (table 2). Feed evaluation systems on the basis of energy are suitable to optimise diets to achieve a targeted production. Besides, the requirements present the input required to satisfy needs for NE and a minimum amount of MP and P. Usually no boundaries are formulated for the maximum input of N and P.

Energy flows in beef cattle

In beef production the ingestion of energy is the driving force of the system. Energy ingested with the feed (GE) is distributed between faeces, urine and fermentation gases, respiration (gas) and heat. Of the GE ingested with the feed, only a small proportion is deposited in the body. A varying proportion of between 20 and 45% is lost in the faeces as indigested organic matter. Part of the remaining digested energy (DE) is lost in fermentation gases carbon dioxide (CO_2) and methane (CH_4) and in fermentation heat produced in the rumen. These losses are usually around 18% of the DE. The remaining ME is used for maintenance, deposited in the body as fat or protein or oxidised and lost as CO_2 in respiration and heat. Efficiency of utilisation of ME is around 60%, leaving between 27 and 39% of the GE ingested with the feed to cover maintenance and to deposit fat or protein. As shown in table 2, between 52 and 76 % of the NE is lost in maintenance. Taking all losses into account, results in the deposition in the body as fat and protein of only between 7 and 19 % of the GE ingested with the feed. The distribution between the different destinations varies with the type of animals or the segment of the whole production cycle. Segments are reproducing cows, calves, replacement heifers, some bulls for reproduction, and growing and fattening male and female animals either as stockers or in feedlots.

Nitrogen flows in beef cattle

Protein in animal production is usually expressed as crude protein (Nx6.25). Protein requirements in beef cattle fall apart in a requirement for rumen degradable intake protein (DIP) for the rumen microbes and a requirement for Metabolisable Protein for maintenance and production (milk, growth, pregnancy) of the animal. Metabolisable protein falls apart in digestible microbial true protein and digestible (rumen) undegradable intake protein. Except in fast growing animals below 300 kg of bodyweight and in cows and replacement heifers in early lactation, the requirement for DIP determines the minimum N level in the diet. According to NRC (2000) beef diets never need over 130 g DIP kg^{-1} TDN, the equivalent of 20.8 g N kg^{-1} TDN. Diets with a TDN of below 75 (% DM), contain only small amounts of fat and TDN approaches the value of Digestible Organic Matter (DOM), an expression more commonly used in countries other than the US and Canada. Assuming that in such diets, 65% of the DOM is fermented in the rumen (FOM); the 20.8 can be converted to 32 g of N per kg FOM, the maximum that can be captured in microbial protein synthesis.

Growth means the deposition of nutrients in the body. In beef cattle this deposition is a mix of fat, protein, water and a small amount of ash. When maturing, the ratio in which nutrients are deposited changes from predominantly protein and water to predominantly fat. Regardless body weight or frame size, NRC (2000) assumes in the Empty Body Weight (EBW) a fat percentage at slaughter of 28%. Assuming 4% ash and a water to protein ratio of 3.25 this results in 16% protein or 25.6 g N per kg EBW.

Excreted N is distributed between faeces and urine. In faeces, N originates from undigested feed N and endogenously secreted N, a large proportion of which has been converted into microbial N in hindgut fermentation. Feed N in faeces is usually close to 10 % of the ingested N and the endogenous losses are closely related to the amount of DM excreted in faeces and amount to around 9 g of N per kg undigested feed DM.A large proportion of faecal N is of microbial origin, either from the rumen or from freshly synthesised microbial N in hindgut fermentation. Nitrogen in faeces is usually present in rather complicated organic compounds and is not easily converted into ammonia. N in urine originates from a surplus of rumen degradable protein (DIP), from microbial nucleic acids synthesised in microbial protein synthesis in the rumen and from MP oxidised in the body. The majority of N in urine is present in urea that is easily converted in ammonia that in turn easily escapes in gaseous form. Depending on the type of housing conditions in The Netherlands it is assumed that N losses due to volatilisation in NH_3, range from 7.5 to 44%. Such losses occur between excretion and storage, during storage and during application to the land. According to Lotz (2004) around 50% of the N excreted by feedlot cattle in the US is lost, primarily as ammonia (NH_3), nitrate (NO_3^-), nitrous oxide (N_2O) and nitrogen gas (N_2).

As indicated earlier, feeding MP in excess of requirements is inevitable. To ensure a sufficient supply of DIP, diets for beef cattle seldom have a CP content of below 12.5%. The extensive recycling of N through urea synthesis in the liver and the return of a large part of that to the rumen (Lapierre and Lobley, 2001) would allow feeding below DIP requirements. An interesting observation was reported recently. When alternating the feeding of a low (9.1 % CP) and a high (13.9 % CP) diet every third day (Archibeque et al., 2005), N retention was improved and consequently urinary N losses decreased. A possible explanation is that a reduction in the recycling of N lags behind the reduction in CP intake, securing the provision of RIP through recycling and maintaining, at least for a while, a better environment for the rumen microbes. In general low levels of dietary CP cause a deficiency in DIP and impair the activity of microbes in the rumen. This may negatively influence feed intake, resulting in an impaired growth. A lower gain increases the relative proportion of the feed lost in maintenance. Besides, it prolongs the fattening period and as a result also increases the proportion of total feed lost in maintenance and consequently to the environment. In all classes of beef livestock, maintenance requires between 44 and 71% of the total requirement of MP. The only way to reduce N excretion is then to reduce the cost of maintenance as proportion of the total requirement. This can be achieved by a faster growth in stockers and feedlot cattle or a higher longevity of beef cows, so that lower numbers of replacement heifers are needed.

Phosphorus flows in beef cattle

As can be seen in table 3, the P content in animals varies between 7.4 and 8 $g.kg^{-1}$. Even in a 600 kg animal this amounts to less than 5 kg of deposited P. When not utilised by the animals P is predominantly excreted in manure. It is not volatised, but when not taken up by plants it accumulates in the soil. In the long run the soil may get saturated and the surplus P is washed out and causes eutrofication. Phosphorus is recommended by NRC (2000) for beef cattle at levels varying between 1.3 and 3.4 g P kg^{-1} DM or between 2.0 and 4.8 kg^{-1} TDN. Erickson et al. (1999) fed crossbred finishing steers up to over 30% below recommendations without observing negative affects. This suggests that recommendations could easily be reduced by some 25%. According to Knowlton et al. (2004), in practice overfeeding is quite common, mainly because P deficiency is thought to impair reproductive performance. A second reason for overfeeding with P is the inclusion of feeds in the diet that are naturally high in P. This is particularly true when significant amounts of by-products of grain processing or ethanol production are included in beef diets. The popularity of high-P by-products may prevent lower P recommendations to become accepted in practice.

The first challenge here is to minimise P input with the feed. This may make it desirable to restrict the inclusion of by-products in diets for beef cattle. However, such ingredients are economically attractive and besides, if not consumed by animals they might also become a burden to the environment. As indicated in table 1, between 40 and 70% of the dietary phosphorus is lost in maintenance. So, again reducing P intake will reduce P losses in excreta, but also reducing the length of the fattening period will reduce the loss in maintenance and consequently the loss of P to the environment.

Greenhouse gases

Methane

According to EPA (EPA, 2005), feedlot cattle in the US are fed with highly digestible diets with a DE/GE ratio of 0.85. Of the ingested energy 3% is lost in CH_4. The DE/GE ratio in diets for stockers, replacement heifers and beef cows was assumed to be 0.66; 0.66 and 0.64 respectively of which in all cases 6.5% was lost in CH_4. Ways to reduce the loss of CH_4 are at least twofold, feeding high concentrate diets or the inclusion of rumensin in the diet, both of which shift the fermentation pattern towards propionate (Moss et al., 2000). Both are already common practice in the US feedlot cattle. For the other categories there does not seem to be much need to feed high concentrate diets or to include rumensin. Promising developments for the future to reduce losses of CH_4 are in the field of novel defaunating agents like saponins or the immunisation of cattle against methanogens.

Ammonia and nitrous oxide

An important proportion of N excreted by ruminants is as urea in the urine. Due to mixing with faeces the urea is easily converted into and escapes as gaseous ammonia (NH_3). Ways to limit ammonia losses by interventions at animal level are limited. First of all the N input with the diet should be reduced and kept at its minimum. Under the many conditions under which beef cattle are kept, the needs of the rumen microbes often dictate the minimum level of dietary (crude) protein. This level often exceeds the requirements of the animal itself. A next option could be to synchronize the degradation of protein and carbohydrates in the rumen to ensure that rumen degradable protein is captured in microbial protein. However, if this microbial protein is not needed by the animal it will be oxidised and used as a source of energy. The resulting ammonia is converted back into urea in the liver and excreted in the urine. A further option is to shift the excretion of N from urine to faeces. This can be achieved by feeding more fibrous diet in which hind gut fermentation will capture urea recycling through the body. It will than be excreted as microbial protein in the faeces rather than in as urea the urine.

Feeding strategies to minimise nutrient losses to the environment

National or regional strategies

In order to limit the supply of nutrients to the environment, in The Netherlands and other countries in the EU, restrictions have been put on the maximum amount of N and P that can be applied with animal manure to a given area of land. The maximum application of manure is further restricted to the growing season and depends on the soil type (clay, sand or peat). This system requires an estimate of N and P losses per animal and farm. This estimate has been made on the basis of calculating the annual N and P balance per animal. Such balances were derived by calculating N and P in an energy input required to satisfy the animal's needs for NE and MP of a combination of feeds, and subtracting the amount deposited in body, offspring or milk. As an illustration, table 3 gives values for N and P deposited in animals and used in the environmental legislation in The Netherlands. For N the results are very close to those that can be calculated with equations presented by NRC (2000). In the case of N a correction is applied to account for inevitable gaseous losses of N in NH_3.

Table 3. N and P in different categories of animals in beef production

	Age (months)	Weight (kg)	N deposited (g/kg)	P deposited (g/kg)
Calves at birth	0	40	29.4	8.0
Calves at weaning	7	200	29.0	7.6
Stockers	7-24	200-450	27.0	7.4
Stockers/feedlot	> 24	450-533	25.6	7.4
Replacement heifers	15-24	325-490	27.0	7.4
Replacement heifers	24-36	490-533	25.6	7.4
Beef cows, bulls	> 36	597-980	22.5	7.4

A proper estimate of nutrient losses to the environment further required the design of an average diet fed to cattle. This diet was derived from known national productions of concentrates and estimated forage productions. Based on animal numbers and their energy requirements, the available feeds were distributed over the different animal categories. In this approach the production and consumption of fresh grass was derived from a national feed balance, based on cultivated areas. For each category of animals average diets have been designed and each category of animals has subsequently been allocated a standard N and P excretion. An overview of the excretions for beef and dairy cattle is shown in table 4. Because production conditions differ widely between farms, there is a need to make the excretions of N and P more farm or herd specific. For dairy cattle, by far the most important ruminant production activity in The Netherlands, a diversification has been made on the basis of milk production per animal and the urea content in the milk. The development of a further diversification is in progress.

Table 4. Standard N and P excretions for ruminants in The Netherlands

	Age (months)	Weight (kg)	N excreted (kg/yr)	P excreted (kg/yr)
Calves < 1 year	0-12	40-325	32.8	9.3
Calves > 1 year	12-26	326-530	70.2	24.1
Dairy cows	>26	600	110.3	41.5
Veal calves	0-8	40-245	24.9	
Beef cattle	3-18	75-640	32.3	11.8
Suckling cows	>26	600	76.4	30.3

As yet in The Netherlands no restrictions are imposed with regard to the loss of CH_4.

Herd management

From the previous sections it may be concluded that the amount of feed, its quality and its utilisation determines animal production as well as the quantity of nutrients lost to the environment. The driving force in this concept is energy, no matter whether it is expressed as dry matter, TDN, ME or NE. It has also become apparent that in beef cattle the minimum N input is determined by the requirement for DIP rather than MP and that in the later stages of the fattening period, overfeeding with MP is inevitable. Overfeeding with P is often also practically inevitable, because feed ingredients are based on by-products. Possibilities to reduce the N and P levels in diets for beef cattle are therefore limited to avoid feeding above requirements.

A further strategy to limit the losses of nutrients to the environment is to avoid underfeeding with energy because that enlarges the proportion of energy and nutrients lost in maintenance. Weight loss at any stage of the fattening period should be avoided. In growing animals weight gain should be optimised so that the length of the fattening period is kept at its minimum.

The number of animals should be such that there is enough land available to make efficient use of the fertilisation value of animals waste. Here the N:P ratio is important. The number of replacement animals should also be kept to a minimum. This can be achieved by maintaining a high reproduction efficiency and a high longevity of the female animals.

Conclusions

In beef cattle production it is inevitable that losses to the environment occur. The loss of N and P in excreta and the loss of CH_4 are presently of major concern. All three losses can be manipulated by feeding management, but the introduction of trade off values is needed to optimise the three losses. In beef production, a varying but high proportion of the feed is lost in maintenance. Besides it is inevitable to feed above MP requirements, because a minimum amount of DIP has to be provided to the rumen microbes. Feeding below DIP requirements may impair feed intake and consequently daily gain, resulting in a higher proportion of the feed being lost in maintenance with an inevitable side effect of a larger loss of energy in CH_4.

Overfeeding of P is also common because of the inclusion in beef diets of by-products of the food industry from which starch or sugar has been removed. Options to reduce maintenance losses are shortening the fattening period to realise target weight and to improve reproduction efficiency. Outside the animal proper waste management is required in order to reduce gaseous and runoff losses.

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