Feeding Strategies for Mitigating Nitrogen and Phosphorus Production and Greenhouse Gas Emissions from Domestic Animals in Alberta

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Science to Social Issues

Contents

Preface

The purpose of this report is several-fold. It is important to state upfront what this report is not about. It is not about the beneficial management practices (BMPs) for manure and methane. The BMPs for manure have been well described for cattle and pigs (Alberta Cattle Feeders Assoc. and AAFRD 2002; Alberta Pork and AAFRD 2002). First, we have attempted to model and quantify nitrogen and phosphorus excretion from domestic animals in Alberta. This exercise was intended to generate more specific Alberta coefficients for nitrogen, phosphorus and methane emissions and to compare these with IPCC coefficients and those available in the Canadian C.E.E.M.A. model (Kulshreshtha et al. 1999). Second, we have quantified the effects of various mitigation practices and discussed their applicability in Alberta livestock production systems. Third, we have attempted to showcase the limitations of the various mitigation strategies with the corresponding research gaps.

We do realise that this report is more comprehensive than the original task we were mandated to undertake. However, we believe that this format is a more comprehensive approach and ties together methane, manure and nitrogen (N) and phosphorus (P) excretion in domestic animals in Alberta and Canada. We have attempted to showcase Alberta but more comprehensive data suggested the linkage of Alberta and the rest of the country in terms of the quantitative analyses that we undertook.

We believe that this is the most thorough study of its kind for the Albertan animal industries and that is has yielded a substantial amount of information above and beyond that which is directly applicable to greenhouse gas emissions and N and P excretion. We have confidence in the conclusions presented, our interpretation of the literature, and in the general validity of the quantitative analysis. In some instances, however, lack of appropriate data meant we had to use our best judgement in arriving at solutions. Examples of such limitations were the protein and phosphorus content of diets actually consumed (particularly by ruminant animals) and the length of specific feeding periods (e.g. backgrounding).

The report consists of seven sections: executive summary; an overview of Alberta livestock feeding systems to put the report in perspective; coefficients for emissions and excretions in 1980, 1990 and 2010; literature review for mitigation strategies; evaluation and quantification of mitigation strategies; summary; and literature cited. Results from in-depth analyses are presented for swine, poultry and beef and dairy cattle. A more superficial approach was used for sheep, goats, horses, bison, and elk and deer because of time constraints and the small numbers of these animals in Canadian and Alberta's agriculture.

1 Executive Summary

1.1 Swine

Nitrogen and phosphorus modelling was done using nitrogen (N) digestibility of about 75-88% with a retention of 30-50% and phosphorus (P) digestibility and retention values of 20-50% and 20-45%, respectively. Percent nitrogen and phosphorus excretions in the swine industry were projected to increase by 28 and 35% from 1990 to 2010, respectively, with the swine population increasing by 36%.

A variety of mitigation strategies for the reduction of nitrogen, phosphorus and methane were examined for swine. The most promising strategy to reduce nitrogen and phosphorus excretion by pigs involved three components: a reduction of dietary protein contents with the addition of free amino acids, an increase in dietary energy contents, or a reduction in the contents of non-starch polysaccharides. The second most promising strategy was the addition of phytase to diets. Primarily, phytase reduces the need to supplement diets with inorganic phosphorus and thus reduces phosphorus excretion, but it also improves the availability of other nutrients and animal performance. The effectiveness of such measures, however, is not known and requires further research. However, according to our model, a 10% reduction in dietary protein concentration, combined with a 5% improvement of protein retention, feed efficiency and reproductive efficiency, reduced nitrogen excretion to 93% of 1990 levels. The same strategies would result in about 25-30% decrease in phosphorus excretion.

1.2 Poultry

As with pigs, reduction of dietary protein contents is the most effective strategy to reduce nitrogen excretion by poultry. It appears that it is possible to implement a minor (10 to 15%) reduction in dietary protein contents immediately. Further reductions, however, require research into amino acid requirements, possibly combined with the adoption of the concepts of digestible amino acids and of ideal protein. Other means of reducing nitrogen excretion by poultry are less effective, so that successful reduction of nitrogen excretion will necessitate a combination of mitigation strategies. A combination scenario, which was found to be effective in reducing nitrogen excretion, was a reduction of dietary protein contents by 10%, combined with an improvement of feed efficiency by 5% and the addition of phytase and non-starch polysaccharide digesting enzymes to poultry diets. These changes are all within the scope afforded by poultry production and could be adopted immediately. Full adoption of these strategies would reduce the nitrogen excretion by poultry in 2010 to 96% of the 1990 values. Methane emissions would increase to 106% of the 1990 values. Adoption of these strategies would be encouraged by high prices for dietary protein, e.g. soy bean meal, compared to free amino acids, and low prices for fat (to increase dietary energy content) and enzymes.

Daily poultry methane emissions were assumed to equal 0.0071 g per kg body weight. It was therefore estimated that a total of 448 tonnes of methane were emitted by Canadian poultry in 1990. The C.E.E.M.A. model assumes that there are no direct methane emissions from poultry. Methane emissions and nitrogen excretions were projected to increase by 25 and 30%, respectively, from 1990 to 2010.

Methane production by poultry has received little attention so it is difficult to recommend specific mitigation practices. It appears that a reduction of non-starch polysaccharides is a viable approach, although definitive data are not available. It is expected that most methods to reduce nitrogen excretion will also have a minor effect on methane production, but again there are no data available.

1.3 Cattle

For Alberta cattle, nitrogen excretion has been estimated to be 18,380 and 23,065 and 25,767 tonnes in 1990, 1996 and 2008-12, respectively. And phosphorus excretion for Alberta cattle has been estimated at 9,190, 11,532 and 12,883 tonnes per year for 1990, 1996 and 2008-12, respectively. Nitrogen and phosphorus excretions were reduced in conjunction with many of the methane mitigation strategies considered. However, the main mitigation strategy of reducing dietary protein content by 10% only reduced nitrogen excretion by an estimated 2%. This low level was because most beef cattle consume diets with a surplus of nitrogen, which do not contain any additional protein supplements. It thus would be very expensive to replace these feeds in the diet with feeds containing less protein. The combination of strategies, which were developed, changed projected nitrogen and phosphorus excretions in 2010 from 127% to 117% of 1990 levels.

Coefficients for methane emissions and nitrogen and phosphorus excretions per head of cattle were generally higher than those used in the current Canadian C.E.E.M.A. model. Dairy cattle were the exception, and lower coefficients were obtained (140 vs. 91 to 103 kg methane per cow per year). This meant that our estimated methane emission for cattle in 1990 was 18,397 thousand tonnes of carbon dioxide equivalents, which is 11% higher than the C.E.E.M.A. model estimates. Beef cattle were responsible for 70% of the emissions in 1990, with emissions from beef cows comprising 40% of the total. Methane emissions were projected to increase by 31% from 1990 to 2010, even though cattle numbers were projected to increase by 39%. Dairy cattle, which on a per animal basis emit the most methane, were projected to decrease in numbers by 2010, otherwise methane emissions would have been higher.

A variety of mitigation strategies were examined for cattle. The two most effective strategies for reducing methane emissions were a reduction in carcass fatness and an improvement in forage quality. Of these strategies, carcass fatness was close to ideal in 1990 thus it will be difficult to achieve further reductions in methane emissions by this route. However, currently there is a trend towards increased fat content in carcasses which will aggravate methane emission problems. The best combination of available mitigation strategies resulted in methane emissions which were 103% of 1990 levels. This combination of strategies included reducing the length of the backgrounding period, improving growth rate substantially, increasing the use of ionophores, improving genetics and reproductive technologies, replacing urea in ruminant diets with nitrates, and incorporating malate in diets. If effective ruminal methane inhibitors become available by 2010, methane emissions may be reduced to 62% of 1990 levels. A major problem with the incorporation of mitigation strategies into management systems for beef cattle is that most emissions come from beef cows and replacement animals that graze pasture in the summer and consume forage-based diets in the winter. This extensive production makes adoption of methane mitigation strategies very difficult.

1.4 Other Livestock

Sheep were calculated to produce 123,052 tonnes of carbon dioxide equivalent methane in 1990, which was lower than the 157,229 tonnes estimated by C.E.E.M.A. Emissions were only projected to increase marginally by the year 2010 because of improved reproductive efficiencies. Horses and goats emitted 134,645 and 10,500 tonnes of carbon dioxide equivalent methane in 1991. No information on bison or elk and deer populations was available in 1990, but these classes of livestock were estimated to emit 81,637 and 118,205 tonnes of carbon dioxide equivalent methane, respectively, in 1996.

1.5 Summary

In summary, it would be possible to decrease nitrogen and phosphorus excretions of swine and poultry in the year 2010 to 1990 levels through reductions in dietary protein content, increased use of synthetic amino acids, incorporation of enzymes in the diet, improving growth and reproductive efficiency. Methane emissions are quantitatively insignificant in these classes of animals. It will not, however, be possible to reduce methane emissions to 1990 levels in ruminant animals unless a specific inhibitor of methane is commercialized. Similarly, it is apparent that nitrogen and phosphorus excretions in 2010 will remain above 1990 levels because of the difficulties in adopting any of the proposed mitigation strategies under the extensive conditions of beef production.

2 Overview of Alberta Livestock Production Systems

2.1 Swine

Alberta's swine production is now largely based upon confinement feeding indoors. Methods of production are very similar across western Canada, since diets are based on barley, wheat and canola meal in the west.

2.2 Poultry

Alberta's poultry production is now entirely based upon confinement feeding indoors. Production is similar across western Canada, with the use of smaller cereal grains in the west.

2.3 Beef Cattle, Dairy Cattle, and Sheep

Feeding systems for breeding beef cattle and sheep are heavily forage-based in western Canada. A variety of forage is used for winter feeding. Cattle in the southern prairies are allowed to graze, often on native range, for all but 1 to 3 months of the year whereas cattle in northern regions are fed conserved forage for up to 7 months or more in the winter. Grass-alfalfa mixes are often used for hay, with brome being a very popular grass. The average forage contains about 2.6 Mcal/kg of digestible energy, with dry cows in the winter receiving poorer quality forage and lactating cows or calves receiving the better quality forage. Many producers use grass-legume or cereal silages as all or part of the winter diet. The majority of cows are fed at least some cereal straw during the winter, either indirectly when bedding is consumed, or deliberately. Grain (barley or oats) will be included in the diet when large amounts of straw are fed, particularly after calving in the spring. Most calves and lambs are born in winter (January through March) and spring. It is common to feed cereal grain to calving herds after calving in January through March, especially if poorer quality forages are being used. Protein supplements are not commonly fed to cows in the winter although operations that are attempting to maximize the use of low quality forages will often utilize 32% protein supplements. Cows will usually receive trace mineralized salt, some source of vitamin A, and often a phosphorus (P) or complete range mineral supplement in the winter.

In the summer essentially all beef cattle and sheep in Alberta are on pasture. Native range is common in southern Alberta. Cattle are often allotted to pastures containing some trees in the northern regions of all western provinces. Tame pastures containing predominately grasses (brome and fescue) are common, but with some alfalfa are widely used for pasture in regions with more productive climate and soils. Salt is always provided free choice in the summer and in addition P supplements may also be available.

In Alberta it is common to feed replacement cattle and sheep some grain during the time from weaning at approximately 7 months of age to 1 year of age. Again, salt, supplemental vitamin A and trace minerals are provided during this time. When they become yearlings, the replacement animals are usually on grass or are fed conserved forage and receive little grain or protein supplementation.

Growing and fattening of steers and heifers are often managed similar to replacement heifers during their first winter. The backgrounding period after weaning until spring, is often followed by some time on grass. The so-called "grasser" cattle are in high demand in the spring. The backgrounding period is variable in length, with cattle going into the feedlot at various times throughout the winter and spring or after grazing in the summer. Some calves can be in the feedlot for about 240 days with yearlings about 120 to 150 days. It has been estimated by Alberta livestock specialists that about 30 to 40% of calves go directly into the feedlot after weaning. In the feedlot, the proportion of grain in the diet is increased over time until it comprises 80 to 95% of the dietary dry matter. The rate at which forage is decreased and grain is increased in the diet depends upon the age and weight of the animal; younger and smaller animals usually receive a higher percentage forage in the diet to give them time to grow before they fatten whereas animals which are heavier and older are put on a full-grain feed within 2 to 3 weeks. Often cattle are shipped from neighbouring western provinces to Alberta for feedlot finishing. Feedlot rations usually contain a minimal amount of added protein supplements, along with vitamins, minerals and proteins. Generally, however, dietary protein concentrations are not as high as recommended by the National Research Council (NRC) (1996, 2001), and with older animals protein supplements are often included primarily as a means of mixing other supplemental nutrients with the diet. Almost all feedlot diets in western Canada are based upon barley grain, which is usually dry rolled or tempered rolled before feeding. However, in recent times, especially in the last two years, corn, both grain and silage, has been fed in southern Alberta. Cereal silage is commonly used as the roughage source. Use of ionophores is very extensive in western feedlots.

Systems for growing and finishing lambs in western Canada are comparable to those used in beef production systems.

Dairy farmers use their best forage for feeding lactating cows and use poorer quality forage for their dry cows and replacements. Growing calves will receive 25 to 50% of their diet as grain but the amount of grain is greatly reduced when dairy calves are older than 6 to 9 months. Lactating cows receive high quality forages, consisting of alfalfa-grass hay/silage. Cereal silage is also used. All lactating cows are fed grain mixtures containing barley. Canola meal is often used to meet at least part of the supplemental protein requirements of the cows. High amounts of grain can be fed; it is not uncommon for diets to contain 60% concentrates by dry weight. Excessive feeding of grain reduces butterfat levels in milk, thus care is taken to restrict its use and to include a good fiber source in the diet. If there is a decreased demand for milk fat it is probable that the proportion of grain included in the diet of lactating dairy cows would increase since the requirement for milk fat imposes some restrictions on feeding practices. The use of total mixed rations is increasing rapidly in dairy herds in western Canada and some extension specialists have suggested that this is the single best management practice that dairy farmers can use to increase production and profitability. There is little use of Rumensin in dairy diets at this time, but there is potential for use to increase.

3 Mitigation Strategies: A Literature Review

3.1 Swine

3.1.1 Nitrogen

Current practice in pig nutrition is to supply dietary protein to cover the animal's need for lysine, which is usually the limiting factor for protein deposition (Allee et al. 2001; CAST 2002). As there is a discrepancy between the amino acid composition of feed and the animal's requirements, other amino acids are supplied in excess of the requirement and cannot be fully utilised. Some 20 years ago, the concept of the ideal protein was introduced. An ideal protein supplies all amino acids exactly in the ratios needed by the animal's body. Consequently, if an ideal protein is fed to animals, all amino acids are utilised equally well, and the wastage of protein and N excretion are minimised.

According to the NRC recommendations (1998), a daily intake of 200 g of ideal protein could satisfy the requirement of growing pigs. Currently the protein intake of these animals is between 300 and 400 g/d. Similarly, the protein requirement of non-pregnant sows can be met by 3% balanced protein in the diet while common sow diets contain at least 12% protein. However, a reduction of dietary protein contents by 30 to 50%, although possible, is not practical as it necessitates the inclusion of free amino acids that are very expensive (e.g. isoleucine) to maintain animal performance.

Möhn and Susenbeth (1995) compared a diet with a 20% reduction in dietary protein contents using synthetic amino acid supplementation to diets formulated according to then current recommendations. Nitrogen excretion was reduced by about 35% in the low protein group. Protein retention was not affected by the reduction of protein intake at 60 kg live weight, but was lower at 85 kg live weight. Similarly, Tuitoek et al. (1997) found no effect of a 20% reduction in protein intake at 60 kg live weight, but observed a reduced daily gain at heavier body weights. It appears that pigs up to 60 kg live weight can be grown successfully on rations containing 20% less protein than recommended. For heavier pigs, a 10% reduction in dietary protein an be implemented immediately. To achieve greater reduction in dietary protein content using synthetic amino acids, further research is needed to identify the factor(s) limiting animal performance and to improve diet supplementation.

Other strategies advocated include multiphase and split gender feeding, good feeding management (fine grinding, pelleting, extrusion, micronization, removal of fiber and germ), genetic modification and special feed additives like phytase, growth promoting substances, and antibiotics, a proper calcium:P ratio of about 1.25:1, and raising lean pigs among others (CAST 2002; Alberta Pork and AAFRD 2002).

3.1.2 Phosphorus

The amount of P excreted in manure is influenced by the amount of P consumed and the digestibility of P in the diet. The NRC (1998) recommends that pigs should be fed for available P requirements. Such a recommendation is based on that fact that feeds vary in P availability (e.g. 50 vs 10 to 20% in wheat compared to corn. Using ingredients with higher digestibility and or bioavailability will help decrease P excretion (CAST 2002; Cromwell 1992). Cromwell et al. (1993, 1995, 2000) and CAST (2002) are among numerous scientists recommending supplementation of diets with microbial phytase to decrease P excretion by an estimated 20 to 30%. Other strategies to reduce P excretion are similar to those for reducing N excretion, as stated in the previous paragraph.

3.1.3 Salt

The recommended salt level in the diet for gestation sows and lactating sows is 0.4 and 0.5%, respectively, with the optimum being 0.13% sodium (Na) and 0.17% chlorine (Cl). However, pigs can tolerate 13% dietary NaCl if the water supply is adequate. Since most of the sodium in the diet is absorbed and there may be no limit to absorption capacity of the proximal colon, it is imperative to formulate diets that meet the requirements without any allowance for luxury consumption. For example, in Southern Alberta, levels of Na in water can be high enough to require special consideration in ration formulation.

3.1.4 Some of the more promising strategies to reduce N and P excretion in swine

Rate of live weight/lean gain (research versus commercial pigs)

Möhn and de Lange (1998) using purebred Yorkshire pigs observed a protein retention of 130 g/d and a daily gain of about 900 g/d. Quiniou et al. (1996) using improved genotypes reported protein deposition of up to 180 g/d and daily weight gains of over 1000 g/d. This is between 15 and 50% greater than the protein deposition observed on farms in 1997.

The main reasons for the greater animal performance in research versus on-farm production are superior diet formulation and better animal health status and management. For diet formulation, the key is to match nutrient intake to the animal's performance. This necessitates knowledge of both the observed and potential performance of the animals and close control of the nutrient supply. Phase feeding has been proposed as an adequate tool for shortening periods of both over- and underfeeding the animals. Although it is documented that acute disease severely affects animal performance (e.g. Ball and Bayley 1986), there is little information about the degree of growth impairment due to subclinical infections. A management strategy to improve animal health status is the all-in, all-out system that allows for a thorough cleaning of animal facilities, thus decreasing the pressure of infectious agents. This strategy also facilitates the phase feeding strategy. The downside is that implementation of these strategies would require modifications to building design and feeding systems.

A possibility to improve growth performance would be growing entire male pigs instead of castrated males. Entire male pigs have a lean growth potential about 15% greater than that of castrated males (de Lange 1997). To implement this strategy it is necessary to legalize the slaughter of entire male pigs. A drawback is the boar-taint of meat of entire male pigs, which can curb consumer acceptance. Methods to prevent, detect and reduce boar taint require further research and development.

Efficiency of feed utilization

Improving the efficiency of feed utilization is associated with an increase in animal performance. The strategies outlined above, improved animal health and management or boars instead of barrows, will have a direct effect on feed utilization. A further means is an increase in dietary energy concentration for pigs below approximately 50 kg body weight. Growth in these animals is usually limited by energy intake due to their limited digestive capacity. Larger animals of an improved genotype may profit from an increase in dietary energy content particularly if their growth potential is greater than their current voluntary feed intake. A further effect of increased dietary energy concentration is a reduction of methane production (Fuller and Boyne 1972). Conversely, it may be beneficial to restrict the feed intake of animals with a low genetic capacity for lean growth, as feed energy supplied in excess of the requirement to maximize lean growth can only be used to deposit fat, which is less efficient than lean deposition. The key to improved feed efficiency is to match the feeding regimen to the animal's performance (Cromwell et al. 1993, 1995, 2000; CAST 2002).

Reproductive efficiency

Given the current production system with 3 week weaning, a sow can have a maximum of 2.57 litters per year (114 d gestation, 21 d lactation, 7 d to new pregnancy). In practice, a well managed swine herd can only achieve an average of about 2.3 litters/sow/year due to animals' delayed returning to service (21 d) and other management considerations resulting in a longer lactation period. Therefore, the current practice only leaves room for a 10% improvement in farrowing frequency. The number of pigs born alive per litter is approximately 10, and has been slowly but steadily improving over the last 20 years. Although this number is expected to increase further, the increments are small.

The key issue for reproductive performance is the pigs marketed per sow and year. Comparing the pigs marketed per sow and year to reproductive performance in a good breeding facility (23 to 24 piglets born alive per year) indicates losses of animals during nursing and fattening. Methods to improve should concentrate on management and improving animal health status. Improved reproductive performance can either increase total production of pigs, or lead to a reduction of the breeding stock in relation to market pigs. Only in the latter case would it lead to a reduction of N and P excretions and greenhouse gas emissions.

Modifiers of digestion and/or metabolism

Phytase addition to feed renders cereal and oilseed phosphate available by cleaving ortho-phosphate groups from phytic acid. This reduces the need to supplement feed with inorganic phosphate and reduces P excretion by animals. Additional effects are an increased availability of other minerals (e.g. calcium and zinc) and an increased protein digestibility (for summary see NRC 1998; Alberta Pork and AAFRD 2002; CAST 2002). Frequently, there have been reports about increased growth rate, protein deposition and improved feed efficiency associated with the addition of phytase to feed. Various scientists including Pierce et al. (1997) and Ketaren et al. (1991) estimated that phytase addition improved growth and protein deposition by 15% while feed efficiency was improved by 10%. Phytase addition to feed appears one of the most promising mitigation practices, but may require measures to be implemented because it is not currently cost effective in Canada.

Addition of cellulases and hemicellulases may improve animal performance by degrading non-starch polysaccharides that may interfere with digestion of other nutrients like N and P (Li et al. 1995). This improvement does not necessarily occur (Thacker and Baas 1996), especially in diets based on corn and soybean meal (NRC 1998; Allee et al. 2001). A beneficial effect of the addition of these enzymes may be a reduction in methane production, which appears to be linearly related to the ingestion of non-starch polysaccharides (Jensen 1996). These enzymes and their potential benefits need further research, however, because there is insufficient information at the present time.

Metabolic modifiers that show promise are exogenous growth hormone administration and the use of ß-adrenergic agonists. Effects of growth hormone administration are increased daily gain, improved feed efficiency and increased carcass leanness (Campbell et al. 1988). The effect on these parameters may reach an improvement of up to 25% (Bos 1989). Apart from altering carcass composition towards greater protein content, ß-adrenergic agonists increase carcass weight relative to live weight and increase feed efficiency (Beermann and Hollis 1993). Feed efficiency may be improved by as much as 12%, while protein content in carcass can be increased by up to 10%, with a similar reduction in fat content. Although beneficial for animal performance, the use of these metabolic modifiers in pig production may curb consumer acceptance of pork and lead to export difficulties as these compounds are not currently legal in some areas (e.g. the E.U.). It should be noted that other countries (e.g. Australia, U.S.A. for ractopamine) are using these products.

Antibiotics are widely used in pig production to sustain optimal performance by suppression of microorganisms that cause adverse effects (NRC 1998). Dietary inclusion of antibiotics improved growth rate by 4 to 16% and feed efficiency by 2 to 7% (NRC 1998). The trend towards a ban of feed antibiotics in Europe may lead to a similar move in Canada, thus depriving the pig industry from an effective growth promoter. In that case, pig performance can be expected to suffer unless viable alternatives are developed.

3.2 Poultry

Compared to pig production, there is less scope to decrease N and P excretion and greenhouse gas emission from poultry production. The key management procedures for successful poultry production have long been established so that there is only a small margin to improve poultry production further. Indications are the almost constant egg production per hen and year between 1990 and 1996 (Statistics Canada 1991 1997) and the feed efficiency of broilers have hardly changed since 1977 (Agriculture

Canada 1991; Leeson and Summers 1997). The short generation interval of poultry allowed intensive breeding programs so that further genetic improvement is expected to be slow, especially as the focus of breeding tends to change (e.g. from growth rate as primary objective to a greater breast muscle percentage).

3.2.1 Protein

Compared to the recommendations of NRC (1994), Nahm and Carlson (1998) suggested that with the supplementation of synthetic amino acids the protein content in layer diets can be reduced by 12 to 15% during rearing, and by about 20% during laying. The same authors suggested that a 20% reduction in protein content in broiler diets was sufficient to support optimum performance. In turkeys, performance can be maintained at dietary protein contents of 15% below the recommendations of NRC (1984), if free lysine and methionine are added to the diets (Waibel et al. 1995). It appears that a reduction of dietary protein content of 10 to 15% below the current recommendations is possible without negative effects on performance if the diets are balanced by the addition of free amino acids. The costs and benefits of using synthetic amino acids relative to normal protein supplementations need to be calculated before they can be implemented.

To achieve greater reductions in dietary protein content, however, a different approach is needed. A possibility would be to formulate diets on the basis of digestible amino acids and adopt the concept of ideal protein. Although diet formulation on the basis of true digestible amino acids has been successful (e.g. Rostagno et al. 1995), the applicability of this concept to poultry nutrition is still under debate (Moughan and Donkoh 1991). Nixey (1994) proposed the adoption of diet formulation on an available amino acid and ideal protein basis to minimize N excretion by turkeys, but cautioned that the amino acid pattern of the ideal protein changed with the age of the birds. To fully assess these concepts, further research is needed.

3.2.2 Phosphorus

Poultry lack sufficient intestinal enzyme (phytase) to release P from phytate and thus the most applicable P reduction technique has been to increase P bioavailability through the use of microbial phytase and the decrease in inorganic P in poultry diets (CAST 2002). Other strategies include feeding close to P requirements, minimizing safety margins, using phase-feeding, improving gender and strain, and feeding vitamin D3 metabolites (Boling et al. 2000; Biehl et al. 1998; CAST 2002).

3.2.3 Some of the more promising schemes to reduce N and P excretion in poultry

Rate of live weight/lean gain and egg production

There is little discrepancy between the observed growth performance at research stations and the growth performance of broilers and turkeys at the best production units. It is possible, however, to improve the performance of broilers and turkeys on less well managed farms. Strategies to achieve this should concentrate on management procedures, such as improving the quality of drinking water and air as well as lowering the effects of infectious agents on birds.

Similarly, an improvement in layer performance will be difficult to achieve. When the theoretical maximum egg production of 310 eggs/hen per year is compared to the current (2001) observed performance of 268 eggs/hen and year (Statistics Canada 2000), the margin for improvement is only 14%. Furthermore, considering that hens do not exceed an egg production rate of 80% for about a third of their productive life (Leeson and Summers 1997), this reduces the margin for improvement to less than 4%.

Efficiency of feed utilization

It is possible to improve feed efficiency by increasing dietary energy concentration. Leeson and Summers (1997) estimated that a 20% increase in dietary energy content results in a 10% improvement in feed efficiency. The adoption of this strategy, however, is dependent on the cost of the additional dietary energy versus the savings from overall feed use. Additionally, an increase in dietary energy concentration may decrease the methane production by poultry, analogous to the effect seen in pigs.

A second possibility is a short-time feed intake restriction during the early growth, e.g. day 6 to 11 (Zubair and Leeson 1994), resulting in compensatory growth later on, and a 10% improvement in feed efficiency. A similar effect can be obtained by modifying the light-dark cycle (Leeson and Summers 1997).

Reproductive efficiency

The reproductive efficiency of birds is a minor issue for N and P and greenhouse gas production. Breeding birds produce about 110 viable eggs per year so they contribute only about 1% to the greenhouse gas production of poultry. Although desirable, a decrease of N and P excretion and methane emission from breeding birds would have only a minor impact on the overall emissions.

Modifiers of digestion and/or metabolism

The addition of non-starch polysaccharide (NSP) digesting enzymes can improve both the digestibility of NSP itself, as well that of other nutrients by decreasing the viscosity of the digesta. The addition of ß-glucanase to barley-based diets may improve daily gain up to 25%, together with an improvement of feed efficiency of about 8% (Hesselman et al. 1982; Biehl et al. 1998). In wheat-based diets, the addition of xylanase and arabinoxylanase has been shown to be effective (Steenfeldt et al. 1998). In the prairie region, the addition of these enzymes to poultry diets is already widely practised (Leeson and Summers 1997). If the methane production of birds follows the same principle as that of pigs, it can be expected that addition of NSP-digesting enzymes to diets will also lead to a reduction in methane emissions.

The effect of phytase addition to poultry diets is primarily an increase of phosphorus availability thereby reducing the need to supplement diets with inorganic phosphate and reducing phosphorus excretions. Phytase frequently has no effect on broiler growth rate, but may improve feed efficiency (Kies et al. 1997).

Treatment of broiler chickens or turkeys with growth hormone alone does not affect growth rate or feed efficiency (Cogburn 1991; Bacon et al. 1995). Treatment of broilers with triiodothyronine increases lean gain, reduces fat deposition and acts synergistically with growth hormone (Cogburn 1991). The supplementation of broiler diets with clenbuterol (ß-adrenergic agonist) may increase carcass protein gain by as much as 10 to 15% (Rehfeldt et al. 1997). Hamano et al. (1994), however, found no effect of clenbuterol on live weight gain in broilers fed adequate protein, but reported a significant increase in feed efficiency regardless of protein intake. At present, the administration of metabolic modifiers does not appear to be a viable option considering the difficulties in application (growth hormone), inconsistency of effectiveness (clenbuterol) and the lack of legalization for legal use in Canada.

Antibiotics including ionophores are widely used in poultry production to sustain optimal performance by suppression of microorganisms that cause adverse effects (NRC 1994). The trend towards a ban of feed antibiotics in Europe may lead to a similar move in Canada, thus depriving the poultry industry of an effective growth promoter. In that case, poultry performance can be expected to suffer unless viable alternatives are developed.

3.3 Ruminants

3.3.1 Protein

A portion of the N excreted from animals ultimately contributes to atmospheric nitrous oxide. As an example, Varel et al. (1999) point out that up to 75% of the N from feedlots can be lost to the atmosphere. In the process, the N:P ratio in fresh manure falls from 5:1, which is close to that required by plants, to a ratio of 1:1 in older manure. Agriculture and Agri-Food Canada (1999) in the Canadian Economic and Emissions Model for Agriculture (CEEMA) use a coefficient of 2% for the N excretion of a grazing animal, which ends up as nitrous oxide. Coefficients for anaerobic lagoons, liquid manure storage, solid manure storage and other manure storage are 0.1, 0.1, 2, and 0.5% respectively. It is therefore obvious that one way to reduce nitrous oxide emissions related to livestock is to reduce N excretion.

Excess nitrogen in ruminant diets

Requirements used by nutritionists for diet formulation in North America are based upon the Nutrient Requirements of Domestic Animals series which are minimum requirement figures and do not include a margin of safety. Nutritionists, livestock producers, and in particular feed companies are loath to underfeed nutrients and thus often include a safety margin when diets are formulated. According to Cheeke (1991) in a book on applied animal nutrition, "Many nutritionists use their judgement to provide a margin of safety by increasing the figures by 5 or 10 percent or more." Therefore Van Horn et al. (1996) made an excellent point when they claim that "eliminating dietary excesses where they exist is the easiest way to reduce on-farm nutrient surpluses." Examples are given below where nutrient intakes and hence excretions have been reduced by more judicious diet formulation for ruminant animals.

Janzen et al. (1994) calculated the efficiency of N retention in body tissue and milk when diets containing 50% cereal (barley) silage or alfalfa were fed to lactating cows. Efficiencies averaged 23% when silage was fed compared with the 28% when cereal silage was fed. The extra N in the diet was equivalent to 0.15 kg of N/day or 54 kg/year which could be saved if the cereal silage rather than alfalfa was used.

Stone et al. (1992; cited by Fox et al. 1995) reported that when the Cornell Net Carbohydrate and Protein System computer model (forerunner of NRC 1996) was used to balance a diet for 280 lactating cows producing an average of 11,800 kg milk yearly, there was a reduction in N excretion of 25% and a yearly saving of $74,600 (US) without any adverse effect on milk production. In another example, Van Horne (1994) calculated that N excretion could be reduced by 15% by balancing for ruminally degradable and undegradable protein rather than simply crude protein.

Examples of dietary nutrient excesses are also well documented for other nutrients. Van Horn et al. (1996) concluded that it is common for dairy producers to over-feed phosphorus. They summarized reports in which P intakes were 35 to 40% above requirements for dairy herds and P excretions were three times higher than they would have been if P had been provided at the required level. Morse (1992) was able to reduce the dietary intake of P and hence the amount excreted without changing the amount retained by the animal. Although such studies tend to show that nutrients are over-fed, it must be remembered that the concentration of P in grains is often considerably higher than the animal requires thus some over-feeding is to be expected when high-grain diets are fed.

In summary, there is ample information to suggest that some diets could have the protein content (hence N content) reduced by 20% without any adverse effect on performance. However the N content of many diets will not be able to be reduced because many feeds contain more N than the animal requires and the cost of the diet would rise considerably if these feed ingredients were constrained. More conservative diet formulation could reduce N intakes by an average of 10% for dairy cows but since relatively little protein supplementation is used for beef animals, savings in the order of only 3 to 5% could be achieved through the use of more judicious diet formulation.

Improving the balance of amino acids to the ruminant animal

For many years a crude protein system was used to formulate diets for ruminant animals (Santos et al. 1998). This was because rumen microbial synthesis was capable of supplying all of the protein required by animals at a low production level (e.g. in dairy cows producing up to 4500 kg of milk per lactation). Animal productivity levels are now higher, thus dairy cows or very rapidly growing young calves or lambs require a source of protein in addition to the microbial protein supplied from rumen fermentation. This additional protein is diet protein that escapes rumen fermentation and is available for digestion in the small intestine. Protein systems which considered not only the supply of N to the rumen microorganisms but also the protein supply to the intestine became available in the 1970's and have gradually increased in use until the present time. However, since 1990 nutritionists have become increasingly aware that systems which only differentiate protein into ruminally degradable protein and ruminally undegradable protein are of limited use since what is really important is the supply of amino acids at the level of the small intestine. Considerable advances in terms of improved diet formulation are therefore to be expected over the next few years as more attention is paid to the amino acid nutrition of ruminant animals.

Santos et al. (1998), after a survey of the literature, concluded that in spite of expectations, benefits were not consistently observed when soybean meal was replaced in diets by protein supplements which provided more ruminally undegradable protein. However, positive responses to an increase in provision of ruminally undegraded protein were generally obtained with fishmeal, which has amino acids present in almost ideal concentrations. In other cases, such as with corn gluten meal, milk yields were actually depressed when more ruminally undegraded protein was given. The authors suggested that the substitution of protein supplements to increase ruminally undegraded protein may have had the effect of reducing ruminally degraded protein thus causing reduced microbial protein synthesis in the rumen. Further, they recommended that consideration should be given to the amino acids lysine and methionine, which they considered to be the two most limiting amino acids in diets for lactating cows.

Responses in milk production have been observed in situations where a blend of protein supplements has been used to provide a better balance of amino acids to the small intestine. Ferguson et al. (1994) found that 95% of 7000 cows responded to this type of supplementation in early lactation, with responses being obtained in 26 of 35 herds.

Oldham (1993) has recognized the need for balancing ruminant diets on the basis of amino acid requirements. He has suggested that lysine and methionine were limiting in many ruminant diets but that phenylalanine, tryptophan and histidine may also be first-limiting in some circumstances. In studies of Schwab et al. (1992a,b) lysine was the first-limiting amino acid and methionine the second.

Information from Rode and Kung (1996) in Table 1 can be used to give some idea of the reductions in N excretions that can be achieved if individual amino acids are used to meet requirements rather than if the amino acids are provided by using a protein which escapes rumen fermentation. According to information in this table, if 20 g of lysine was deficient in the diet of a lactating cow, this amount of lysine could be provided by 20 g lysine, 2520 g canola meal, 13,800 g alfalfa, or 3840 g of corn gluten meal. These amounts of feeds would provide 3.8, 169, 397, and 430 g N, respectively. Therefore in some cases over 100 times more N must be supplied than the animal actually requires if feeds, rather than individual amino acids, are used to meet amino acid deficiencies. Excessive protein intakes in such circumstances, not only will result in increased N excretion, but also can increase uterine protein content and adversely affect sperm viability and embryo development (Ambrose 1999; NRC 2001; Fox et al. 2000).

Unfortunately, ruminant animals cannot simply be fed amino acids or the majority will be degraded in the rumen and never reach the small intestine. However ruminally protected amino acids have been developed which resist ruminal fermentation. Examples of ruminally protected amino acids include SmartamineJ M (70% methionine) and SmartamineJ ML (15% methionine and 50% lysine) produced by Rhone-Poulenc, and Mepron7 M85 which provides methionine and is supplied by Degussa Corporation (Rode and Kung 1996). At this time, however, such products are not widely used in the feed industry because of inconsistency of responses and cost.

Table 1. Intake of feed source (g/day) required to supply one gram of methionine or lysine to the small intestine

Source: adapted from Rode and Kung 1996

Feed	Protein (%)	Ruminally undegraded protein (%)	Methionine		Lysine	
			Intake to supply 1 g (g)	Nitrogen in feed (g)	Intake to supply 1 g (g)	Nitrogen in feed (g)
Pure amino acid			1	0.094	1	0.19
Alfalfa hay	18	4.5	1821	52.4	690	19.9
Corn grain	10	6.0	1482	23.7	1010	16.2
Barley grain	13	2.6	4807	100.0	1282	26.7
Soybean meal	55	19.3	649	57.1	86	7.6
Canola meal	42	11.7	607	40.8	126	8.5
Corn gluten meal	70	42.0	113	12.7	192	21.5
Blood meal	96	67.2	139	21.4	16	2.5
Fish meal	68	47.6	75	8.2	29	3.2

In summary, there is ample evidence to indicate that nitrogen intakes could be reduced by 20% or more in many diets if diets were balanced precisely on the basis of amino acid requirements rather than on the basis of crude protein or ruminally available protein. However it must be pointed out again that there are many instances (e.g. animals grazing pasture) in which available feeds contain a surplus of nitrogen and it would not make economic sense to reduce these feeds in the animal's diet.

3.3.2 Phosphorus

Phosphorus is the most prevalent mineral deficiency in the world in grazing animals (McDowell 1992). A P deficiency results in animals chewing on rocks and bones, stiffness, fragile bones, appetite depression, lethargy, unthriftiness, reduced growth rate, decreased feed efficiency, impaired reproduction, and decreased milk production (NRC 1985, 1989, 1996; McDowell 1992). Diet digestibility is also reduced when P is deficient (Fishwick et al. 1977) since P is required for normal microbial growth and fiber digestion.

Growing animals

Estimated dietary requirements for young growing calves have ranged from 0.22 to 0.31% (Wise et al. 1958; Teh et al. 1982), with Jackson et al. (1988) indicating that a diet that contained 0.26% P was inadequate for 70 kg calves. The dairy NRC (1989) recommends a minimum 0.31% P in the diet of a young growing animal, decreasing to 0.23% when the animal is over 1 year of age. Requirements for growing beef cattle for 200 kg calves can range from 0.23 to 0.5% depending upon diet and growth rates (NRC 1996). Growing sheep require from 0.16 to 0.38% P in the diet (NRC 1985).

The economics of P supplementation was examined in a review by Mathison (1986). In experiments where P in the control diet provided no more than 70% of requirements, an extra 0.044 kg gain was associated with each 1 g of supplemental P provided (i.e. 1 pound of extra gain was associated with the provision of an additional 10 g of P). Since 10 g of P now is worth about 2.5 cents it is clear that it does not pay to skimp on P supplementation. Mathison (1986) also determined that when P deficiencies were corrected, feed intake increased by 0.07 to 0.15 kg per g of P provided and feed efficiency was improved by 0.005 kg gain per kg of feed (i.e. in the order of 5% with forage-based diets) for each g of P supplemented. Because of improvements in digestibility and efficiency of utilization, liveweight gains can be increased by supplemental P even when feed intake is kept constant (Garner et al. 1982).

Reproduction

Phosphorus is required for normal reproduction, thus deficiencies can substantially reduce fertility (Dunn and Moss 1992). Severe P deficiencies result in anestrus, with moderate deficiencies resulting in silent and irregular estrus periods and infertility (Hignett 1950; Hignett and Hignett 1952). Hignett and Hignett (1951) noted improved fertility on farms where P was supplemented, in a survey of 50 farms. Theiler et al. (1928) reported that P supplementation increased the calf crop from 51 to 80%. Black and Tash (1943) increased the percentage calf crop from 64 to 85% in southern Texas with P supplementation. Black et al. (1949) noted large responses in calving percentage due to P supplementation.

Call et al. (1986) fed 48 heifers individually variable amounts of P from weaning through their eighth gestation. Phosphorus deficiency symptoms appeared within 6 months when a deficient diet was fed with symptoms including general unthriftiness, weight loss, reduced feed consumption, reluctance to move, abnormal stance, spontaneous bone fractures and finally impaired reproductive performance.

McDowell (1992) obtained increased reproductive performance in 17 different experiments in Latin America with the mean percentage calf crop increasing from 53% to 76% when supplemental P was provided.

Small et al. (1997) reported that, although serum phosphorus concentrations at time of breeding and 21 days after breeding were generally hyperphosphatemic in relation to known levels of adequacy, serum phosphorus concentrations were higher in heifers and cows which conceived than in those which did not.

Fishwick and Hemingway (1989), on the basis of plasma inorganic phosphorus concentrations concluded that 10 g of phosphorus daily is adequate for cows during the last 19 weeks of pregnancy. This is equivalent to the earlier estimate of 10 g by Preston (1977). Call et al. (1986) indicated that 12 g of phosphorus daily is adequate for 450 kg beef cows over the entire year. NRC (1985, 1989) requirements for phosphorus in the diet of pregnant sheep and dairy cows are 0.18-0.22% and 0.24%, respectively. Calculations from NRC (1996) for beef suggest requirements for pregnancy are in the range of 0.17 to 0.2%.

Lactation

Many reports demonstrate increased milk production in lactating beef cows and hence greater calf weaning weights when supplemental P is provided (Preston 1977). Preston (1977) also presented data showing that P supplementation improved lamb crop and weaning weight when supplemental P was provided to ewes. Fishwick and Hemingway (1989) indicated that lactating beef cows require 12 g of phosphorus daily in the first 6 weeks of lactation. The NRC (1989) dairy bulletin indicated that 1.83 g of phosphorus are required for each 1 kg of 3.5% fat corrected milk produced whereas a 1.4 g/kg figure is used in the beef NRC (1996). Dietary requirements for milking ewes and dairy cows range from 0.26 to 0.29% and 0.28 to 0.48%, respectively (NRC 1985, 1989). A 650 kg beef cow producing 10 kg of milk and consuming 13 kg of dry matter requires 0.24% P in the diet (NRC 1996).

a. Formulate Diets with Lower Phosphorus Concentrations

Although P deficiencies adversely affect the productivity of ruminant livestock, responses to supplementation will not occur unless P is deficient. Thus Blake et al. (1977), Noller et al. (1977), Carstairs et al. (1980), and Holroyd et al. (1983) did not find any reproductive response when supplemental P was provided. There is evidence that responses to P supplementation may not occur even when P intakes are less than current NRC requirements.

Dairy requirements in particular may be overestimated. Although the dairy NRC (1989) uses a value of 50% for the expected true absorption of P, the beef NRC (1996) uses a 68% absorption. Therefore for lactating dairy cattle the requirements of P in the diet would be reduced from the current 0.28 to 0.48% down to 0.20 to 0.35% if the beef value for the true availability of P was used instead of the dairy NRC value. Even this correction may be too conservative, however. In a recent study Martz et al. (1999) measured true digestibilities of corn silage in nonlactating cows between 80 and 94%. These values were similar to the 84% measured previously in lactating cows (Martz et al. 1990). Minson (1990) believed that the true availability of P in forages is between 65 and 100%.

There is supporting experimental data also indicating that current NRC (1989) P requirements for lactating cows are too high. Valk and Šebek (1999) concluded that diets containing 0.28% P were adequate for cows producing 9000 kg milk per lactation but that 0.24% P was not adequate. Experiments of Call et al. (1987), Brodison et al. (1989), and Brintrup et al. (1993) all confirmed that 0.33% or lower dietary P is adequate for dairy cows producing between 5000 and 7500 kg milk per lactation. Thus there is little question that P intakes can be reduced below current NRC (1989) requirement levels without adversely effecting production.

There are experiments with beef cattle that suggest that 450 kg beef cows can do well on diets that provide 10 to 12 g of P daily throughout the entire year (Preston 1977; Call et al. 1986; Fishwick and Hemingway 1989). This amount is considerably lower than the required yearly intake estimated from NRC (1996).

There are also indications that P requirements as given in the NRC (1996) are too high for feedlot animals. Erickson et al. (1999) determined that the P requirement of yearling steers (385 kg initial weight) was 0.14% or less when corn-based diets were fed, which is considerably higher than the current NRC (1996) estimate that suggests initial requirements are in the range of 0.26%, dropping to 0.22% as the animal fattens.

On the basis of the discussion, it is clear that current NRC requirements overestimate animal needs for P. At the very least the information indicates that there is no need for safety margins when formulating diets for most animals. In the case of lactating dairy cows intakes can be reduced below requirements without adversely affecting animal performance.

b. Correct Other Nutrient Deficiencies

Animals will not respond to supplemental nutrients if another nutrient is more limiting in the diet. In most cases where a P deficiency exists there are other deficiencies as well. Teleni et al. (1977) stated that reproduction difficulties may be more related to protein deficiencies than P deficiencies. In a similar vein Gartner et al. (1982) concluded that there is no evidence of impaired reproduction due to a P deficiency in a forage diet that is not accompanied by a general state of undernutrition or by a deficiency of energy, protein or some other nutrient.

c. Analyze Feeds for Phosphorus

The phosphorus content in feeds is quite variable. As an example, one third of barley grain, alfalfa hay, brome hay, Russian wildrye, barley greenfeed, and barley straw samples in Alberta would be expected to have P concentrations which deviate more than 13, 22, 35, 54, 26, and 50%, respectively, from mean values for the feed (Alberta Agriculture 1981). This means that diets cannot be adequately formulated without testing feed. Economically, feed testing pays since P is the most expensive mineral to supplement. For example, at the current cost of 0.25 cents per gram of supplemental P, the cost of one feed analysis would be covered in 100 days for 20 animals if 5 g of supplemental P were saved per head daily.

d. Feed Supplements with High Phosphorus Availability

Phosphorus supplements should be highly bioavailable to reduce the need for supplemental phosphorus in the diet and hence its excretion. Although variation in biological availability should be of no direct concern to livestock producers, it will be to reputable feed companies who will want to use high quality ingredients in the manufacture of supplements. Data in the dairy NRC (1989) indicate that the order of decreasing availability of phosphorus in supplements is sodium phosphate, phosphoric acid, monocalcium phosphate, dicalcium phosphate, defluorinated phosphate, bone meal and soft phosphates. The beef NRC (1996) suggests that defluorinated phosphate and monoammonium phosphate are equal in availability to dicalcium phosphate.

According to NRC (1989, 1996), phytate phosphorus in grains and oilseeds has a similar availability as inorganic phosphorus in ruminant animals. Tamminga (1996) indicated that although up to 85% of the phosphorus in forages may be present as phytic acid, phosphorus in this form is completely hydrolyzed in the rumen.

e. Maximize Animal Productivity within Constraints of Optimizing Profitability

Cattle and sheep require phosphorus just to maintain themselves. Thus if levels of production are increased, the amount of phosphorus required to produce each kilogram of gain and milk is decreased because maintenance costs are spread out over more units of production It should be noted, however, that improvements in efficiency of utilization of phosphorus decrease at higher levels of productivity. Van Bruchem et al. (1999) believed that the limits have been reached in improving efficiency of phosphorus utilization through improvements in productivity in the Netherlands and that other avenues to improve efficiency of phosphorus use must be examined.

f. Allow Animals to Become Deficient for a Short Time in Their Production Cycle

A deficiency of phosphorus can be corrected relatively quickly. Thus, although phosphorus and growth were depressed, feeding a phosphorus-deficient ration 2 months prior to breeding did not affect fertility of heifers in an experiment of Littlejohn and Lewis (1960). O'Moore (1952) reported that herds with a history of infertility were always associated with pastures that had less than 0.15% phosphorus; on such pastures a combination of phosphorus and protein supplementation resulted in animals coming into estrus within 10-35 days. The NRC (1974) indicated that it would be acceptable to lower phosphorus intake by 10% for short-term intervals.

It has been indicated that phosphorus deficiencies appear "rather quickly" and that they will appear before a calcium deficiency (NRC 1989). However "rather quickly" needs to be more closely defined. Call et al. (1986) noted reductions in feed intake and milk yield between 6 and 14 weeks after the start of lactation when deficient diets containing 0.24% phosphorus were fed to dairy cows. In contrast, for cows placed on trial in the 17th week of lactation, Valk and Šebek (1999) didn't observe any adverse effects on feed intake or milk production until the completion of the lactation (37 weeks), although feed intake was adversely affected in the subsequent dry and lactation periods. Underwood (1981) and Ternouth (1990) both indicated that a reduction in feed intake is a longer-term response to a phosphorus deficiency. Gartner et al. (1982) noted that decreases in feed intake occurred in as little as 3 weeks in young phosphorus-deficient animals, but in older animals as long as 22 weeks was required for differences in feed intake to appear.

Call et al. (1986) noted that bones provide a store of phosphorus which supplies body needs until there is serious skeletal depletion of phosphorus; thus reproduction in cows was not impaired until cows were fed a very low phosphorus diet for more than 1 year. Similarly, Valk and Šebek (1999) didn't observe any adverse effect of a phosphorus deficiency on reproduction in their dairy cows. They suggested that fertility would be maintained even with inadequate phosphorus intakes with respect to feed intake and milk production.

It must, however, be noted that if feed intake and digestibility are reduced in phosphorus-deficient animals, performance will suffer if the shortage persists for too long. It is therefore advisable not to allow any marginal phosphorus deficiency to exist for more than a few weeks in young growing animals whereas a deficiency in older animals may last several months. There are, however, critical time periods when phosphorus intakes must be adequate. It is not too serious if the diet of a beef cow contains inadequate phosphorus in the middle of pregnancy but it is necessary to feed phosphorus at requirement levels towards the end of pregnancy to ensure ease of calving as well as subsequent fertility and milk production.

g. Eliminate Free-Choice Feeding Wherever Possible

Free-choice feeding results in variable intakes

Voluntary consumption of mineral mixes provided on a free-choice basis is influenced by factors such as soil fertility, forage quality, season, water, and palatability of mineral mixture (McDowell 1996). Large variations in phosphorus intake exist between individual animals even when animals are fed and managed similarly. There is abundant evidence that ruminant animals do not voluntarily consume the correct amount of phosphorus in their diet. Both over- and under-consumption can occur. McDowell (1996) points out that many researchers (e.g. Gordon et al. 1954; Arnold 1964; Coppock et al. 1972; Coppock et al. 1976; Muller et al. 1977) have provided evidence supporting the concept that cattle have little, or at least not a very specific, appetite for calcium or phosphorus.

Gordon et al. (1954) found that cattle or sheep failed to consume enough phosphorus-containing supplement to correct a deficiency. A similar conclusion was reached for lactating dairy cows by Coppock et al. (1972; 1976).

Tait et al. (1992) reported that, although 350 kg cattle consumed an averaged of 135 g of a mineral-salt mixture daily on a uniform small pasture, mean intakes for steers over the period ranged from 36 to 175 g daily. The variation on any one day was higher, and ranged from 4 to 240 g. A full one-third of the animals consumed either less than 72 or more than 182 g per day.

Rode et al. (1994) evaluated intake of a commercial salt/mineral mixture (12.5% Ca, 12.5% P and 20% NaCl) in small, highly productive pastures. Over two entire grazing seasons, intakes averaged 115 g daily. However intakes varied from about 60 g daily to over 350 g daily within 20-day intervals when there were 15 to 35 heifers in each of two groups. Variation between individual animals would have been much higher.

Range cows and calves received supplemental phosphorus in a salt mixture ad libitum from June to October over three grazing years in the Northern Great Plains in a study reported by Karn (1997). Mean overall supplemental phosphorus intake was 4.0, 2.6, and 0.6 g per day in 1978, 1979 and 1980. Supplemental intake was only roughly inversely proportional (r=-0.57) to phosphorus concentrations in the plants as determined from extrusa phosphorus concentrations. Supplemental phosphorus had no influence on weight gain.

From the above results it must be concluded that the relatively common practice of providing phosphorus supplements on a free-choice basis cannot be recommended in most circumstances. The only time when free-choice feeding is warranted is under grazing situations where provision by other feeding methods is often impractical. It is rather fortunate that any surplus phosphorus consumed by grazing animals does not normally result in environmental problems since manure from grazing animals is well spread out, and our soils are normally phosphorus deficient.

Alternative to free-choice phosphorus feeding

If animals require phosphorus, it should be provided by controlled feeding if at all possible. The method of choice is to mix it with the complete diet. Alternatively, phosphorus supplements can be added to grain mixtures. There is inadequate information to evaluate the effectiveness of providing phosphorus supplements to ruminants less frequently than the recommended practice of at least once daily. However, we do know that there is tremendous variation in intake of free-choice mineral mixes on a day-to-day basis. Provision of controlled amounts of phosphorus supplements in grain mixtures once or twice weekly could not be a worse alternative than allowing free-choice consumption.

More attention should be paid to using water as a vehicle for supplementing phosphorus and other nutrients. McDowell (1992) summarized experimental results reported by researchers at the King Ranch in Texas in which adding phosphorus to drinking water (approximately 1 g/5 L) improved the pounds of calf weaned per acre by 53% above non-supplemented controls and by 23% above animals that received supplemental bonemeal on a free-choice basis. Soluble products such as Na_2HPO_4 and ammonium polyphosphate are, however, more expensive than the calcium phosphates which can be fed free-choice. Of course provision of phosphorus in drinking water will only work if there is no other supply of water.

h. Feasibility of Reducing Phosphorus Excretions

Dairy

Phosphorus excretions can be reduced markedly when necessary. Thus van Bruchem et al. (1999) reported that the dairy sector in the Netherlands reduced phosphorus excretion by some 30% between 1984 and 1996. They suggested that this progress has been achieved through in-depth, disciplinary research programs. However to meet requirements in their national legislation by the year 2008, efficiencies of phosphorus use at the whole farm level must increase from about 30 to about 50% for phosphorus. Whole farm nutrient balances (Van Horn et al. 1996; Kuipers and Mandersloot 1999; van Bruchem et al. 1999) are helpful in achieving such reductions.

The most obvious approach to reducing excretion is to reduce intake. Thus Morse et al. (1992) demonstrated that reductions of phosphorus intake from 147 to 108 and 70% of daily NRC recommendations resulted in corresponding reductions in phosphorus excretion. Tamminga (1996) also suggested that the best approach to reducing phosphorus excretion is to reduce the phosphorus input in the concentrate part of the diet.

Consideration should also be given to the other factors discussed above. Novel approaches can be tried. Driedger and Loerch (1999) suggested limit-feeding grain to dry cows as an alternative to feeding hay for the purpose of reducing nutrient excretions. Such an approach would not be useful, however, since grain contains much more phosphorus than the cow requires. Tamminga (1996) noted that up to 1.5 kg of phosphorus may be able to be mobilized from body stores in early lactation, which is the amount excreted in 150 kg of milk.

Beef and Sheep

The approaches to reducing phosphorus intakes and excretions outlined above are all applicable for beef and sheep farms. When animals are fed mainly forage-based diets, modifications to free-choice supplementation programs will probably yield the most reduction in phosphorus excretion. However, as pointed out above, over-supplementation under grazing conditions is not normally an environmental problem.

Feedlot production deserves special mention because of the quantities of manure produced and because of the difficulties that will be faced in reducing phosphorus excretion. Feedlot animals require a low concentration of phosphorus in the diet but grains contain relatively high concentrations of phosphorus. Even in the early part of the feeding period for young calves, the concentration of phosphorus required in the diet will normally be less than 0.35%. Since average Alberta barley contains 0.35 to 0.37% phosphorus (Suleiman 1995), in almost all circumstances there will be little need for supplementation except with young calves. In fact, data presented by Erickson et al. (1999) in which the phosphorus requirement for yearling steers was found to be less than 0.14%, demonstrate that phosphorus in normal diets containing in excess of 80% grain on a dry matter basis will provide more than two times the phosphorus requirements of the animal even without supplementation. Because older cattle do not exhibit deficiencies for some time, and because phosphorus requirements decrease to very low levels by the time the animal has been in the feedlot for a few months, little supplemental phosphorus should be used in feedlot. The appropriate recommendation is that no supplemental phosphorus should be provided to most feedlot cattle except during the first month when supplements may be necessary to alleviate any deficiency in incoming cattle. Supplemental phosphorus may also be required for very young animals or when high-forage diets are fed on a long-term basis.

Conclusions

In conclusion, mainly reducing the use of supplemental phosphorus can substantially reduce phosphorus excretions in ruminant production. Feed testing programs to ascertain the level of phosphorus supplementation required and implementation of alternatives to free-choice feeding of mineral supplements will be most effective in reducing phosphorus excretions. Recommended levels for dietary phosphorus are currently high enough so that diets can be formulated without safety margins. Use of phosphorus supplements in the feedlot can be eliminated for most cattle with the exceptions of the first month the animals are in the lot, for very young cattle, and with high-forage diets. The greatest potential for reductions in phosphorus excretions is for dairy cattle because feed composition and intake are highly controlled and current recommendations are high.

Considering the huge environmental threat from excessive P excretion in manure of dairy and beef cattle, there is an urgent need to initiate comprehensive research that clearly establishes the effects of reduced intake of P on reproductive function and health of dairy cattle. Such research is now underway in Alberta.

3.4 Other Methods of Decreasing N and P Output

3.4.1 Implants

The main methods applicable here include changing feed quality, improving animal genetics, and using agents to influence growth rates. The effect of feed quality will be considered in the following section on feed efficiency, and the effects of genetics will be addressed in the section on reproductive efficiency and genetics since in beef production the reproductive performance of cows is markedly affected by genetics as is the rate of growth of the animal. The following discussion then, is centred on the use of growth promotant implants. It is important to realize, though, that any method which increases rate of lean body tissue will have similar effects as outlined in the following section.

The importance of growth promotant implant technology is illustrated in the following statement: "No other management tool offers beef producers a greater return on investment than growth-promoting implants" (Mader 1998). Active ingredients in implants include estradiol, zeranol, progesterone, testosterone and trenbolone acetate (Mathison 1993; NRC 1996; Mader 1998). The ultimate effect of these implants is to enhance the rate of protein excretion in the body (NRC 1996).

Improvement in rates of gain and feed efficiency due to implanting are expected to be in the order of 10 to 20% and 5 to 10%, respectively, in yearling cattle (Mader 1998). Feed intakes are increased by about 6% (NRC 1996). Gould et al. (1982) reported improvements in gains of implanted pastured cattle were in the range of 11 to 20%. Mathison (1993) gave 8 to 10% as the expected improvement in gain in implanted calves while Mader (1998) suggested weaning weights would increase by 5 to 10 kg and daily gains by 0.045 kg/day when calves were implanted at 2 months of age.

Trenbolone acetate implants were not approved for use in Canada in 1990, thus the use of these implants represents a methane mitigation factor which was not available at that time. Mader indicates that the trenbolone acetate stimulates cell membrane androgen receptors, increasing protein production and also reducing corticotropin hormone production. The latter effect reduces rate of protein catabolism and hence protein turnover. According to Mader (1998) combinations of estrogen and trenbolone acetate give an additional 3 to 5% increase in daily gains and a 3% improvement in feed efficiency above that achievable with estrogenic type implants alone.

In terms of reductions in methane emissions, information suggests that reductions in N and P and methane emissions will be approximately in the same order as changes in feed efficiency when ionophores are used. Thus reductions of about 7% can be assumed in most cases except when trenbolone acetate combination implants are used; in such cases reductions of methane emissions in the range of 10% can be used.

Special mention needs to be made of bovine somatotropin (BST). This hormone is available to producers in the U.S. but not in Canada. It increases milk production, persistency of lactation, and dry matter intake without substantially altering milk composition (Bauman 1992; Burton et al. 1994). Improvements in milk yield over the lactation interval are in the range of 10 to 15% for the multiple sustained release injection of BST (Burton et al. 1994). It is clear that the use of exogenous hormone does not adversely influence energy metabolism; thus there is an increase in efficiency of feed use associated with BST use because of a reduction in the proportion of energy being used for maintenance. Information suggests that a 10% increase in milk production results in a 2-4% improvement in feed efficiency and a 3-5% reduction in methane emissions, with the higher values being applicable when the percentage of grain in the diet was increased because of the extra production. Using a value of 12.5% improvement in milk yield when BST is used, this would suggest an improvement in feed use of 5% when BST is used and the percentage of grain in the diet increases with milk production. Although this is lower than the 9% obtained by Surgeoner (1995) in a literature summary, it is more realistic. Burton et al. (1994) have pointed out that feed intake is increased in cows treated with BST, and that there is not much influence of BST on how the feed is utilized within the animal. Thus the approach we have utilized in our report is more likely to be correct.

In terms of reduction of methane emissions with BST use, using the 12.5% as the expected increase in milk production, our results would suggest that methane should be reduced by about 6% if grain feeding increases. Bauman (1992) gave 5.5% as the estimated reduction in methane per kg of milk produced and pointed out that the percentage of grain in the diet will be increased when BST is used.

3.4.2 Ionophores

Ionophores are feed additives that modify activity or microorganisms in the rumen and thus affect products of fermentation. Their mode of action is through interference with ion transport through the cell membrane of bacteria (Yokoyama and Johnson 1988). Specifically, they will increase the proportion of feed fermented to propionate, reduce methanogenesis, inhibit protein breakdown, and reduce lactic acid production and hence reduce problems with acidosis (Yokoyama and Johnson 1988; NRC 1988). In addition, ionophores, particularly monensin, reduce the incidence of bloat (Goodrich et al. 1984). Improvements in digestibility have been noted when the products have been fed (Goodrich et al. 1984; Delfino et al. 1988).

Ionophores are used commercially in Canada. Brand names are Rumensin, Bovatec and Posistac, which contain active ingredients of monensin, lasalocid, and salinomycin, respectively.

In terms of greenhouse gas, N and P mitigation strategies, ionophores have the following effects: 1) a reduction in the amount of feed the animals require for maintenance and hence a reduction in methane emissions and some reduction in nitrogen and P excretion, 2) reduction in protein breakdown in the rumen and hence a reduction in the amount of protein needed in the diet, and 3) a specific reduction in methane production in the rumen.

Ionophores are primarily used in the feedlot. Under these conditions Goodrich et al. (1984), in summarizing data from nearly 16,000 head of cattle, determined that cattle fed diets containing monensin gained 1.6% faster, consumed 6.4% less feed and required 7.5% less feed per unit liveweight gain than cattle fed control diets. Raun (1990) summarized data indicating that use of monensin increased feed efficiency by 5.6% and gain by 1.8% while reducing dry matter intake by 4% when high concentrate diets (mean 16% forage) were fed.

There is evidence that ionophores have a positive influence on the efficiency of utilization of forage diets as well. Goodrich et al. (1984) noted that with pasture cattle, daily gains were improved by 13.4% when cattle were fed ionophores. Sprott et al. (1988) concluded that when ionophores are used with low quality diets, feed or grass intake may decrease and therefore an improvement in feed efficiency may be obtained whereas supplementation of higher quality forage diets may result in an increased rate of body weight gain, presumably because more useful energy is derived from a given amount of feed.

Ionophores are increasingly being used in the diet of beef cows. According to NRC (1996) information, 12% less feed is required for cows at maintenance when ionophores are used in the diet. This is consistent with data summarized by Goodrich et al. (1984). Sprott et al. (1988) concluded that ionophores do not affect fertility but can reduce postpartum interval to estrus. Further, in the 13 studies that they reviewed, ionophores had no significant effect on suckling calf growth, although a slight positive result was seen in nine of the trials.

In this study we have assumed that ionophores reduce the maintenance requirement of the animal by 12% since this is assumption used in the NRC (1996) method to include ionophores in the diet. Thus for an animal at maintenance the savings in feed are 12% and it could also be inferred that methane production will be reduced by at least this amount. For animals with moderate rates of gain (approximately 1 kg daily), intakes will be approximately twice maintenance, thus only half of the feed is being used for maintenance and the expected improvement in feed efficiency is only 6%. For animals consuming three and four times the maintenance feeding levels (e.g. very high rates of gain and dairy cows), improvements in efficiency of feed utilization would be 4 and 3%, respectively, according to NRC (1996) methodology. This approach seems to fit the data quite well, since it is sometimes difficult to measure a response in rapidly growing animals and dairy cows. However, the approach is artificial and without a biological basis. It is more likely that the effect of ionophores is reduced as feed intake and passage rates increase and that there is no feed effect that is specific to the maintenance feeding level.

Ionophores can influence protein and P excretion from ruminant animals in two different manners.

First, their use is associated with reduced protein breakdown in the rumen. A reduction in ruminal protein breakdown increases the amount of protein that escapes from rumen fermentation, an effect which is usually positive in higher producing animals. This effect is difficult to quantify. Moreover this positive effect of ionophores is not considered in the most recent NRC (1996) bulletin on the nutrient requirements of cattle. Thus in this study no benefit has been assigned to ionophores for this effect.

The second major effect of an ionophore on nitrogen excretion is associated with its effect on feed requirements. As discussed above, the amount of feed required by the animal is decreased when ionophores are fed. There is a protein cost associated with dry matter consumption since more digestive enzymes, microbial cells, cellular material from the gastrointestinal tract, etc. are excreted with higher intakes. According to NRC (1984) the amount of protein in such losses (i.e. metabolic fecal protein) averages 3.34% of dry matter intake. This translates into a 0.53% reduction in nitrogen or about a 25% reduction in P requirements in the diet which is associated with metabolic fecal losses. Reductions in nitrogen excretion associated with ionophore feeding can therefore be calculated as: (% savings in feed from ionophore feeding x 0.53%)/(% feed nitrogen). As an example, if a pregnant beef cow was receiving a diet containing 1.28% nitrogen (8% crude protein), the feed savings with an ionophore would be 12%, and thus the percentage reduction in nitrogen excretion would be 4.97%. Because of time constraints for this analysis this can be approximated by assuming that a bull and an average beef cow consume a diet containing 1.6% N, replacement heifers consume a diet containing 1.9% N, feedlot animals and calves consume a diet containing 2.24% N, and dairy cows consume a diet containing 2.56% N. Thus to determine the percentage reductions in nitrogen excretions due to ionophore feeding the respective factors for multiplying the percentage feed savings are 0.33, 0.28, 0.24, and 0.21, respectively.

3.4.3 Zeolite

Zeolite, a generic term used to describe materials containing various minerals, has been used in air and water filtration, environmental cleanup involving heavy metals and radioactive contamination, as a soil amendment for golf courses, in greenhouses, cat litter, and paper production among other uses (Bechtel and Hutchenson 2003). It is also used in feed as a pellet binder and flow agent, to improve ammonia utilization, bind toxins and heavy metals, as a buffering agent and for reducing bloat and metabolic problems. In a trial conducted by Bechtel and Hutchenson (2003), a specific zeolite containing potassium, calcium, and clinoptilolite (CZ; St. Cloud Mine, Winston, N.M.) with specific characteristics to bind ammonia and certain toxic substances was added at a level of 1.2% to feedlot diets. This particular zeolite also has a very high buffering capacity (high in potassium and calcium, low in sodium, high cation exchange capacity, and low free crystalline silica and minimal clay levels). Adding the zeolite at 1.2% did not affect initial manure nitrogen, phosphorus or potassium levels. However, after storage from 15 to 30 days, manure nitrogen loss was reduced from an average of 32% in the control diet to 11% in the zeolite diet: a two-thirds reduction in manure-nitrogen losses. However, manure phosphorus and potassium levels did not change in the stored material. Bechtel and Hutchenson (2003) speculated that the dietary zeolite excreted in the manure binds ammonia, reducing nitrogen losses.

Bechtel and Hutchenson (2003) caution that on a worldwide basis, there has been considerable research on a variety of applications for zeolites, but results are sometimes misleading, at least partially because the general term "zeolite" is often used to describe materials with vastly different characteristics and efficacy.

3.4.4 Non-Traditional Management Procedures for Beef Cows

According to data collected by Dr. John Basarab in an extensive survey covering 6,249 beef herds in Alberta, the calving percentage expressed as a percentage of cows bred was 83.5% in Alberta in the 1986/87 and 1988/89 production years (Mathison 1993). Losses to weaning of calves born live were 2.7% of the calves. There is therefore room to increase percentage calf crop to 90% of cows bred and reduce losses to weaning to 1.5%. Using broad assumptions concerning when non-pregnant cows are culled, this might translate into a practically possible 5% increase in calves weaned per cow bred and a corresponding decrease of 5% and similar decreases in N and P excretion and in methane emissions per cow in the breeding herd.

Traditional management procedures to improve reproductive performance in beef and dairy cows include pregnancy checking, condition scoring for improved feeding, bull evaluation, winter feed testing, vaccinations for scours and other diseases, feeding replacement heifers separately and adequately, feeding first-calf heifers separately and adequately, trace mineral supplementation, etc. The costs associated with such procedures will more than likely be recovered in the form of an improved calf crop.

Reducing bull numbers

In July 1997, there were 30 and 21 cows per bull in eastern and western Canada, respectively, according to Statistics Canada information. The reason for the difference is that very few bulls are used in dairy production which represents a greater part of the cattle population in eastern Canada. Results obtained by artificial insemination can rival those obtained from natural service with a bull. In addition, costs of the two systems can be somewhat comparable when factors such as interest, depreciation and feeding costs of the bull in the natural mating system are included and balanced against the cost of semen, technician for insemination, facilities, and heat detection in the artificial insemination system.

Under some pasture and breeding situations it will not be possible to replace bulls with artificial insemination. Moreover some bulls are required for semen production and clean-up bulls are required. Thus even if there was widespread adoption, the number of cows per bull would probably not exceed 50 in eastern Canada and 40 in western Canada. Nevertheless a reduction in bull numbers to these levels would significantly reduce methane emissions, particularly in the beef industry where bull use is now quite high. Improvements in techniques for synchronizing estrus and improving pregnancy rates will increase artificial insemination adoption rates.

Multiple births

One of the major problems in ruminant production is that breeding females must be kept on a year-round basis and very few offspring are produced. Thus in the beef and dairy production systems the average number of calves born per cow per year is between 0.8 and 0.9. On this basis, sheep production is more efficient with two to three lambs being born per breeding ewe. The costs of keeping the breeding female can be quite high. It has been estimated that 75% of the feed costs for beef cows are associated with maintenance (Ferrell and Jenkins 1985).

Because efficiencies of calf production play a small part in the overall efficiency in dairy production, there is not much incentive for multiple births in this industry. In contrast, in the sheep industry multiple births are necessary for survival, thus there has been emphasis on this characteristic for some time. There may be potential for multiple births in the beef industry. The reason is that more than 50% of the feed units used in the beef industry are used to meet the maintenance requirements of breeding females in contrast with 3% in the poultry industry (Gregory et al. 1997). Compared in a different way, the beef cow can produce about 0.7 of her weight each year in progeny in comparison with factors of about 8 for pigs, 70 for chickens and more than 1000 for some aquatic species (Gregory and Dickerson 1989; cited by Gregory et al. 1996). For this reason Guerra-Martinez et al. (1991) suggested that the costs per unit of beef output could be reduced by 24% if cows produced twins.

Cattlemen generally recognize that multiple births lead to more calving problems, more death losses, greater problems in cows accepting their calves, and smaller and less uniform calves at weaning. Many producers therefore would not be happy with a high proportion of twins in their herd. Nevertheless, twinning is actively being pursued as a strategy for the beef industry in research being conducted in the USDA facility at Clay Centre, Nebraska. In the Clay Centre work, which was implemented in 1981, the number of calves per parturition increased from 1.07 to 1.29 from 1981 to 1993 (Gregory et al. 1997). There was a high correlation between twinning and ovulation rate; thus selection could for twinning could take place indirectly by selecting for ovulation rate. The authors also noted that there was a positive relationship between twinning and growth traits. Gregory et al. (1996) reported that cows with twins produced 58% more calf weight at 200 d of age than cows with singles. However assistance at calving was required in 42% of the cows with twins in contrast with 20% for singles. Calf survival to 200 days was 15.2% greater with singles. With access to creepfeed, calves born as singles had an 8% greater daily gain to weaning and a 3% greater daily gain from weaning to slaughter (overall advantage for the single daily gain from birth to slaughter was 5% but the singles were also 20 kg heavier at birth).

In summary, it would appear that it is possible to wean a 150% calf crop in a beef herd. If beef cattle genetics and management practices could be modified to accommodate this high degree of multiple births without adversely affecting the birth, survivability or performance of offspring, methane emissions by beef cows could be reduced by almost 50% in terms of emissions per product produced.

Increased use of cross breeding systems

One of the major advances in terms of improvements in beef production and hence reduction in methane emissions per kg of liveweight gain has been in the area of breeding programs. Smith (1989) has suggested that the genetic response in feed efficiency that can be achieved is about 1% per year if good selection practices are used. Substantially greater one-time responses are possible when cross breeding systems are used (Woodward 1995). For calculation purposes, we can use the two breed rotation as an example. The average degree of heterozygosity obtained is 67% (86% for the three breed rotation) (Woodward 1995). Thus the expected improvement in growth rate of the calf is 67% of 8.5 (i.e. heterosis for individual growth) = 6% for growth. We can predict this would result in a 3% improvement in feed efficiency and a similar reduction in methane emissions. Similarly, an improvement of 67% of 14.8% (maternal heterosis) equals 10% in calf crop, and this should reduce the number of cows and bulls required in the herd by this amount with a resulting decrease in N, P and methane emissions. However, the use of crossbreeding was well established in beef cattle populations prior to 1990, thus very little response can be expected in this area in terms of reductions in N, P and methane emissions.

New reproductive technologies and novel production techniques

The rate of genetic improvement can be enhanced through the application of new reproductive technologies. The multiple ovulation and embryo transfer (MOET) scheme is one such strategy. The MOET scheme has been available for cattle since the 1970s (Ruane and Thompson 1991). The purpose of this approach is to allow more selection in females, the same way that artificial insemination has allowed more selection within males. In addition, the procedure can be used to breed replacements from younger females, which also shortens the generation interval. This procedure may be quite useful for cattle because of their long generation interval.

In practical MOET schemes, the number of embryos recovered per donor animal flushed ranges from four to seven and no effect has been noted on subsequent fertility (Callesen et al. 1996). Nicholas (1996) gave the expected rate of improvement with the technique over that of conventional selection techniques as 30 to 65% for beef cattle, 15 to 100% in sheep depending upon flock size and 10 to 25% for dairy cattle. Thus, if expected genetic responses in rate of gain are 1% per year due to normal selection procedures (Smith 1989), with MOET schemes it is possible to increase rate of gain in cattle to 1.5% per year. By the year 2010 this would equate to an improvement in growth rate of 15% which information would suggest would decrease methane emissions by 7%.

Smith (1989) has suggested that it should be possible to almost double the rate of improvement if cloning is incorporated into the system. Furthermore, the application of marker assisted selection during the coming decade will greatly enhance the rate of genetic progress in cattle and sheep.

Possibilities of new production practices exist. One such possibility is the use of the single bred heifer system. In this system, heifers are bred and produce only one calf. They are then finished for subsequent slaughter. Replacement heifers would be selected from calves of these heifers and also from extra cows so there would be enough breeding females to keep the system going. The advantage of such a system is that while the heifer is producing the calf it is also growing in weight. This means that the proportion of feed going towards maintenance in the total beef production system is reduced. Newman et al. (1993) evaluated the system in terms of efficiency of feed utilization. Calves were weaned and heifers slaughtered at 3, 5 and 7 months after calving. At the end of the test period, there was no difference between these treatment groups and a conventional group in terms of digestible energy required to produce lean product.

It is now possible to sex semen and this technology will undoubtedly affect commercial cattle and sheep production in the future. Nicholas (1996) has suggested that the sexing of semen on large-scale dairy cattle progeny testing scheme could increase the rate of genetic improvement by 25%. Moreover, if the right number of females could be obtained for breeding purposes with the remainder being males, the rate of gain and feed efficiency of the total population of calves would increase because of the superiority of males in this regard.

In conclusion, there is no question that N and P and methane emissions from ruminants can be substantially reduced in the short term through the use of ionophores however the long-term effect is unclear. Additional research is required, however, to further quantify the extent to which N and P and methane emissions change in long-term feeding situations, to determine the relative ability of different ionophores among the other factors discussed.

3.5 Methane Reduction Strategies Modifiers of Digestion and/or Fermentation

3.5.1 Specific Inhibitors of Methane Production

Chlorinated methane analogues, such as chloroform, carbon tetrachloride, and methylene chloride, were first reported by Bauchop (1967) to inhibit methanogenesis in rumen contents. Chloroform significantly inhibits methanogenesis through inhibition of methyl-CoM reductase (Gunsalus and Wolfe 1978). Halogenated alkanes are also known to block the function of corrinoid enzymes (vitamin B_{12}-dependent enzymes) in methanogenesis (Kenealy and Zeikus 1981). Therefore, their specificity for the "target" organism is debatable. However, in comparison with ionophores, unsaturated fatty acids, and sulfate, halogenated methane analogues are the most potent of the methane inhibitors (Chalupa 1984).

Although there are problems with use of chemicals for direct inhibition of methane, numerous examples of positive results are available. Amichloral (a hemiacetal of chloral and starch) was shown to inhibit methane production, increase fermentation efficiency and reduce amino acid degradation (Chalupa et al. 1980). Mathers and Miller (1982) observed that chloral hydrate inhibited methane production without reducing flow of non-ammonia nitrogen into the small intestine. Cattle performance was improved and there was a persistent decline in methane production when cattle were fed derivatives of 2,4-bis (trichloromethyl) benzo[1,3]dioxin-6-carboxylic acid (Davies et al. 1982). Since the methane analogues are directly toxic to methanogenic bacteria, their use results in an increased production of gaseous hydrogen (Demeyer et al. 1986), and a decreased molar percentage of acetate with an accompanying increase in propionate. It must, however, be remembered that methane inhibitors often reduce digestion and depress feed intake.

α-Bromoethanesulfonic acid (BES) is a potent inhibitor of methanogenesis and growth in *Methanobacterium ruminantium* (Balch and Wolfe 1979) because it is a structural analogue of the co-factor mercaptoethanesulfonic acid (HS-coenzyme M) used by methanogenic bacteria (Taylor et al. 1974). Since HS-CoM is found only in methanogenic bacteria, BES functions as a specific inhibitor when used in mixed microbial systems. Moreover, BES can inhibit methanogenesis by all species of methanogens growing on any of the recognized substrates (Oremland and Capone 1988), and the compound is inexpensive, water soluble and readily obtained commercially. Although this would suggest that BES is ideal for commercial use in inhibiting methane production, it has been found that mutants of *Methanosarcina* strain 227 were resistant to 0.24 mM BES when previously exposed to levels of 0.024 mM, and a strain of *Methanobacterium formicicum* was found to be resistant to 0.2 mM BES without any prior exposure (Smith and Mah 1981). Resistance to BES appears to be conferred by impermeability to the compound, since cell-free extracts of resistant mutants were susceptible to BES inhibition of methyl-CoM reductase (Smith 1983). Immig et al. (1996) determined that the proportion of methane in rumen gas dropped from 40% to less than 1% after a 2 g pulse dose of BES was given, but that microbes were able to adapt to continuously administered BES within 4 days. We have confirmed that BES does not reduce methane production in sheep in an experiment involving prolonged administration (Dong, unpublished results). It can therefore be concluded that this compound will not play a significant role in reducing methane production from ruminant animals.

Other compounds have also been examined for their use as antimethanogenic substances with varying results (Czerkawski and Breckenridge, 1975; Chalupa 1984; Czerkawski 1986). McCrabb et al. (1997) presented results in which bromochloromethane chemically complexed with α-cyclodextrin (to overcome the highly volatile nature of the bromochloromethane) was used to reduce methane emissions in cattle. This compound reduced methane emissions for 28 days in this experiment and for at least 12 weeks in other experiments, leading to the patenting of the compound (May et al. 1995). Although no improvements in daily gain were observed when the product was fed, there were improved efficiencies in feed conversion (McCrabb et al. 1997). Another promising candidate as an inhibitor of methyl-CoM reductase is seleno-CoM (Oremland and Capone 1988). However, only very limited work has been done with this compound.

Defaunation is a term for the elimination of protozoa from the rumen. Anaerobic protozoa lack mitochondria, but often contain membrane-bound organelles, called hydrogenosomes, in which the hydrogen is produced when pyruvate is converted to acetyl-CoA and carbon dioxide (Müller 1988). It is assumed that there is a symbiotic hydrogen transfer between methanogens and anaerobic protozoa, similar to that existing between bacterial species, which allows protozoa to dispose of their electrons as hydrogen and produce more acetate. Stumm et al. (1982) estimated that 10-20% of methanogens are attached on to the surfaces of protozoa, but that methanogens detached from protozoa when exogenous hydrogen was supplied. Hino (1983) reported that starch fermentation and ATP synthesis by *Entodinium* spp. were reduced under a high partial pressure of hydrogen; this inhibition disappeared when *Entodinium* spp. were co-cultured with rumen methanogens. Reductions in methane production are often accompanied by accumulation of hydrogen in defaunated animals (Whitelaw et al. 1984).

Experimental results consistently demonstrate that defaunation reduces methanogenesis in the rumen. The extent of reduction normally varies from 20 to 50%, depending upon diet composition (Kreuzer et al. 1986). Whitelaw et al. (1984), for example, observed a 50% decrease in methane production following defaunation of cattle fed a barley-based diet, whereas Itabashi et al. (1984) did not detect any reduction in methane emissions from defaunated animals fed forage-based diets. The effect of defaunation on ruminal methanogenesis can be attributed to several factors, such as the lower rumen digestion of fiber (Veira 1986), a shift of the digestion from rumen to hindgut (Van Nevel and Demeyer 1996), the loss of methanogens that are normally symbiotically related to protozoa (Krumholz et al. 1983), and the loss of hydrogen/formate-producers for methanogenesis (Müller 1988). Some compensation may, however, occur since Van Nevel and Demeyer (1988) indicate that defaunation can increase rumen volume, thereby increasing mean retention time of digesta in the rumen which tends to favour methanogenesis.

Defaunation can reduce methane production and have beneficial effects on nitrogen metabolism in ruminants under some circumstances (Jouany et al. 1988), and it does result in reductions in acetate and butyrate production (Whitelaw et al. 1984; Kreuzer et al. 1986), which may also be beneficial. However, fiber digestion can be inhibited and ruminal starch degradation can be increased (Van Nevel and Demeyer 1988). Taken as a whole, then, it would seem logical to use defaunation as a method for reducing methane production and improving efficiency of production. However, as with many of the inhibitors of methanogenesis, many of the defaunation agents are toxic to the animal and as a result defaunation methods that can be practically used to reduce methane emissions are yet to be developed.

In summary, there is no question that halogenated and other compounds should be carefully considered in future attempts to limit methane production. In our opinion specific methane inhibitors will more likely be effective than defaunation agents, although currently there is a major study on defaunation occurring at the Agriculture and Agri-Food Canada Lethbridge Research Station. Van Nevel and Demeyer (1988) indicate that a positive effect of methane inhibitors on animal performance can be obtained when they are administered to slowly growing ruminants fed high-roughage rations normally associated with production of large amounts of methane and low proportions of propionic acid in the rumen. These authors (van Nevel and Demeyer 1996) have also concluded, however, that drastic inhibition of methane is not unequivocally successful because of adaptation of rumen microbes, toxicity of anti-methanogenic products to the host, and negative effects which the products can have on digestion and animal performance. Specific questions that need to be addressed relate to product safety, with further studies on the effect of such products on animal performance being warranted. Long-term efficacy must also be considered in light of the susceptibility of chloroform, carbon tetrachloride, dichloromethane, and chlorinated ethanes and ethenes to anaerobic degradation (Bouwer and McCarty 1983) and the known ability of microflora to adapt to the inhibitors resulting in only short-term inhibition. Consumers are also becoming increasingly concerned over the use of additives in livestock diets, and this trend may also restrict the widespread adoption of methane inhibitors for ruminants.

However, if the concern is primarily to inhibit methanogenesis and thus reduce greenhouse gas emissions, these products may be the key to the future. In particular, the bromochloromethane and α-cyclodextrin complex developed by McCrabb et al. (1997) is a product already available which may solve the methane emissions problems in ruminant livestock.

3.5.2 Additions of Nitrates to the Diet

Ability to utilize nitrates and/or nitrites as terminal electron acceptors is widespread among anaerobes. The reduction of nitrate to ammonia is an eight-electron reduction: $NO_3^- + 4H_2 + 2H^+ \rightarrow NH_4^+ + 3H_2O$. If nitrate is utilized as a terminal oxidant, the carbon source may be fully oxidized and, assuming similar stoichiometries for oxidative phosphorylation with oxygen (Ingledew and Poole 1984), the ATP yields will be the same as with oxygen. Since free energy changes are much more negative for nitrate reduction than for methanogenesis ($\Delta G^{o=}$ is -599.8 kJ for nitrate reduction versus -139.1 for methanogenesis; Weimer 1998), the energy available to nitrate-reducing bacteria is much greater than that for methanogens reducers, and nitrate reducers easily out-compete methanogens and other anaerobic hydrogen utilizers. Methane emissions from ruminants are thus substantially reduced when nitrate is administered (Takahashi and Young 1991). Moreover, since nitrates are rapidly reduced to nitrites, and the nitrites can be subsequently reduced to ammonia, nitrates could in theory be used as a non-protein nitrogen source in ruminant diets. This would need to be a highly controlled process, however, since nitrites can oxidize haemoglobin to methaemoglobin and interfere with oxygen transport oxygen, causing toxicity. Diets containing more than 0.45% nitrate N are potentially toxic to ruminant animals (Emerick 1988; Weimer 1998), whereas additions of nitrate N to the diet in amounts equivalent to 4.7% of the digestible carbohydrates would be required to provide a complete alternative to electron disposal from normal rumen fermentation, thus addition of nitrate to the diet is not a feasible way of completely eliminating methane emissions.

Although addition of nitrates to the diet was previously dismissed as a means of controlling methanogenesis because of the worries about nitrate toxicities and an exacerbating effect on nitrogen excretions in manure and odour (Mathison et al. 1998; Weimer 1998), under conditions where methane emissions have a negative economic impact on livestock production this method of reducing emissions will work since ruminant animals can adapt to quite high levels in the diet under controlled feeding situations. Moreover, the nitrogen contained in the nitrates can replace the nitrogen from urea, which is commonly incorporated into ruminant diets, and there is the possibility that microbial protein production in the rumen may be substantially increased when nitrates are fed which could improve animal productivity.

3.5.3 Addition of Malate to the Diet

The malate-fumarate reaction catalysed by fumarate hydratase is a near equilibrium reaction thus malate and fumarate effects within the rumen are expected to be similar. Fumarate can be used as an electron acceptor via the fumarate reductase system to enable organisms such as *E. coli* and others to grow anaerobically (Ingledew and Poole 1984). Fumarate serves as an oxidant for anaerobic respiration by being the oxidized half of the succinate-fumarate couple. In addition to NADH, hydrogen and formate which can donate electrons to fumarate reductase, α-glycerol phosphate (*E. coli*) and lactate (most propionic acid bacteria) have been shown to function as NAD^+-independent donors for fumarate reductase. From a stoichiometric point of view it is not economically feasible to include enough fumarate in the diet to channel electrons and hydrogen completely away from methane production; however, this pathway may prove to be important with respect to ruminal methane production via a stimulatory effect of fumarate or malate on selected ruminal microbial species. Linehan et al. (1974) observed that malate is stimulatory to *Selenomonas ruminantium*, a propionate-producing rumen microorganism.

Martin and Streeter (1995) demonstrated that incorporation of malate in incubations resulted in increased propionate and 7 to 28% decreases in methane productions in vitro. The authors cite work in which milk persistency, rates of gain and feed efficiencies were improved when malate was fed. They suggested that more research on malate is required and that the chemical may be useful in stimulating, rather than inhibiting, specific microbial populations and thus altering the competitive balance in the rumen. Montano et al. (1999) also observed that malic acid tended to increase ruminal pH but had no effect on rumen fermentation.

Kung et al. (1982) found that malate additions to the diet increased volatile fatty acid concentrations in the rumen in early-lactation cows but had no effect on midlactation cows. Sanson and Stallcup (1984) reported that the product enhanced daily gain and feed efficiency. Martin et al. (1999) found that DL-malate increased rumen pH thus alleviating subclinical acidosis and improved steer performance in one of three feedlot trials when added to the diet in amounts from 80 to 120 g/day. These authors suggested that malate acts as an electron sink in the rumen and thus has an effect on electron flow in the rumen. They suggested that malate might be a good alternative to antimicrobials, particularly in the adaptation period when animals first enter the feedlot.

One problem with malic acid additions to the diet is the high cost of the product. Martin et al. (1999) indicated that the product cost $0.18 US per day when added to the diet at a rate of 80 g/day. This is about 30% of the cost of gain of feedlot cattle in Canada. However, Callaway et al. (1997) reported that alfalfa contains from 2 to 8% malate in its dry matter; thus the possibility exists that it could be incorporated in the diet in desired amounts by judiciously using forages that have been selected and grown for this characteristic. However, alfalfa causes bloat and there needs to be careful consideration of the cost-benefit for its use in the feedlot.

In personal communications with Dr. Itabashi of Japan, who is heading up their ruminant work on methane emissions, it was learned that their research has demonstrated inhibition of methane emissions when malate is fed to cattle. They were vigorously pursuing malate additions as a viable means of reducing methane emissions. Further work is therefore required on this product.

3.5.4 Addition of Oils to the Diet

It has been known for some time that the addition of unsaturated fatty acids to diets of ruminants resulted in a depression in methane emissions (Czerkawski et al. 1966a,b; Czerkawski et al. 1975; Van Nevel and Deymeyer 1981). The mechanism by which this is accomplished is through a direct toxic effect on the bacteria and through competition for electrons and hydrogen between biochemical pathways involved in methanogenesis and the reduction of the double bonds in unsaturated fatty acids (Dong et al. 1997). Johnson and Johnson in a review attributed the reduction in methane emissions to a decrease in the amount of substrate fermented rather than to a direct effect of the oils on methanogenesis and concluded that dramatic decreases in methane production from added fat will only occur if digestion is limited. In fact, lipids do depress fiber digestion in the rumen and total tract (Dorequ et al. 1991; Ferlay and Doreau 1992), with the extent of depression depending upon the nature and amount of lipids as well as the animal species and experimental conditions. Tamminga et al. (1983) suggested that lipid does not influence the digestion of starch or soluble carbohydrates.

We examined the use of canola oil as a means of reducing methane production based upon some of this early work and found that the addition of canola oil to a diet containing 85% barley-based concentrate reduced methane production by 33% in steers. However, digestibility of the fiber was reduced; thus the metabolizable energy content of the diet was not different from that of a control barley-based diet. Similarly, canola oil did not improve efficiency of dry matter use for gain in steers in the study of Engstrom et al. (1994), even though daily gain was increased, which would tend to confirm that any beneficial effect to the animal of supplemental lipids in reducing methane emissions would be negated by a depression in feed digestibility.

In further studies (Dong et al. 1997), we compared canola oil to coconut oil as methane inhibitors in an in vitro system when the oils were added at 10% of an in vitro diet since, in our interpretation of the literature, fatty acids of medium chain, such as those found in coconut oil, were more effective inhibitors of methanogenesis. Inhibition of methanogenesis was greater with the coconut oil, which contains medium-length fatty acids. Machmüller et al. (1998) reported that coconut oil when added at 3 to 6% of the diet was a more effective inhibitor of methanogenesis than crushed oilseeds such as rapeseed, sunflower seed and linseed. In subsequent work, Machmüller et al. (1999) fed mature sheep diets containing different proportions of hay and concentrate, and 0, 3.5 or 7% coconut oil over 21-day periods. Coconut oil in the diet reduced the numbers of rumen ciliate protozoa by 88 to 97%. Fiber digestibility was numerically reduced, but the researchers could not detect a statistical change in energy availability to the animals. Methane emissions from the sheep were reduced by 28 and 73% when diets containing 3.5 and 7% oil, respectively, were fed. Energy lost as methane was thus 7.5, 5.7 and 2.5% of the gross energy consumed by sheep. The authors did, however, suggest that half of the reductions achieved in methane emissions were due to the substitution of concentrate for hay in their experimental design. Palatability problems were, however, encountered, and the authors suggested that growth might be impaired when coconut oil was included in the diet because of reduced intakes.

In conclusion, addition of oils to diets has been shown to inhibit methane emissions in cattle and sheep. The technology may be more applicable for use when grain is included in the diets. Expected reductions in emissions are in the range of 25 and 15% when grain- and forage-based diets, respectively, are fed since lower amounts of oils must be used in forage-based diets than in grain-based diets (3% vs. 5%) due to the reduction in digestibility of fiber when oils are included in the diet.

4 Evaluation and Quantification of Mitigation Strategies

4.1 Ruminants

4.1.1 Reduction in Dietary Nitrogen and Phosphorus Intakes

Objective:

Ruminant diets often contain an excess of nitrogen and phosphorus. The simplest way to reduce nitrogen emissions is thus to reduce dietary N and P intakes.

Key Assumptions:

1. Ruminant diets contain a minimum of 10% and over 25% N and P, respectively, above that required by the animal. (Note that in some circumstances there will be a much greater excess, but this cannot be corrected because using lower N and P containing feeds would be very expensive.)
2. Diets for higher producing animals such as dairy cows and rapidly growing cattle could have their N and P contents reduced by an additional 10% and 25% if diets were formulated on the basis of amino acid requirements and ruminally protected amino acids and high P bioavailability feeds were used.
3. If intakes are reduced, N and P excretions should be reduced by approximately the same percentage (true for an animal at maintenance but not quite true for lactating and growing animals since they are retaining some nitrogen).

Commodity Application:

This mitigation technique for reducing N and P emissions would have application throughout Alberta and Canada. Almost all diets for dairy cows would be affected whereas little change would be expected in the diets of grazing animals since few of these receive supplemental protein and P, especially in the feedlot in any case.

Adoption:

Increased feed costs would accelerate reductions in N and P intakes. For N, we are moving towards balancing ruminant diets on the basis of amino acids. This trend will accelerate in the future, especially as concern grows about nitrogen excretions. Increased emphasis on feed analysis (and the use of near infrared reflectance spectroscopy in analysis) will help identify situations where less supplemental protein should be used. Unfortunately many feeds are given to cattle simply because they are there. It would cost money to switch to lower protein feeds. Thus adoption will be considerably less than 100%, particularly in the beef industry.

Environmental, health and social impact:

A reduction in protein and P content of the diet may help cow fertility in some cases. A reduction in N and P excretion will be environmentally friendly.

Barriers and risks to adoption:

There are no risks aside from occasionally running into an amino acid and P deficiency. This should not be a problem if adequate research information is available and feed is analysed.

Research and information gaps:

More research is needed on amino acid and P nutrition of ruminants.

Potential policy and/or industry measures to encourage use:

Higher protein and phosphorus costs or legislation concerning nitrogen balance on land would have a dramatic effect on nitrogen intake and hence excretion in some instances.

Other considerations

A reduction in protein usage will have a ripple effect on use of high protein byproducts.

Costs and Effect on Production

Item			
Method	Normal improvements	Reduction in protein content of diets by 15%	Greater protein reductions to 20% through use of protected amino acids
Factors which will change rate of adoption	Some reduction in dietary nitrogen content because of better nutrition	Increasing feed prices will make it less economical to overfeed protein and to use amino acids.	Quotas on land disposal would have a marked effect in terms of reducing nitrogen intake.
New capital investment	None	None	None
Increased costs	None	Reduced costs. Net cost of 10% supplemental protein about ~$8/tonne diet.	Reduced protein by $16/tonne diet but protected amino acids cost is about $20 per tonne diet ($20/kg of amino acid)
Feed efficiency (kg/day)	No effect	No effect	No effect
Rate of gain (kg/day)	No effect	No effect	No effect
Milk production (%)	No effect	No effect	No effect
Risks to target animal	None	None	None
Reduction manure P (%) Reduction in N (%)	Reduced 15	Reduced 20	Reduced 30

4.1.2 Effect of Improving Rate of Gain and Milk Production

Improving Gain by Decreased Use of Backgrounding in the Beef Industry

Objective:

Cattle which are backgrounded at a slower rate of gain have a greater portion of their feed used for maintenance thus efficiency of feed utilization is reduced. In addition, N and P emissions per kg of feed are reduced when better quality feed is included in the diet. Thus N and P excretions per kg of product produced will be reduced if backgrounding periods are shortened and animals are put in feedlots. This does not take into account the whole system, just the effect on the animal.

Key Assumptions:

1. Percentage N and P excretions will be decreased by an amount equivalent to approximately 25% of the change in feed efficiencies since the rate of growth is substantially higher in the feedlot. Thus for backgrounding periods of 60, 180 and 240 days, the percentage increases in nitrogen excretion would be 3, 6 and 8% (i.e. changes of about 0.03% per day of backgrounding).
2. The average backgrounding period is assumed to be 150 days.

Commodity Application:

It is most unlikely that the backgrounding period will be reduced in Alberta since it forms part of the risk management tool in the cattle business. It is, however, possible that the practice may have some adoption since grain feeding is likely to increase in the feedlots.

Adoption:

There has been a great deal of feedlot finishing; thus historically the background feeding period is somewhat reduced. Currently it is estimated that about 25% of the cattle in western Canada intended for slaughter go directly to the feedlot to be finished with the other 75% being backgrounded in some fashion. It is anticipated that, if anything, there will be a slight increase in backgrounding over the next 10 years because there is a trend towards smaller animals, which fatten earlier and these animals are better suited to backgrounding conditions.

Environmental, health and social impact:

Less backgrounding means more grain feeding and more feedlots. This may not be as environmentally friendly, especially for N and P excretions, may increase health problems (lactic acidosis, liver abscesses) in cattle, and may have negative impacts on people living close to feedlots.

Barriers and risks to adoption:

Societal concerns about feedlots.

Research and information gaps:

Current information is adequate.

Other considerations

Nitrogen excretions and phosphorus excretions will be reduced if backgrounding times are reduced but nutrient excretions will be more concentrated spatially.

Costs and Effect on Production:

Item			
Method	30 days increase in backgrounding expected	0 days increase	150 days reduction
Factors which will change rate of adoption		Re-educate industry concerning importance of lean body growth and effect of slow grow rates on feed requirements.	High forage and pasture prices. Alternatively, a decrease could be caused by a large increase in cows that require grass.
New capital investment	None	None	None
Increased costs	None	None	None
Feed efficiency (kg/day)	Feed requirements per kg of gain increase 0.3% per day backgrounding	Feed requirements per kg of gain increase 0.3% per day backgrounding	Feed requirements per kg of gain increase 0.3% per day backgrounding
Rate of gain (kg/day)	Gain decreases about 0.5 kg/day of backgrounding	Gain decreases about 0.5 kg/day of backgrounding	Gain decreases about 0.5 kg/day of backgrounding
Risks to target animal	None	None	None
Reduction manure P (%) Reduction in N (%)	Reduced 3	Reduced 6	Reduced 8

Increasing Growth Rate
(Genetics and Implants Used as Example)

Objective:

Liveweight gain in beef cattle and the percentage of protein in gain can be improved through a variety of techniques including genetics and the use of growth promoting implants. This results in an improvement in feed efficiency and hence a reduction in N and P excretions.

Key Assumptions:

1. Improvements in rate of gain and feed efficiency of growing and finishing cattle are expected to be associated with a reduction in N and P excretions. Historic changes are in the range of 1% per year for increased genetics, etc. We have currently reversed this trend so no major increase is expected. Improvements in gain for implants are about 17%, with another 6% from trenbolone acetate implants.
2. Improvements in feed efficiency will be 50% of the improvements in rate of gain.

Commodity Application:

This approach will apply to all growing and finishing cattle in Canada.

Adoption:

There has been an increase in the rate of lean growth in cattle over the last 30 years, although this may now be levelling off. Use of growth promotant implants is already widespread. There is room for some increased use in calves and by some smaller farmers. Trenbolone acetate implants have appeared since 1990.

Environmental, health and social impact:

There will be no adverse effect on the animals, environment or society if rates of gain are improved through genetic means. It has been demonstrated repeatedly that implants are not a threat to the environment and health; a recent trade ruling with Europe has confirmed the safety of such products. Improper implanting may cause an increase in sexual activity.

Barriers and risks to adoption:

There are no major risks associated with higher growth rates, with the possible exception of an ultimate reduction in fertility at very high growth rates. Improper implanting may increase unwanted sexual behaviour in cattle. There is also an increasing interest in "organic" beef where no implants are allowed. We still have not resolved the issue that Europeans will not import beef from cattle that have been implanted.

Research and information gaps:

No idea of the percent decrease in P and N as a result of this strategy. More research is needed.

Other considerations

If animal performance is improved, nitrogen and phosphorus excretions will be reduced.

Costs and Effect on Production:

Item			
Method	0% increase in growth rate — no genetic improvement	8% increase due to growth rate by genetic improvement (5%) and increased use of trenbolone acetate (TBA) type of implants (3%)	15% due to use of TBA implants and normal improved genetics if we move in this direction.
Factors which will change rate of adoption	Trend is towards smaller animals. This trend is because of desire for more fat and smaller cuts	Larger animals are more efficient in the feedlot and marketing, slaughter system. Move this way will depend upon new meat technologies.	
New capital investment		None	None
Increased costs		Improved genetics does not cost a lot so costs will be mainly for implants. Costs of implanting are $4 to $12/head depending on time period.	
Feed efficiency	0	4%	8%
Rate of gain (%)	0	6%	15%
Milk production (%)	0	0%	0%
Risks to target animal	0	None	None
Reduction manure P (%) Reduction in N (%)	0 0	Significant 27	Significant 27

Increased Milk Production
(Growth Hormone as an Example)

Objective:

A variety of methods are available to increase the daily milk production in dairy cows. We will examine only one of these, but the percentage changes are applicable to all changes in production practices.

Key Assumptions:

1. Use of recombinant growth hormone (BST) is expected to increase milk production by 13% across all cows.
2. Based upon past history, milk production per cow is expected to increase 1.5%/year; however we will assume a smaller increase between 1990 and 2010 and of 15% (0.75% per year).
3. A 10% change in milk production will be associated with a change of 4% in feed efficiency and 5% reduction in methane emissions since increased production is expected to be associated with increased grain feeding.
4. Percentage nitrogen excretions will be decreased by an amount equivalent to approximately 25% of the change in feed efficiencies.

Regional/Commodity Application:

All cows are expected to increase in milk production by the year 2010. The use of BST may not have application in Canada since BST is not approved for use. Conversely, since it is approved in other countries, it may appear in our production system by the year 2010.

Adoption:

All herds are expected to increase in milk production. Adoption of an intensive technology such as BST will be slow unless increasing international competition and operational sizes increase the rate of adoption of new technologies.

Environmental, health and social impact:

Politically, it is very difficult to use intrusive technologies to influence milk. Changes are more likely to occur because of changes in genetics, etc., which ultimately can accomplish the same objective.

Barriers and risks to adoption:

Societal concerns about increasing levels of milk production and hormonal modification of cows.

Research and information gaps:

Current information is generally adequate. There may still be concerns about human health effects and the effects on longevity and health of dairy cows.

Other considerations

Nitrogen excretions and phosphorus excretions will be reduced when the product is used.

Costs and Effect on Production:

Item			
Method	15% due to normal genetic improvements	+5% due to more intensive genetics, management changes	Additional 8% possible through BST use more advanced reproductive and genetic technologies
Factors which will change rate of adoption	None	None	None
Increased costs	None	Cost of BST	Cost of BST
Feed efficiency (kg/day)	8	Additional 3	Additional 3
Rate of gain (kg/day)			
Milk production (%)	15	11	28
Risks to target animal	None	Greater production risks	Greater production risks
Reduction manure N (%)	25% of the effect on feed efficiency	25% of the effect on feed efficiency	25% of the effect on feed efficiency
Reduction manure P (%)	26	26	26

4.1.3 Improving Feed Efficiency in Cattle

Ionophores Used as an Example

Objective:

Ionophores (e.g. monensin, lasalocid, salinomycin) can be added to the diet to reduce the amount of feed required by the animal. This will reduce total emissions of methane and the amount of nitrogen excretion by the animal. Such products are currently licensed for use in Canada.

Key Assumptions:

1. Effect will primarily be through a 12% (NRC 1996) reduction in dry matter requirements for maintenance.
2. The effect is similar with grain- and forage-based diets. This assumption is consistent with NRC (1996) but the primary application of ionophore technology has been with grain-based diets.
3. No direct effect of ionophores on methane emissions will be assumed, even though in the short-term methane reductions in the order of 10-30% per kg of feed consumed have been measured with ionophores. This is because adaptation to the products may occur within a few weeks.

Regional/Commodity Application:

Currently not licensed for dairy cattle, but tests are underway. If positive, the product could be used by 100% of beef and dairy cattle over 2 months of age in Canada and in both eastern and western Canada.

Adoption:

Currently there is a fairly high level of use in finishing animals (70%). Very low level of use in rest of industry (<1%). There is recognition that the product will help prevent bloat in the feedlot and on pasture as well as coccidiosis, which will help in adoption. There will be increased use of slow release form in grazing animals for bloat control.

Procedure will be adopted quicker in western Canada because of the size of beef operations and the greater extent of feeding of mixed diets. Does not influence milk production so adoption will be slow in the dairy herd. Quickest adoption will be when grain is included in the diet (i.e. feedlot and replacement animals) since it must be mixed with feed. The products can, however, also be given as a controlled release bolus, in mineral mixes or possibly in water supply at increased cost and reduced efficacy.

Environmental, health and social impact:

No related health/reproductive problems have been identified in ruminants. It has a positive impact on the incidence of lactic acidosis, bloat and coccidiosis.

It is toxic to non-target animals such as horses. There will be short-term residue in animal manure; this is considered beneficial in terms of reduction in horn fly larvae but not for dung beetles.

Barriers and risks to adoption:

Not major since the U.S. currently uses such products. Product response will be consistent in any given application.

Research and information gaps:

We know that there is a short-term specific reduction in methane production as well as a reduction in feed requirements. There does appear to be adaptation to the product, however. We do not know the extent of adaptation or factors influencing it. We need to have more information on the response with roughage-based diets. Mechanism for bloat control is important. There is no research to indicate effects of ionophores on N and P excretions.

Potential policy and/or industry measures to encourage use:

More extension work, with examples of economic implications will help. If the product is to be moved into diets of animals which are not receiving grain the cost will increase and some form of product subsidy or incentive or tax may be required.

Other considerations

The product should be able to reduce N and P excretions by animals by about 2%.

Costs and Effect on Production:

Item			
Method	Same use as now	Increased use	Maximal use
Application of method	Mix with feed	Mix with feed & minerals; some increased costs because new target animals	Higher use of mixed feeds, slow release boluses can be used, possibly mixed with water. Costs of last two alternatives are higher.
New capital investment	None	None	Where feed mixers are not used will need to purchase or buy mixed feed
Increased costs per unit of feed	0.3 cents/kg feed	0.3 cents/kg feed	1.0 cents/kg feed
Feed efficiency	+2 to 12%	+2 to 12%	+2 to 12%
Rate of gain (%)	0%	0%	0%
Milk production (%)	0%	0%	0%
Risks to target animal	None	None	None
Reduction manure P (%) Reduction in N (%)	2 27	2 27	2 27

Improving Forage Quality

Objective:

The objective will be to improve the net/useful energy content of forages to reduce N and P excretion and methane emissions per unit of useful energy.

Key Assumptions:

1. There will be a 1% decrease in methane emissions as a percent of net energy for each percentage improvement in digestibility of forages. No effect is assumed in the feedlot.
2. There will be reductions in N and P excretion associated with improved feed quality and hence reduced feed intake.

Regional/Commodity Application:

This approach is applicable across Alberta.

Adoption:

Agronomists, district agriculturists, nutritionists and others have been emphasizing the importance of better forage quality over the last 100 years. Producers would like to have this and would work towards it. However there is still a great deal of misunderstanding as to what constitutes good quality forage. There is the need for a simple and precise analytical tool to accomplish the goal of providing this information to producers where proper and informed decisions can be made with respect to methods and economics of improving forage quality.

Recently in a study involving 6249 beef herds of cattle in Alberta, Dr. J. Basarab determined that only 17.7% of the producers had their winter feed supply tested (Mathison 1993). Some very limited support and demonstration of the relatively new near infrared reflectance spectroscopy for forage analysis which could increase use of this technology and hence give cattle, sheep and horse feeders information which they could use to improve forage quality.

The ultimate procedure for improving forage quality will involve improved harvesting and storage methods. The use of plastic wrappers for covering bales is one such innovation, which will result in improved forage quality.

Large amounts of the very low quality forage straw are utilized in beef cow diets. The overall quality of cereal crop by-products can be increased by harvesting chaff. Again, additional demonstrations of the value of chaff and improving mechanical means of collecting it, would improve the quality of cattle diets.

Forage quality can be improved by plant breeding but Canada has done little.

It is unlikely that it will pay economically or environmentally to chemically treat forages for feeding ruminants (i.e. ammoniation of straw), although microbiological modification may be possible.

Environmental, health and social impact:

Increasing forage quality should have no negative impact on the animals or environment, with the possible exception that if cows are ad libitum fed a better quality diet, they may become too fat, which will reduce their productivity and longevity.

Positive responses are to be expected on animal health when very low quality diets are fed. Reduction of deterioration of harvested forage will reduce formation of waste products that are burned on some farms and ranches.

Barriers and risks to adoption:

Lack of understanding of the importance of forage quality on the part of livestock producers and lack of appropriate technology to harvest forages properly and prevent spoilage of stored forages.

Research and information gaps:

At this time there is more of a technology gap than information gap. We need support to establish more calibration curves for the near infrared analytical equipment. This technology is as simple as measuring reflected light from ground samples with a $50,000 to $100,000 machine and provides the most accurate analysis of forage digestibilities and other aspects of nutritive value.

We need research support for quantifying forages losses in the field, during harvesting, during storage and during feeding so that the true economics can be used in an educational program.

We need to use a systems approach to develop better forage systems from the field to the manure pile.

More research into the genetic control of forage quality is essential.

Potential policy and/or industry measures to encourage use:

More extension work, with examples of economic implications will help. Government could coordinate the obtaining of animal samples required for calibrating the near infrared instrumentation. Support and demonstration of procedures such as maceration to reduce drying time of cut forages would improve hay quality.

Political considerations:

All help in this area would be considered positive.

Other considerations

Improved forage quality will also improve animal productivity and reduce nitrogen and phosphorus excretions.

Costs and Effect on Production:

Item			
Method	+1% improvement in forage	+3% improvement in forage	15%
Factors which will change rate of adoption	Better management of forages and harvesting, plastic wrap on bales, new crops	Others plus, education, forage testing, better quality forages, forage harvesting and storage	More application to move to this level.
New capital investment	None	Very little. New balers cost about $40,000 (John Deere, June 25, 1999). Hay macerators are still largely experimental.	
Increased costs per uni of forage harvested	None	Feed tests would be about $30/winter/sample. Plastic-wrap costs about $3/bale or $5/tonne of forage.	
Feed efficiency	+3%	+6%	+15%
Rate of gain (%)	6%	12%	30%
Milk production (%)	1% (Not as much since hay is already of high quality)	3% (Not as much since hay is already of high quality)	5% (Not as much since hay is already of high quality)
Risks to target animal	None	None	None
Reduction manure P (%) Reduction in N (%)	1 26	2 26	2 26

Reduction in Fat Content of Market Cattle and Milk

Objective:

It takes feed energy to put fat on animals or in milk. This increase in feed energy requirements is accompanied by an increase in N and P excretion and methane emissions. If we reduce fat content of animals, we will therefore reduce N and P excretion and methane emissions.

Key Assumptions:

1. Cattle which are fed to a weight of 100 kg more than they are suited for will have a 17% decrease in feed efficiency and a 17% increase in methane emissions per weight gain.
2. Nitrogen and P excretions will be increased by excessive fatness by about 25% of the decrease in feed efficiency.
3. A decrease in milk fat percentage from 3.5 to 3% will reduce feed requirements by about 5% and methane emissions by about 4%.

Regional/Commodity Application:

This approach will to apply to all beef animals marketed and to all dairy cows in Canada.

Adoption:

Unfortunately we are moving towards smaller and fatter animals that will decrease feed efficiency and increase methane emissions per unit of weight produced in our beef industry. This trend is unlikely to change in the next 10 years since there is about a 10-year cycle in the beef business.

There has been less emphasis placed upon milk fat in the dairy industry. However there is still a surplus of solids-not-fat in Canada. This may disappear in the next 10 years, which would help reduce fat levels.

Environmental, health and social impact:

It would be a very positive step if fat could be reduced in animal products since supposedly this would result in healthier foods for humans. All other aspects of fat reduction in animal products would also be positive.

Barriers and risks to adoption:

Major barrier to a reduction in fat in beef are concerns about palatability and tenderness. These problems do not seem insurmountable since the problems can be cured by better pre- and post-slaughter procedures and possibly by dietary changes to influence palatability. However the trend towards greater fatness is in the industry and it will continue for some time. The risks of adoption of a lower fat carcass thus could be a reduction in market share to other countries or to other types of meats.

Research and information gaps:

Intensive work on meat quality and development of processing techniques which allow for larger and leaner type of animals is needed.

Potential policy and/or industry measures to encourage use:

This is something the beef industry will have to handle. There could, however, be severe penalties attached to over-fat carcasses.

Other considerations

Nitrogen excretions and phosphorus excretions will be reduced if fat is reduced.

Costs and Effect on Production:

Item			
Application of method (kg of extra weight on animal and hence excessive fat)	50 kg extra weight (fat) and 0.1% decrease in milk fat	0 kg extra weight (fat) and 0.2% decrease in milk fat	30 kg less weight (fat) and 0.5% decrease in milk fat
Policy or factors which will change rate of adoption	Trend towards more marbling in beef	Recognition that fat will decrease efficiency and thus competitiveness	Genes for marbling, use of genetic markers
New capital investment	None	None	None
Increased costs	Increased costs of feeding in the feedlot by about 8%	Feeding costs stay the same	Decreased feeding costs by 4%
Feed efficiency	-8%	0%	4
Rate of gain on forage-based diets (%)	-16%	0%	+8
Milk production (%)	There is expected to be less fat in milk. A 0.1% reduction in milk fat should improve feed efficiency and reduce methane by 1%.	There is expected to be less fat in milk. A 0.2% reduction in milk fat should improve feed efficiency and reduce methane by 2%.	There is expected to be less fat in milk. A 0.5% reduction in milk fat should improve feed efficiency and reduce methane by 5%.
Risks to target animal	None	None	None
Reduction manure P (%) Reduction in N (%)	Reduced 26	Reduced 26	Reduced 26

4.1.4 Improved Reproductive Performance

Increase in percentage calf crop

Objective:

The objectives of this mitigation strategy are to increase the number of offspring per breeding female and thus to reduce the percentage of the total feed used to maintain the females in the production system.

Key Assumptions:

1. The percentage decrease in methane emissions in the breeding herd achieved will be proportional to the increase in offspring born. It should be possible to increase the percentage calf crop by 5% by 2010.
2. Percentage decreases in N and P excretions are 25% of percentage decreases in feed requirements.

Regional/Commodity Application:

The primary application of this technology will be in the beef industry.

Adoption:

Cattlemen are continuing to adopt new and better management procedures, which should result in a general improvement in reproductive performance. This trend will continue.

Environmental, health and social impact:

None.

Barriers and risks to adoption:

Cattlemen are slowly improving their management capabilities, thus reproductive performance is slowly increasing.

Research and information gaps:

Primary need is to implement the information, which is known at the present time.

Potential policy and/or industry measures to encourage use:

Increased extension activities.

Other considerations

If reproductive performance is improved there will also be less nitrogen and phosphorus excreted in the beef system.

Costs and Effect on Production of Reducing Bull Numbers and Using Advanced Reproduction Strategies:

Item			
Method	0% change	2% increase in calf crop	5% increase in calf crop
Factors which will change rate of adoption		Will result with increased economic pressures	Greater economic pressures which may force some producers out of business
New capital investment	None	None	Minimal, calving shelters
Increased costs	0	Some improvement in feeding and extra labor	Improvement in feed amounts and quality and extra labor
Reduced feed (kg feed required per calf weaned and per kg gain in feedlot)	0%	2% for cows	5% for cows
Increased calf weaned/ cow due to reproduction (%)	0%	2%	5%
Milk production (%)	0%	0%	0%
Risks to target animal	None	None	Minimal
Reduction manure P (%) Reduction in N (%	0 0	Some 31	Some 31

Increase in the Incidence of Twinning

Objective:

The objective of this mitigation strategy is to increase the number of offspring born per female by using a twinning strategy. This will reduce the percentage of the total feed used to maintain the females in the production system.

Key Assumptions:

1. The percentage decrease in N and P and methane emissions in the breeding herd achieved by twinning will be proportional to the increased number of offspring born.
2. The amount of N and P and methane produced will not be increased when an animal has twins. This assumption may not be exactly correct since twinning will increase the requirements of the individual animal but not in the same proportion as if two cows were required to produce the calf.

Regional/Commodity Application:

The primary application of this technology will be in the beef industry.

Adoption:

Cattlemen are continuing to adopt new and better management procedures that should result in a general improvement in reproductive performance. Most of the technology for twinning is still in the experimental stage and adoption will be slow. Increasing financial pressure will, however, cause beef producers to look at alternative beef production methods.

Environmental, health and social impact:

Increased calf mortality and assistance required during calving has been associated with twinning.

Barriers and risks to adoption:

Cattlemen are slowly improving their management capabilities, thus reproductive performance is slowly increasing. Until this time, cows genetically have not had the capability of routinely producing twins. There is now this possibility as a result of research work at Clay Centre, Nebraska by the USDA. Cattlemen traditionally have not been highly in favour of twins because of the increased calving problems and deaths associated with twinning. The risks would be a 20% higher assistance rate and a 15% higher death rate in newborn calves. This is probably too great for the majority of the cattlemen to accept. Heifer calves born twin with males are often sterile (freemartins).

Research and information gaps:

For twinning technology to work well there would be a need to genetically develop cattle that can routinely produce twins without having calving problems.

Potential policy and/or industry measures to encourage use:

The industry will pick up the technology if it works.

Other considerations

If reproductive performance is improved there will be less nitrogen and phosphorus excreted in the beef system.

Costs and Effect on Production:

Item			
Application of method	Same as before, about 3% twins	Possibility exists now for increasing calf crop to 120% with twins	With industry goal as twinning, % calf crop could be increased to 150%
New capital investment	None	Increased costs for breeding stock	Increased costs for breeding stock
Increased costs	-3	Greater costs for calving assistance, better feeding management, etc. Cost could be $40/calf.	Greater costs for calving assistance, better feeding management, etc. Cost could be $60/extra calf.
Reduced feed (kg feed required per calf weaned)	3%	15%	20%
Increased no. calf weaned/ cow due to reproduction (%)	3%	20%	30%
Milk production (%)	0%	0%	0%
Risks to target animal	None	Death loss increased by 15%	Death loss increased by 15%
Reduction manure P (%) Reduction in N (%)	Minimal 27	Minimal 27	Minimal 27

Reduction in Bull Numbers

Objective:

The objectives of this mitigation strategy are to use artificial insemination to reduce the number of bulls required in beef production.

Key Assumptions:

1. The percentage decrease in methane emissions due to bulls will be proportional to the percentage decrease in bull numbers.
2. Percentage decreases in nitrogen excretions are 25% of percentage decreases in feed requirements.

Regional/Commodity Application:

The primary application of this technology will be in the beef industry. The technology could be applied all across Canada but may be harder to apply under range conditions in western Canada.

Adoption:

There has been a very slow trend towards increased use of AI and less use of bulls in the beef industry, but the industry will be a long time in changing significantly unless the procedure is associated with implementation of newer genetic/reproductive technologies.

Environmental, health and social impact:

None.

Barriers and risks to adoption:

Bulls will still be needed since artificial insemination programs are very difficult to run under many pasture situations.

Research and information gaps:

Increased information on estrus synchronization would be very beneficial.

Potential policy and/or industry measures to encourage use:

Research into estrus synchronization methodology.

Other considerations

If reproductive performance is improved, there will also be less nitrogen and phosphorus excreted in the beef system.

Costs and Effect on Production of Reduced Bull Numbers:

Item			
Method	5% reduction in bull numbers	15% reduction in bull numbers through increased use of AI and better bull management	50% reduction in bull numbers
Policy or factors which will change rate of adoption		Better management and bull testing for fertility	Associated with new reproductive/genetic technologies
New capital investment	None	None	None
Increased costs	0	Costs are about similar for bull and many AI systems (bull depreciation, interest and feed vs. semen, heat detection and facilities). Costs of bull evaluations are $20 to $50/head	
Reduced feed	0%	Proportional to bull reduction	Proportional to bull reduction
Milk production (%)	0%	0%	0%
Risks to target animal	None	None	None
Reduction manure P (%)	Some	Some	Some
Reduction manure N (%)	27	27	27

Improvements in Management, Genetics and Reproductive Performance due to Enhanced Technologies

Objective:

The objective of this mitigation strategy is to evaluate a combination of new strategies that will increase the number of offspring per breeding female and rates of gain of the offspring and hence will improve feed efficiency and reduce methane emissions.

Key Assumptions:

1. The percentage decrease in methane emissions in the breeding herd achieved will be proportional to the increase in offspring born. In addition, there will be a reduction in methane emissions because of increased growth rate of the offspring. Taylor (1985) suggests efficiency of energy use for lean growth can be increased by 30% with single sex bred heifer and multiple ovulation and embryo transfer technology.
2. Percentage decreases in nitrogen excretions are 25% of percentage decreases in feed requirements.

Regional/Commodity Application:

The primary application of this technology will be in the beef industry but improvements in milk production are also possible with the newer genetic/reproductive technologies.

Adoption:

There will be increased use of embryo transplants, sexing technology, etc. as the demand for high quality cattle grows. It is anticipated that factors such as marker assisted selection, etc. will become quite important close to 2010.

Environmental, health and social impact:

Some concern about application of technologies such as cloning, genetic modification, etc.

Barriers and risks to adoption:

Public attitudes, it is undesirable to have cattle that are too genetically similar, unforeseen consequences of manipulation of genome.

Research and information gaps:

There will be a flurry of activity on genetic and reproductive technologies. The opportunities for advances are dependent upon such research activities.

Potential policy and/or industry measures to encourage use:

The industry will pick up the technology if it works and is cost effective.

Political considerations:

There is concern about the ethics of genetic technologies.

Other considerations

If reproductive performance is improved there will also be less nitrogen and phosphorus excreted in the beef system.

Costs and Effect on Production of Reduced Bull Numbers and Using Advanced Reproduction Strategies:

Item			
Method	0 change	15% enhancement in growth, reduction in cow numbers, and carcass quality. Single calf heifer technology would reduce cost of cows. Improvements in growth rate of animals through other technologies such as multiple ovulation and embryo transplants, semen sexing, marker assisted selection, etc.	30% enhancement in growth, reduction in cow numbers, and carcass quality. Single calf heifer technology would reduce costs of cows. Improvements in growth rate of animals through other technologies such as multiple ovulation and embryo transplants, semen sexing, marker assisted selection, etc.
Factors which will change rate of adoption		Increased research	Increased research
New capital investment	None	None	Minimal on farms but research and service facilities will increase
Increased costs		Difficult to estimate	Difficult to estimate
Reduced feed (kg feed required per calf weaned and per kg gain in feedlot)	0%	5% where applicable	30% where applicable
Milk production (%)	0	10	20
Risks to target animal	None	Minimal	Minimal
Reduction manure P (%)	0	Some	Some
Reduction in N (%)	0	27	27

Addition of Nitrates to Feed as a Competitive Methane Inhibitor

Objective:

Nitrates will be added to the diet as competitive inhibitors of methanogenesis. These compounds out-compete methanogens for hydrogen and electrons and thus reduce methane production.

Key Assumptions:

1. Nitrate additions have reduced methane emissions by up to 80% (Takahashi and Young 1991). However in excessive amounts they can be toxic to animals. Moreover, if nitrates are added in the form of ammonium nitrates rather than with inorganic cations, the extent of dietary additions will be severely limited because of the amount of nitrogen provided in the ammonium nitrate. We will thus assume a maximum of 0.5% of nitrate nitrogen addition to the diet, which should reduce methane emissions by about 10% since 3 to 5% in the diet should completely eliminate methane emissions (Mathison et al. 1998).
2. Nitrogen excretions will be increased slightly when nitrates are fed at this level, particularly if ammonium nitrates are used. We have thus restricted usage to those diets where the nitrates may replace urea in the diet as a supplemental nitrogen source.
3. Nitrate additions will have no positive effect (i.e. increased microbial growth is not assumed) or negative effect on the animal (used in place of urea and with equal efficiency).

Regional/Commodity Application:

This approach will apply to all beef and dairy cattle in Canada. Its use will, however, be primarily limited to animals being fed a nitrogen-limiting diet.

Adoption:

Since urea is normally included in many protein supplements available in Canada, adoption of this mitigation would not be difficult. Feed companies would simply replace urea in these supplements with nitrates, with warnings about the need for adaptation to the new feed.

Environmental, health and social impact:

Nitrates can kill cattle when fed at 0.45% of nitrate nitrogen in the diet so there is some concern. However urea can be fed to cattle, and it has been used as a dietary additive for years. Aside from this and the potential to make explosives from ammonium nitrate, there should be no concern if nitrates are only used in circumstances where nitrogen is limiting in the diet.

Barriers and risks to adoption:

Toxicity is a potential problem. When limited amounts are used toxicity will occur only in a very few isolated cases, much the same as is the case for urea toxicity now.

Research and information gaps:

Feeding trials are needed in which the effect of nitrates on rate and efficiency of gain are measured and compared with urea-fed cattle. Data on the effect of dietary nitrate additions on microbial growth in the rumen (expected to be positive) are needed.

Potential policy and/or industry measures to encourage use:

Nitrates will not be used in the diet unless there is a greenhouse gas emission reason to do so. Thus some tax or penalty for non-use or incentive for use would be needed. Alternatively, a regulation could be put into effect, which did not allow the use of urea in ruminant diets. Feed companies would then simply switch to nitrates providing they had sufficient research information showing no negative effects.

Political considerations:

It will be hard to explain why nitrates will actually help the environment!

Other considerations

Nitrogen excretions could be slightly increased. Possibility of use for explosives manufacture must be considered.

Costs and Effect on Production:

Item			
Application of method	0	0.1% of nitrate N in diet	0.5% of nitrate N in diet
New capital investment	None	None	None
Increased costs	0	Bagged ammonium nitrate cost \$326/tonne in Edmonton, which amounts to \$0.94/kg of N. This is slightly higher than urea. Feed costs might increase by \$0.2-\$0.4/tonne	Bagged ammonium nitrate cost \$326/tonne in Edmonton, which amounts to \$0.94/kg of N. This is slightly higher than urea. Feed costs might increase by \$1-2/tonne
Feed efficiency (%)	0	0	8
Rate of gain (%)	0	0	0
Milk production (%)	0	0	0
Risks to target animal	Possible toxicity	Possible toxicity	Possible toxicity
Reduction manure P (%)	0 if used properly	0 if used properly	0 if used properly
Increase in N (%)	??	??	??

Addition of oils to grain diets

Objective:

The addition of vegetable oils to diets has been shown to reduce methane emissions significantly. The objective of this strategy is thus not necessarily to use dietary oils to increase the energy content of the diet, rather to reduce methane emissions.

Key Assumptions:

1. Addition of oils to grain-based diets will reduce methane emissions by 20%. Higher levels of inhibition may be achieved if coconut oil is used, but this would be more expensive. The strategy will not be effective in hay-based diets because reductions in diet digestibility will make the practice uneconomical.
2. Addition of oils will cause not change in dietary energy content. This corresponds with literature results and is because the oils reduce digestibility, even of a grain-based diet.
3. Dietary oils will have no influence on N and P excretions.

Regional/Commodity Application:

This approach will be assumed to apply to all cattle fed high grain diets in Alberta (feedlot animals as well as dairy cows). Some dairy diets already incorporate oils.

Adoption:

Rate of adoption will depend upon economics unless specific incentives or penalties are used. Thus some dairy diets contain added fat at the present time and oil has been used in feedlot diets under some circumstances. However, the reduction in digestibility which accompanies dietary oil additions means that the expected increases in energy content do not occur which has an adverse effect on economics.

Environmental, health and social impact:

There will be no problems but producing vegetable oils is expensive, thus cropping strategies may change. There is some concern about medium-length fatty acids which may get into human diets. Could increase the amount of unsaturated fatty acids in animal products which is considered to be positive.

Barriers and risks to adoption:

Adoption would be very rapid if economics were positive.

Research and information gaps:

Research is necessary to determine the relative effects of various vegetable oils on methane emissions, dietary energy content, and performance.

Potential policy and/or industry measures to encourage use:

Encourage research to see if the use of oils can be justified economically.

Other considerations

We don’t expect any effect on nitrogen or phosphorus excretions.

Costs and Effect on Production:

Item		
Application of method	None	Oil at 4% of diet
New capital investment	None	None
Increased costs	0	Cost of vegetable oil is about 70 cents/kg. Thus if oil were added at 4% of the diet, the increase in feed cost would be about 15%.
Feed efficiency (%)	0	0
Rate of gain (%)	0	0
Milk production (%)	0	0
Risks to target animal	None	None
Reduction manure P (%)	Minimal	Minimal
Increase in N (%)	??	??

4.2 Summary and Conclusions of Mitigation Practices

4.2.1 Swine

In summary, it would be possible to decrease N and P excretions of swine and poultry by the year 2010 to 1990 levels through reductions in dietary protein content, increased use of synthetic amino acids, incorporation of enzymes in the diet, and improved growth and reproductive efficiency. Methane emissions are quantitatively insignificant in these classes of animals.

The most promising strategy to reduce nitrogen and phosphorus excretion by pigs involved three components: a reduction of dietary protein contents with the addition of free amino acids, an increase in dietary energy contents, or a reduction in the contents of non-starch polysaccharides. The second most promising strategy was the addition of phytase to diets. Primarily, phytase reduces the need to supplement diets with inorganic phosphorus and thus reduces phosphorus excretion, but it also improves the availability of other nutrients and animal performance.

The effectiveness of such measures, however, is not known and requires further research. However, according to our model, a 10% reduction in dietary protein concentration, combined with a 5% improvement of protein retention, feed efficiency and reproductive efficiency, reduced nitrogen excretion to 93% of 1990 levels. The same strategies would result in about 25-30% decrease in P excretion.

4.2.2 Poultry

As with pigs, reduction of dietary protein and P contents is the most effective strategy to reduce nitrogen excretion by poultry. It appears that it is possible to implement a minor (10 - 15%) reduction in dietary protein contents immediately. Further reductions, however, require research into amino acid requirements, possibly combined with the adoption of the concepts of digestible amino acids and of ideal protein. Other means of reducing nitrogen excretion by poultry are less effective, so that successful reduction of nitrogen excretion will necessitate a combination of mitigation strategies. A combination scenario, which was found to be effective in reducing nitrogen excretions, was a reduction of dietary protein contents by 10%, combined with an improvement of feed efficiency by 5% and the addition of phytase and NSP-digesting enzymes to poultry diets. These changes are all within the scope afforded by poultry production and could be adopted immediately. Full adoption of these strategies would reduce the nitrogen excretion by poultry in 2010 to 96% of the 1990 values. Methane emissions would increase to 106% of the 1990 values. Adoption of these strategies would be encouraged by high prices for dietary protein, e.g. soy bean meal, compared to free amino acids, and low prices for fat (to increase dietary energy content) and enzymes. Daily poultry methane emissions were assumed to equal 0.0071 g per kg body weight. It was therefore estimated that a total of 448 tonnes of methane were emitted by Canadian poultry in 1990. The C.E.E.M.A. model assumes that there are no direct methane emissions from poultry. Methane emissions and nitrogen excretions were projected to increase by 25 and 30%, respectively, from 1990 to 2010.

Methane production by poultry has received little attention so it is difficult to recommend specific mitigation practices. It appears that a reduction of non-starch polysaccharides is a viable approach, although definite data are missing. It is expected that most methods to reduce nitrogen excretion will also have a minor effect on methane production, but again there are no data available.

4.2.3 Cattle

Alberta cattle were estimated to excrete 18,380 and 23,065 and 25,767 tonnes of N in 1990, 1996 and 2008-12. For phosphorus, they were estimated to excrete 9,190, 11,532 and 12,883 tonnes per year for 1990, 1996 and 2008-12. Nitrogen and P excretions were reduced in conjunction with many of the methane mitigation strategies considered. However, the main mitigation strategy of reducing dietary protein content by 10% only reduced nitrogen excretions by an estimated 2%. This low level was because most beef cattle consume diets with a surplus of nitrogen, which do not contain any additional protein supplements. It thus would be very expensive to replace these feeds in the diet with feeds containing less protein. Therefore, a combination of strategies was developed.

The best combination of available mitigation strategies resulted in methane emissions that were 103% of 1990 levels. This combination included reducing the length of the backgrounding period, improving growth rate substantially, increasing the use of ionophores, improving genetics and reproductive technologies, replacing urea in ruminant diets with nitrates, and incorporating malate in diets. Other strategies include feeding to requirements, precision feeding, feed assays, use of high forages, feeding feedstuffs with high bioavailable P and N. It will not, however, be possible to reduce methane emissions to 1990 levels in ruminant animals unless a specific inhibitor of methane is commercialized. Similarly, it is apparent that N and P excretions in the near future will remain above 1990 levels because of the difficulties in adopting any of the proposed mitigation strategies under the extensive conditions of beef production.

Other mitigation strategies will be applied to a greater or lesser degree. A realistic decrease in nitrogen intake of 3% and hence excretion is all that could be expected to be achieved because most ruminant diets contain a surplus of nitrogen even though no protein supplements are added. However, if forage quality increases then dietary nitrogen content and hence nitrogen intake will also probably increase which will tend to negate any decrease in intake because of closer attention being paid to dietary nitrogen requirements.

Although it is very clear that methane emissions can be reduced substantially by reducing the length of the backgrounding period and increasing the time in the feedlot, the emphasis in the research community has been towards an increase in use of grazing strategies for growing/finishing cattle. Similarly, even though the reduction of excessive fatness will substantially reduce methane emissions it is unlikely that there will be any significant adoption of this mitigation strategy by 2010 since the trend is now towards fatter animals.

5 Key Research Gaps

The key research gaps are:

- Lack of basic understanding of the factors affecting dry matter intake and the relationship of feed intake and feed quality to manure production.
- Lack of detailed knowledge of amino acid and phosphorus requirements of ruminants.
- Lack of knowledge on the effects of genetics and implants on nitrogen and phosphorus excretion.
- Lack of knowledge on the effects of ionophores on nitrogen and phosphorus excretions relative to the effects of ionophores on maintenance energy requirements.

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