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OPPORTUNITIES FOR MITIGATION OF GREENHOUSE GAS EMISSIONS IN RUMINANTS THROUGH NUTRITIONAL STRATEGIES

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ABSTRACT

Global warming today is an issue about which the entire world is concerned. Global warming is the increase in average temperature of earth and oceans in recent times, resulting in a continued increase in temperature in future. The gases like carbon dioxide (CO_2), methane, ozone, nitrous oxide and sulphur hexafluoride as well as water vapours generally called greenhouse gases collect in the atmosphere like a blanket stopping the sun's heat and radiated off the earth's surface. Carbon dioxide is the most important greenhouse gas being added continuously to the atmosphere by human activity. Methane is the second most important greenhouse gas, accounting for one-fifth of the global warming, after CO_2, which is responsible for one half of the warming. The livestock are responsible for about 18% of global warming effect, even more than the contribution of the transportation sector. The culprit is methane, the natural result of bovine digestion, and the nitrogen emitted by manure. The deforestation of grazing land adds to the effect. This phenomenon of climate change in its own right poses a challenge to the livestock sector, by way of marring its productivity. The mitigation and adaptation strategies are specifically crucial for the animal agriculture sector, which provides livelihoods to about 1.3 billion people and contributes about 40% to global agricultural output. The impact of animal agriculture sector on global warming and that of the ensuing climate change on livestock productivity, and the resultant economic implications, is so significant, that it needs to be addressed urgently. The present paper aims at reviewing the nutritional strategies for ruminants as an option for climate change mitigation. Overall, there does not appear to be the possibility for large or quantum reductions in CH_4 emissions from ruminant systems from currently available nutrition-based technologies. However, technical efficiency in production systems should be optimised so as to minimise emissions per kg of milk or meat produced, and there is a key role for animal nutrition in achieving this optimisation.

Key words: Climate change, ruminants, mitigation.

INTRODUCTION

Ruminants produce greenhouse gases (GHG) in a number of ways. Enteric fermentation gives rise to methane (CH_4), nitrogen excreted especially by grazing ruminants promotes the formation of nitrous oxide, and stored manure gives rise to both CH_4 and nitrous oxide. Ruminant production systems also use fossil fuels and electrical power, and use products such as fertiliser, feedstuffs, pesticides that have incurred emission of GHG in their production. Many mitigation strategies have been proposed. This review examines a number of nutritional strategies to reduce of enteric CH_4. It does not consider biotechnology based interventions (e.g. immunisation, bacteriophages and bacteriocins, enzyme additives, yeast additives) or non-nutrient chemical additives (e.g. halogenated analogues). Accumulation of hydrogen (H) produced by microbial metabolism (e.g. rumen fermentation) is avoided mainly by CH_4 synthesis by rumen methanogens, which is a normal part of the fermentation process. Strategies to reduce enteric CH_4 production can therefore seek to reduce the production of hydrogen, inhibit methanogenesis and redirect hydrogen into alternative products, or provide alternative sinks for hydrogen. Nutritional abatement strategies are generally based around one of these fundamental processes. However, at a whole system level, nutrition can impact in other ways. For instance if animal performance is improved through better nutrition, energy for maintenance is reduced as a proportion of total energy requirement, and CH_4 associated with maintenance is reduced (Hindrichsen et al., 2006). Thus CH_4 emissions per kg milk or meat will be reduced. Similarly if improved animal performance leads to animals reaching target slaughter weight at a younger age, then total lifetime CH_4 emissions are reduced. On the other hand, going for increased performance may reduce longevity and thus even increase total lifetime emissions when accounting for rearing for replacement (Blaxter and Clapperton, 1969). For this reason, and because CH_4 mitigation strategies can impact on emissions of other GHG at some other point of the production system, the effect of mitigation strategies should be assessed on the full production system, i.e. a life-cycle analysis. To date, there are few such assessments of nutritional abatement strategies. Some other considerations are needed. Mitigation strategies need to be financially neutral at worst, and feasible at farm level, otherwise farmers will not willingly adopt them. They need to be acceptable by society, and what is acceptable in one society may not be in others (e.g. ionophores are banned in the EU, but are used in many other regions). Finally, different animal production systems throughout the world mean that mitigation strategies are not universally applicable (Czerkawski, 1969).

Diet quality – replacing roughage with concentrates:

Many experimental databases suggest that a higher proportion of concentrate in the diet leads to a reduction in CH_4 emissions as a proportion of energy intake (Blaxter and Clapperton, 1965) due mainly to an increased proportion of propionate in ruminal VFA. The scope for reductions in CH_4 emissions depends on the starting level of concentrates, as there are dietary limitations, and there are large differences in current usage of concentrates in different regions of the world. Maximum impact would be to change meat producing cattle and sheep from a predominantly forage diet, with approx 0.06 – 0.07 of GE being emitted as CH_4 and put them onto a feedlot diet, with emissions of 0.03 of GE (Johnson and Johnson, 1995). This would involve a radical change to the production systems in many areas of the world. Grain based feeding of beef cattle is primarily a North American system with this feeding practice being used to a lesser extent in Europe and Australia, and to a much smaller extent in other world regions. The scope in the dairy sector is lower, and milk quality is impacted once concentrates go above about 0.5 of the diet, a level which has already been reached in North America and many European countries (Hindrichsen et al., 2006)

Because other factors impact the total GHG budget (as production increases less animals are needed for a given output, and less land and/or less fertiliser is required for the animal enterprise; beef cattle or sheep reach target slaughter weight at an earlier age, with less lifetime emissions; extra concentrates need to be grown and processed, and associated GHG emissions need to be accounted for), this strategy should be considered from a whole system perspective. Lovett et al. (2006) examined the effect on on-farm and off-farm emissions of increasing concentrate feeding from 376 to 810 and 1540 kg/cow/lactation. Total emissions (both on and off-farm) were 1.149, 1.103 and 1.040 kg CO_2 equivalents per kg milk, respectively, for low, medium and high concentrate levels, i.e. a decrease of 9.5% between the extremes. Lovett et al. (2006) did not consider a possible increase in emissions from manure (Hindrichsen et al., 2006), so this reduction may be a slight overestimate. The financial cost to the producer of implementing the measure depended on the pedigree index of the cows. With low or medium index cows, costs were higher. With high index cows, it was profitable to go to the higher concentrate level. The implication of these studies is that careful consideration needs to be given at an individual farm level to ensure that the measure is cost effective and that a sufficiently large net reduction in GHG emissions is achieved to justify this attempt and its associated other problems.

Diet quality – carbohydrate type:

Structural carbohydrates (cellulose and hemicellulose) ferment at slower rates than non-structural carbohydrates (starch and sugars) and yield more CH_4 per unit of substrate fermented due to a greater acetate:propionate ratio (Czerkawski, 1969). It has also been suggested that non-structural carbohydrates should be further subdivided as soluble sugars have a higher methanogenic potential than starch (Johnson and Johnson, 1995). This suggests that cereal feedstuffs will result in lower emissions than by-product feedstuffs with higher fibre levels. However if looking at a systems analysis, GHG emissions associated with the cultivation and subsequent processing of starch-based animal feeds will have to be fully attributed to the animal feed whereas the emissions associated with cultivation and processing of by-products (e.g. sugar beet pulp) have to be divided between the waste product (beet pulp) and the main product (sugar). Consequently a greater net benefit to the atmosphere might result from the use of more fibrous concentrates due to their lower embedded GHG emissions. This subject needs experimental data as well as whole system or life cycle analysis (Van Dorland et al., 2007).

Forage species

The forage species fed to ruminants has been shown to influence CH_4 emissions. Animals fed legume forages have been observed to emit less CH_4 compared to emissions from grass-fed animals (Beever et al., 1985), although others (Van Dorland et al., 2007) reported no differences. Lovett et al, 2006 speculated that this may in part be due to the higher levels of intake and digestibility generally associated with legumes, and thus a modified ruminal fermentation pattern combined with higher passage rates. However, Beever et al. (1985) reported the same effect at comparable intake levels when working with pure swards of clover and perennial ryegrass. While this strategy has promise, farmers are often slow to replace grass with clover for reasons such as pasture management and the risk of bloat. Grass-clover mixtures are better adopted in that respect. As there are also possible benefits from reduced use of fertiliser nitrogen, it is worthy of further investigation, and in particular of whole system analysis.

Pasture management

Improving pasture quality is often cited as a means of reducing emissions (McCrabb et al., 1998), especially in less developed regions, because of improvements in animal productivity, as well as a reduction in the proportion of energy lost as CH_4 due to a reduction in dietary fibre. However, there is evidence that the impact of pasture quality on CH_4 emissions per kg of pasture consumed is small in temperate, well-managed swards. Molano and Clark (2008) reported no difference in CH_4 emissions per kg of grass dry matter intake (DMI) between lambs fed pasture with OM digestibility of 666 or 766 g/kg. Measurements with beef heifers in Ireland fed zero-grazed pastures with a similar range in digestibility showed no impact on CH_4 emissions per kg of DMI, although there was a significant increase in DMI of the high quality pasture (Boland, personal communication). So while it appears that pasture quality in well managed pastures will not have a large effect on emissions per kg of pasture consumed, there could be significant improvements in lifetime emissions or emissions per kg of product which should be examined in a whole system analysis. If pasture improvement leads to increased stocking densities, it could lead to greater emissions per ha. The effect of pasture improvement in Australian sheep farms was recently modelled by Alcock and Hegarty (2006), who reported only a small reduction in CH_4 output per kg liveweight.

However, in their case, the assumed individual sheep productivity was already quite high, and the pasture improvement was calculated to lead mainly to an increase in stock numbers. In addition, the simulation showed little effect on digestibility of the forage, but rather gave an increase in the quantity of forage available. Lovett et al. (2008) modelled dairy production systems in contrasting soil types (wet and impermeable vs dry and free-draining) and reported that the drier soils with a substantially longer grazing season supported milk production with significantly lower GHG emissions per kg of milk produced.

Quality and type of ensiled forage

Farmers ensile grass, maize, or other cereals crops to provide winter forage. When fed to ruminants, maize or other cereal silages could be expected to give reduced CH_4 emissions compared to grass silage due to a higher propionate fermentation because of the starch in the cereal silages, a higher voluntary intake of the cereal silages which will give lower ruminal residence time and restricted fermentation, and the higher voluntary intake may also give better animal performance and thus reduced emissions per kg of animal product. However, there is a need for animal studies to confirm this, and a need for whole system modelling to determine the impact on whole farm emissions. In terms of the effect of quality of cereal silages, there is recent evidence of a decline in CH_4 emissions per kg DM intake as starch content of maize silage increased (McGeough, personal communication).

Plant secondary compounds and plant extracts

There is currently interest in the role of plant secondary compounds such as saponins and tannins in reducing CH4 emissions (Wallace, 2004; Patra et al., 2006). Saponins have been shown to possess strong defaunating properties both in vitro (Wallace et al., 1994) and in vivo (Navas-Camacho et al., 1993) which could reduce CH4 emissions.

Beauchemin et al. (2008) recently reviewed literature related to their effect on CH_4 and concluded that there is evidence for a reduction in CH_4 from at least some sources of saponins, but that not all are effective. Likewise they reported that there is evidence that some condensed tannins (CT) can reduce CH_4 emissions. Some legumes contain CT, but unfortunately these may reduce forage digestibility and the CT containing varieties tend to have weak agronomic performance. McAllister and Newbold (2008) reported that extracts from plants such as garlic could decrease CH_4 emissions. While there is insufficient evidence to conclude on the potential of plant secondary compounds or extracts as mitigation strategies, this is likely to be an area of significant research over the coming years.

Adding lipid to the diet

It has long been noted that CH_4 emissions decrease with increasing fat and oil supplementation (Czerkawski et al., 1966). There is some evidence that the magnitude of the effect is source dependent. Oils containing C12 (lauric acid) and C14 (myrstic acid) are particularly toxic to methanogens (Machmüller et al. 2000; Dohme et al. 2001). Lipids cause the depressive effect on CH_4 emissions by toxicity to methanogens (Machmüller et al., 2003), reduction of protozoa numbers (Czerkawski et al., 1975) and therefore protozoa associated methanogens, and a reduction in fibre digestion (Van Nevel, 1991). This latter point could cause an impact on total tract diet digestibility, and lipids can also depress DMI. Therefore this strategy could negatively impact animal performance. However, if total dietary lipid is kept below 60-70 g/kg DM, the depressive effects on intake and digestibility are generally small (Van Nevel, 1991). Beauchemin et al. (2008) recently reviewed the effect of level of dietary lipid on CH_4 emissions over 17 studies and reported that with beef cattle, dairy cows and lambs, there was a proportional reduction of 0.056 in CH_4 (g/kg DM intake) for each 10 g/kg DM addition of supplemental fat. While this is encouraging, many factors need to be considered such as the type of oil, the form of the oil (whole crushed oilseeds vs pure oils), handling issues (e.g. coconut oil has a melting point of c. 25ºC), and the cost of oils which has increased dramatically in recent years due to increased demand for food and industrial use. In addition, there are few reports of the effect of oil supplementation on CH_4 emissions of dairy cows, where the impact on milk fatty acid composition and overall milk fat content would need to be carefully studied.

Strategies based on processed linseed turned out to be very promising in both respects recently (Martin et al., 2007). Most importantly, a comprehensive whole system analysis needs to be carried out to assess the overall impact on global GHG emissions.

Organic acids

Organic acids are generally fermented to propionate in the rumen, and in the process reducing equivalents are consumed. Thus they can be an alternative sink for hydrogen and reduce the amount of hydrogen used in CH4 formation. Newbold et al. (2005) reported fumarate and acrylate to be the most effective in batch culture and artificial rumen. There have been some recent in vivo studies. Newbold et al. (2002) reported a dose-dependent response to fumarate in sheep. Wallace et al. (2006) described a proportional reduction of 0.4 – 0.75 when encapsulated fumaric acid (0.1 of diet) was fed to sheep. On the other hand, others (McGinn et al., 2004; Foley et al., 2007) reported no or small reductions in CH4 (l/kg DM intake) when beef cattle were fed malate. While the level of reduction in CH4 emissions that could be achieved is somewhat uncertain, the main impediment to this strategy is the current cost of organic acids which makes their use uneconomical. Also, the impact of this approach on voluntary feed intake, effects on animal health and issues of ethics are still questionable.

Ionophores

Ionophores (e.g. monensin) are antimicrobials which are widely used in animal production to improve performance. Tadeschi et al. (2003) reported in a recent review that on feedlot and low forage diets, they tend to marginally increase average daily gain whilst at the same time reducing DMI, thus increasing feed efficiency by about 6%. Monensin should reduce CH_4 emissions because it reduces DMI, and because of a shift in rumen VFA proportions towards propionate and a reduction in ruminal protozoa numbers. In vivo studies have shown that animals treated with monensin emit reduced levels of CH4 (McGinn et al., 2004; van Vugt et al., 2005) but others have reported no significant effect (Waghorn et al., 2008 van Vugt et al., 2005). Van Nevel and Demeyer (1996) reviewed 9 experiments, and concluded that on average monensin reduces CH_4 production as a proportion of gross energy intake by 0.18, with the extent of the reduction being related to the dose and type of diet. Some work has suggested that the monensin induced reduction in CH_4 production may be transitory with CH_4 emissions returning to pre-treatment levels in a period as short as 14 days (Lovett et al, 2006). This is despite the changes in VFA proportions persisting (Mbanzamihigo et al., 1995). Not all long term studies have shown that the effect is transitory (Davies et al., 1982). The reason for the differences between studies is not clear and further work is needed to determine the reduction potential, particularly in dairy cow feeding where the supplementation is long term. But even if the response is transitory, the impact on DMI persists, and should reduce CH_4 emissions by up to 5%, due to the strong relationship between CH_4 production and DMI. However, there are regulations to prevent the use of ionophores as a dietary additive in the Kenya.

CONCLUSIONS

While there are several nutritional strategies that may reduce CH_4 emissions, there is insufficient data on many of these to judge their effectiveness. The greatest lack of information is in the area of whole system or life cycle analysis. This is urgently needed to judge the likely effectiveness of the mitigation strategies, to identify the most important gaps in our knowledge, and to help in directing research efforts to most promising strategies. Other strategies such as plant secondary compounds and extracts require much more research before their potential can be satisfactorily evaluated, while some strategies such as organic acids appear to have little prospect of commercialisation at present. Overall, there does not appear to be the possibility for large or quantum reductions in CH_4 emissions from ruminant systems from currently available nutrition-based technologies. However, technical efficiency in production systems should be optimised so as to minimise emissions per kg of milk or meat produced, and there is a key role for animal nutrition in achieving this optimisation.

IMPLICATIONS

With our current knowledge, it is not possible to significantly reduce GHG emissions from animal agriculture using practical and acceptable nutrition-based strategies. Some of the proposed measures are too costly or are insufficiently proven to be adopted at this stage. In particular the lack of whole system or life cycle analysis inhibits effective evaluation of mitigation strategies, which have generally been assessed to date in short-term studies where one GHG (e.g. CH_4) was studied. There are some potential strategies and further research is warranted. In addition, efficiency in animal production systems should be optimised to minimise emissions per kg of milk or meat produced.

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