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Strategy and Technology for Reducing Methane Emissions from Ruminants – A review

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Abstract : Ruminants on low quality feed possibly produce over 75 % of the methane from the world's population of ruminants. The supplementation to improve efficiency of feed utilization and increase product output may reduce methane production per unit of productions. Other additional strategies are available including improving diet quality, eliminating nutrient deficiencies, using growth promotants, appropriate genotypes, the increased use of ionophores that will reduce total feed fermented and decreased methane per unit of product. Environment-friendly development of livestock production systems demands that the increased production be met by increased efficiency of production. The stoichiometry of rumen fermentation has indicated an important approach to help ameliorate the greenhouse effect, that is, lowering of entric methane production per unit of feed intake or per unit of animal products from ruminants by strategic supplementation.

Index words : Methane, Ruminant, Strategy, Technology

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Introduction

Methane levels in the atmosphere have more than doubled to approximately 1800 ppb over the last 200 years (IPCC, 1990). Ruminants contribute äppoximately 18-20 % of global methane product annually (Gibbs *et al.*, 1989). Ruminant typically lose 6 % of their energy as eructed methane, The levels of ruminant production on roughage based diets are in general well below that possible from the available resources and are often between 10 to 30% of the genetic potential of animal species (Leng, 1991). The reasons for low productivity is complex but it has been argued that the poor feed base which provides imbalanced nutrition is by for the greatest limitation (Leng, 1990). Researchers have focused on finding methods to reduce methane emissions because of its inefficiency, not because of the role of methane in the global warming. However, methane can affect environment indirectly through atmospheric oxidation that produce carbondioxide (CO_2), a potent greenhouse gas (Johnson and Johnson, 1995). Potentially any technology which improves the efficiency of conversion of feed into livestock products lowers the number of animals required to produce the same amount of meat, milk, wool and other products. The increasing in such efficiency can have a significant effect on reducing methane emissions.

Materials and Methods

Literature concerning methane emissions published data (research, review, trianning and conference papers) were complied totalling 37 papers.

Discussion

Livestock Methane Emissions

Recently published estimated (Johnson *et al.*, 1996) that applied 1990 census data conducted by a method independent from Crutzens' for the major contributors, cattle and buffalo, largely confirmed their estimate (**Table 1**). Little change has been expected since 1990 because of static cattle numbers. The world's 1.3 billion cattle with their large body size, feed intake and extensive fermentation produce 73 % of the livestock methane. Water buffalo contribute another 10 %, sheep and goats 12 %, camels and swine about 1 % each, and horses and donkeys about 2 %

Table 1 Global estimates of methane emissions by livestock during recent years 1983 and 1990

Species	Crutzen (1983) estimated No. head x 10^3	Crutzen (1983) estimated Methane (Tg/year)	Gibbs and Johnson (1990) estimated No. head x 10^3	Gibbs and Johnson (1990) estimated Methane (Tg/year)	%
Cattle	1225	54.3	1279	58.1	73.4
Buffalo	124	6.2	141	7.7	9.7
Sheep	1137	6.9	1191	7.0	8.8
Goats	476	2.4	557	2.8	3.5
Camels	17	1.0	19	0.9	1.1
Pigs	774	0.9	857	1.0	1.1
Equine	117	1.7	119	1.7	2.1
Total		73.4		79.2	

Data from Johnson et al. (1996).

Tg = Teregram = 10^{12} g = million metric ton

Methane Emissions and the Greenhouse Effect

The greenhouse effect, or increasing world temperature, is due to the accumulation of gas in the atmosphere. It is clearly ascribable to the major industrial countries, as some 50 % of the increased retention of energy by the atmosphere is a result of the accumulation of CO_2 from combustion of fossil fuel. Industrialized countries presently consume 70% of the world's oil production (Leng, 1993). Methane concentrations in the world's atmosphere are rising rapidly, and although they contribute only 19 % of the averall warming, methane is major component (Mosier *et al.*, 1991). Relative to other greenhouse gases, methane half-life is short, 10 to 12 years, requiring a decreased entry rate of only about 10 % to stabilize present concentrations. About one third of methane comes from nature sources; another third is oil, gas and refuse related, and the balance is from agricultural sources (**Table 2**). Animal agriculture contributes to accumulation of methane gas directly through production of methane in fermentative digestion in the rumen, and indirectly when faecal materials decompose anaerobically (Safley *et al.*, 1992). Ruminant animals produce a relatively small proportion (18 %) of the total global emissions (**Figure 1.**). However, the domestic ruminants represent one of the few sources that can be manipulated. Biotechnology, feeding, management and breeding can be combined to improve animal production and could potentially increase animal production to the extent that in the would, it may be possible to reduce methane generation by up to 60 % from the same product (Leng, 1991).

Table 2 Global sources and sinks of atmospheric methane

Sources	Tg/year	Sinks	Tg/year
Natural sources			
Wetland	110	Hydroxyl (CH)	450
Oceans, hydrates	35	Soils	30
Termites	20	Cl and O	40
Buring and others	5		
Agricultural			
Rice	65		
Livestock	80		
Manure	10		
Biomass burning	30		
Energy and waste			
Gas and oil industries	70		
Coal mines	40		
Charcoal/wood	10		
Wastewater	25		
Landfills	40		
Total, all	540		

Data from Johnson et al. (1996).

Tg = Teregram = 10^{12} g = million metric ton

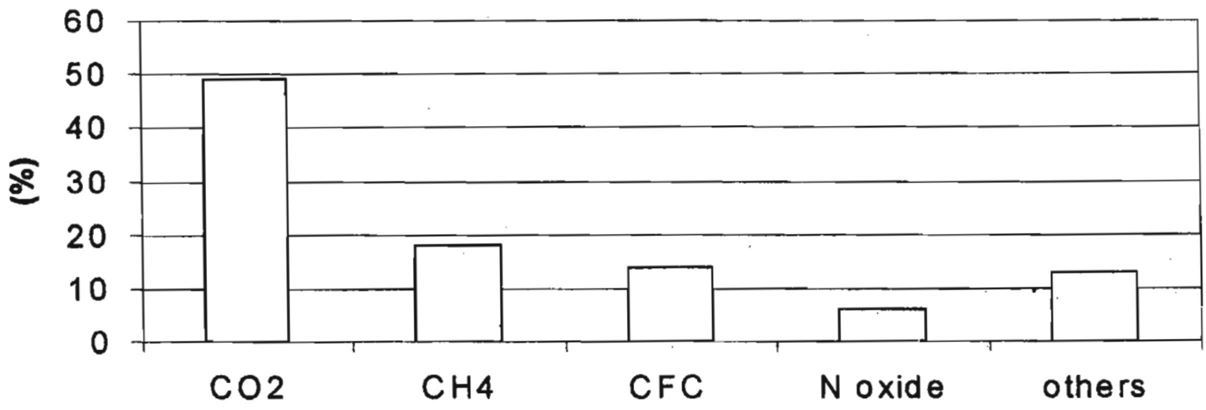

Figure 1 Relative contribution (%) of greenhouse gases to atmospheric warming (Leng, 1993)

Ruminal Methane Production

Ruminant methane production is responsible for approximately 95 % of total global animal and human methane emissions (Johnson *et al.*, 1991). Furthermore, 90 % of ruminant methane is produced in the forestomachs, while only 10 % originates from hindgut fermentation (Murray *et al.*, 1978); Van Nevel and Demeyer, 1995). During the microbial fermentation process in the rumen, carbohydrates, protein and glycerol are oxidized anaerobically to acetate, CO_2 and ammonia, with methane, propionate and butylrate being produced mainly as a result of electron and protein transfer reaction (H- sinks). The reduction of CO_2 with H_2 via methanogenesis keeps the partial pressure of H very low, and this has an important effect on the overall fermentation, hydrogenase activity can proceed towards ethanol as major end-products and allowing more acetate to be produced (Wolin and Miller, 1988).

The efficiency of microbial growth is nutritionally important, because microbial protein flowing from the rumen is the most important source of protein for ruminant. The standard free energy change of overall process of methane production ($CO_2 + 4H_2 \rightarrow CH_4 + 2H_2O$) is negative and allows formation of ATP, which is used by the methanogenic bacteria for maintenance and growth purpose (Russell and Wallace, 1988). Inhibition of methanogenesis lowered microbial growth yields only when H gas accumulated, perhaps because of an impairment of substrate level phosphorylation mechanisms (Van Nevel and Demayer, 1981; 1995). It was also soon observed that inhibition of methanogenesis shifted electron transfer to propionate production as an alternative electron sink in fermentation. It can be speculated that the loss of ATP yield caused by lower acetate and methane production is compensated by an increased ATP yield from propionate formation, during which ATP is also generated (Russell and Wallace, 1988).

Methane Production from Poor Quality Roughage

Methane output relative to product output of ruminants depends on two factors; the efficiency of fermentative digestion in the rumen and the efficiency of conversion of feed to product which in turm depends on the balance of nutrients absorbed (Leng, 1993). The type of carbohydrate fermented influences methane production most likely through impacts on ruminal pH and the microbial population. Fermentation of cell wall fiber yields higher acetic : propionic acid and higher methane lossed (Moe and Tyrell, 1979; Beever *et al.*, 1989). In ruminants on poor quality forage a number of essential nutrients may be deficient and microbial growth efficiency in the rumen is low. In these conditions methane produced may represent 15-18 % of the digestible energy, but correction of these deficiences reduces this to as low as 7 % (Leng, 1993).

Methane production is determined by two animal production parameters (de Haan *et al.*, 1996). First, ruminant animals with low levels of productivity use a large fraction of their feed intake for maintenance and, consequently, the emissions are spread over a relatively small output, resulting in a high level of emissions per unit of product. Second, feed quality has an important impact on the levels of methane emissions. Very low quality of feeds, have low levels of digestibility, and therefore higher emissions per unit of feed intake. Low productivity and poor feed quality are characteristic for most of the land-based production systems in arid regions, and to an ever greater degree in the humid tropics and sub-tropics, where emissions per unit of product are therefore comparatively high. Grazing and mixed systems in the tropics and sub-tropics are thus the main contributors to high methane emission levels. In irrigated areas, fodder is usually of better quality resulting in lower emissions.

Strategy for Reducing Methane in Ruminants

Feed and Feeding Management

Physical and chemical processing of diets such as grinding, pelleting of diets can reduce methane losses by 20 to 40 % (Blexter and Clapperton, 1965). Okine *et al.* (1989) found 29 % reductions in methane when weights were placed in the rumen, which accelerated passaged rate but did not change digestibility. Chemical treatments such as sodium hydroxide (Robb *et al.*, 1979) or ammoniation (Birkelo *et al.*, 1986) of straw have been shown to increase methane loss in proportion to increased digestibility. The decrease undoubtedly relates to the faster rate of passage and lowered cell wall carbohydrate digestibility that occurs when these small particle feedstuffs are fed ad libitum. Faster rate of passage may reduce methane, conceivably through changes in microbial species or site of digestion (Johnson *et al.*, 1996). There are serveral factors that contribute to methane suppression when animals are fed these diets. Starch substrate, low pH, rapid passage and depressed protozoal populations. Ionophores can improvement in feed efficiency (Goodrich *et al.*, 1984; Thornton and Owens, 1981), when added to ruminant diets. One commonly held mode of action is to shift the fermentation parttern to result in a higher propionate production and reduced methane loss (Johnson *et al.*, 1996). Urea and other supplemental nutrients are mixed with molasses (multi-nutrient blocks) to make it palatable to livestock. In addition, molasses provides the energy needed to realize the improved microbial growth that can result from enhanced ammonia levels. Many reports have shown both increased production and reduced methane emissions (Habib *et al.*, 1991; Hendratno *et al.*, 1991; Leng, 1991). On the other hands, Van der Honing *et al.* (1981) found 10 to 15 % decreases in methane loss from dairy cows fed 5 % tallow or soybean oil, because of reductions in methane can result from uptake of H by unsaturated fatty acid additions (Czerkaski, 1969).

To reduce methane emissions, improved breeding, veterinary care, better feeds and improved feeding technologies are the main weapons, although these technologies are usually not employed for their environmental benefits but for increasing profitability. Improvements in animal productivity have two beneficial effects (Van Nevel and Demeyer, 1995).

They direct a greater proportion of feed energy to the production of useful products (milk, meat, draft power, offspring), and thus reduce methane emissions per unit of product. In addition, they lead to reductions in the herd size required to meet a given production level. Methane production was found to be negatively related to the level of intake, while at a maintenance level of feeding, increases in digestibility resulted in higher methane production (Blexter and Clapperton, 1965). For efficient digestion, the rumen requires a diet that contains essential nutrients for the fermentative micro-organisms. Lack of these nutrients lowers animals on low quality feed the primary limitation to efficient digestion is the concentration of ammonia in the rumen. Supplying ammonia can therefore greatly enhance digestive efficiency and utilization of available feed energy. Urea is broken down in the the rumen to form ammonia, and adding urea to the diet has been the most effective method of boosting rumen ammonia levels.

Microbial Feed Additives

A wide range of microbial feed additives for ruminants has been described in cluding bacterial cultures from both ruminal and nonruminal sources (Johnson *et al.*, 1972), and mixtures of bacteria and fungi (Windschitl, 1992; Newbold, 1995). By far the most commonly used products are those based on *Aspergillus oryzae* (AO) and/or *Saccharomyces cerevisiae* (SC). Carro *et al.* (1992) found that SC caused a greater stimulation in bacteria protein synthesis on a high concentrate diet than on high forage diet, and their effect on rumen fermentation and animal productivity has been reviewed recently by serveral authors (e.g., William, 1988; William and Newbold, 1990; Martin and Nisbet, 1992). More consistent results were obtained by Frumhoitz *et al.* (1989) and Mutsvangria *et al.* (1992), the first group added 250 mg AO daily to Rusitec and the percentage of methane in the headspace gas decreased to approximately 50 % of the control value. Protozoal number were reduced by 45 %. Because of the close association between methanogens and cilates, and between ciliates and other members of the bacterial population, the microbial additives could therefore change the composition of the microbial flora and decrease methane inhibition indirectly by altering the balance of the population.

Defaunation of the Rumen

Decreased methanogenesis in defaunated animals can be explained by that low rumen digestibility of the crude fibre fraction of the ration, an altered volatile fatty acid (VFA) pattern in the rumen, with an increased proportion of propionate, due to changes in the composition of the microbial, losse of methanogens attached to ciliates, then loss of protozoa which produce H or formate, which in turn are precursors of methane (Van Nevel and Demeyer, 1995). The lower methane production in the rumen of chemically defaunated is not the result of toxic effects of the defaunating agent on bacteria as the same effect was found in animals raised ciliate free form birth (Kreuzer *et al.*, 1986).

Integrated Farming

Integrated crop and livestock production systems are highly efficient, if potential crop residues are used as livestock feed, the waste products (e.g. urine and faeces) are fed into biogas digestors and the efficient use of effluent to fertilise ponds for aquatic plant. The environmental attributes of such systems methane emissions into the atmosphere and fossil fuel use, are minimised. However, the efficient and almost total harnessing of the energy from high producing crops reduces the land areas required per unit of product (Leng, 1990, 1991).

Conclusions

Ruminant methane production is responsible for approximately 95 % of total global animal and human methane emissions. Furthermore, 90 % of ruminant methane is produced in the forestomachs, while only 10 % originates from hindgut fermentation. Ruminant livestock can produce 250 to 500 L of methane per day, and contribute a significant amount (18 % of the total) of the world production of methane and are targeted as a source which is one of the few easily manipulated. Many factors influence methane emissions from cattle and include the following, level of feed intake, type of carbohydrate in the diet, feed processing, feed additives in the diet, biotechnological supplementation, and alterations in the ruminal microflora. Integrated crop and livestock production systems are highly efficient, if potential crop residues are used as livestock feed, the waste products are fed into biogas digestors and the effluent be used to fertilise ponds for aquatic plants. Implementation of these strategies should result in enhanced animal productivity and decreased contributions by ruminants to the atmospheric methane budget and, thus, reducing environmental pollution.

References

Beever, D.E., S.B. Cammell, J.D. Sutton, M.C. Spooner, M.J. Haines and J.I. Harland. 1989.The effect of concentrate type on energy utilization in lactating cows. Proc. 11th Symp. On Energy Metabolism. EAAP Plublication No. 43: 33.

Birkelo, C.P., D.E. Johnson and G.M. Ward. 1986. Net energy value of ammoniated wheat straw. J. Anim. Sci. 63: 2044-2053.

Blexter, K.L. and J.L. Clapperton. 1965. Prediction of the amount of methane produced by ruminants. Br. J. Nutr. 19: 511-522.

Carro, M.D., P. Lebzien and K. Rohr. 1992. Influence of yeast culture on rumen fermentation (Rusitec) of diets containing variable portions of concentrates. Anim. Feed Sci. Technol. 37: 209-220.

Czerkawski, J.W. 1969. Methane production in the rumen and its significance. World Rev. Nutr. Diet. 11: 240-282.

de Haan, C., H. Stainfeld and H. Blackburn. 1996. Livestock & the Environment Finding a Balance. European Commission Diredtorate-General for Development, Development Policy Sustainable Development and Natural Resources. pp 115.

Gibbs, M.J., L. Lewis and J.S. Hoffman. 1989. Reducing Methane Emissions from Livestock Opportunities and Issues. U.S. Environmental Protction Agency, Washing, D.C. pp 284.

Goodrich, R.D., J.E. Garett, D.R. Gast, M.A. Kirick, D.A. Larson and J.C. Meiske. 1984.

Influence of monensin on the performance of cattle. J. Anim. Sci. 58: 1484-1494.

Habib, G., S. Basit Ali Shah, S. Wahidullah, Jabbar, G. Ghufranullah. 1991. Important of Urea

Molasses Blocks on Animal Production. International Atomic Energy Agency, International Symposium on Nuclear and Related Techniques in Animal Production and Health, Vienna, Australia, 15-19 April.

Hendratno, C., J.V. Nolan and R.A. Leng. 1991. . Important of Urea Molasses Blocks on Animal Production. International Atomic Energy Agency, International Symposium on Nuclear and Related Techniques in Animal Production and Health, Vienna, Australia, 15-19 April.

IPCC (Intergovermental Panel on Climate Change). 1990. Climate Change: The IPCC Scientific Assesment, Cambridge University Press, London.

Johnson, D.E., T.M. Hill, B.R. Carmean, D.W. Lodman and G.M. Ward. 1991. New perspectives on ruminant methane emissions. In: Energy Metabolism of Farm Animals (C. Wenk and M. Boessinger, eds) ETH, Zurich, Switzerland, pp. 376-379.

Johnson, K.A., and D.E. Johnson. 1995. Methane emissions from cattle. J. Anim. Sci. 73:2483-2492.

Johnson, D.E., G.M. Ward and J.J Ramsey. 1996. Livestock methane: current emissions and mitidation potential. In: Nutrient Management of Food Animals to Enhance and Protect the Environment (E.T. Kornegay, ed). CRC, Lewis Plublishers, New York, London. pp 219-233.

Johnson, E.D., A.S. Wood, J.B. Stone and E.T. Moran, Jr. 1972. Some effects of methane inhibition in ruminants (steers). Can. J. Anim. Sci. 52: 703-712.

Kreuzer, M., M. Kirchgessner and H.L. Muller. 1986. Effect of defaunation on the loss of energy in wethers fed different quantities of cellulose and normal or steamflaked maize starch. Anim. Feed Sci. Technol. 16: 233-241.

Leng, R.A. 1990. Factors affecting the utilization of poor quality forages by ruminants particularly under tropical conditions. Nutr. Res. Rev. 3: 277-303.

Leng, R.A. 1991. Improving Ruminant Production and Reducing Methane Emissions from Ruminants by Strategic Supplementation. U.S. Environmental Protection Agency, Washington, D.C. EPA/400/1-91/004.

Leng, R.A. 1993. Quantitative ruminant nutrition- A green science. Aus. J. Agric. Res. 44: 363-380.

Martin, S.A. and D.J. Nisbet. 1992. Effects of direct-fed microbials on rumen microbial fermentation. J. Dairy Sci. 75: 1736-1744.

Moe, P.W. and H.F. Tyrell. 1979. Methane production in dairy cows. J. Dairy Sci. 62: 1583-1592.

Mosier, A. D. Schimel, D. Valentine, K. Bronson and W. Parton. 1991. Methane and nitrous oxide fluxes in native, fertilized and cultivated grasslands. Nature, Lond. 350: 330-332.

Murray, R.M., A.M. Bryant and R.A. Leng. 1978. Methane production in the rumen and lower gut of sheep given lucerne chaff: effect of level of intake. Br. J. Nutr. 39: 337-345.

Mutsvangwa, T., I.E. Edwards, J.H. Topps and G.F.M. Paterson. 1992. The effect of dietary inclusion of yeast culture (Tea-sacc) on patterns of rumen fermentation, food intake and growth of intensively fed bulls. Anim. Prod. 55: 35-40.

Newbold, C.J. 1995. Microbial feed additives for ruminants. In: Biotechnology in Animal Feeds and Animal Feeding (R.J. Wallace and A. Chesson, eds). VCH, Weinhiem. pp 259-278.

Okine, E.K., G.W. Matheson and R.T. Hardin. 1989. Effects of changes in frequency of reticular contractions on fluid and particle rates of passage in cattle. J. Anim. Sci. 67: 3388.

Robb, J., t.j. Evans and C.A. Fisher. 1979. A study of nutritional energetics of sodium hydroxide treated straw pellets in rations fed to growing lambs. In: Energy Metabolism. European Association for Animal Production. pp 26.

Russell, J.B. and R.J. Wallace. 1988. Energy yielding and consuming reactions. In: The Rumen Microbial Ecosystem (P.N. Hopson, eds). Elsevier Applied Science, London, UK. pp. 185-215.

Safley, L.M., M.E. Casada, J.W. Woodbury and K.F. Roos. 1992. Global Methane Emissions from Livestock and Poultry Manure. U.S. Environment Protection Agency, Washington, D.C.

Thornton, J.H. and F.N Owen. 1981. Monensin supplementation and *in vivo* methane production by steers. J. Anim. Si. 52: 628-636.

Van der Honing, Y., B.J. Wieman, A. Steg and B. Van Donselaar. 1981. The effect of fat supplement of concentrates on digestion and utilization of energy by productive dairy cows. Neth. J. Agric. Sci. 29: 79-88.

Van Nevel, C. and D. Demeyer. 1981. Effect of methane inhibitors on the metabolism of rumen microbes *in vitro*. Arch. Tierernahrung. 31: 141-151.

Van Nevel, C. and D. Demeyer. 1995. Feed additives and other interventions for decreasing methane emissions. In: Biotechnology in Animal Feeds and Animal Feeding (R.J. Wallace and A. Chesson, eds). VCH, Weinheim. pp. 329-349.

William, P.E.V. 1988. Understanding the biochemical mode of action of yeast culture. In: Biotechnology in the Feed Indrustry (T.P. Lyons, ed). Alltech Technical Publications, Nicholasville, Kentucky, US. pp 79-100.

William, P.E.V. and C.J. Newbold. 1990. Rumen probiosis: the effect of novel microorganisms on rumen fermentation and ruminant productivity. In: Recent Advances in Animal Nutrition (W. Haresign and D.J.A Cole, eds). Butterworths, London, UK. pp 211-227.

Windschitl, P.M. 1992. Effects of probiotic supplementation of hull-less barley and corn based diets on bacterial fermentation in continuous culture of ruminal contents. Can J. Anim. Sci. 72: 265-272.

Wolin, M.J. and T.L. M iller. 1988. Microbe-microbe interactions. In: The Rumen Microbial Ecosystem (P.N. Hopson, eds). Elsevier Applied Science, London, UK. pp. 343-359.