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Methane production in relation to productivity of livestock and environment: A review

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ABSTRACT

Fermentation of feed in rumen of animal results in production of volatile fatty acids (acetate, propionate and butyrate), and microbial protein is synthesized from protein and non-protein nitrogen. Volatile fatty acids are the source of energy, and protein synthesised is used as source of protein by the host animals. In addition VFA and microbial protein, methane is produced. Feed energy is lost to the tune 5-15% of grass energy. However, feed energy loss in methane is reduced by increasing the concentrate in diet, balance diet, feeding of green fodder, supplementation of deficient nutrient including urea-molasses – minerals, supplementation of feed additives etc. Secondly methane emission reported by outside workers was higher to estimates of Indian workers. Proper feeding of livestock will increase the productivity and protect the environment in terms of global warming.

Key words: Environment, Livestock, Methane Production, Productivity

Methane is produced naturally by ruminants during normal digestion process in the rumen. Microbes ferment the feed consumed by the animal and produce fermentation products that are used to support the animals' maintenance, growth and production requirements. Methane, produced during fermentation process, is wastefully exhaled into the air, representing a loss of 4 to 15% of the animals' feed energy (Dhiman *et al.* 1998) However, Johnson and Johnson (1995) reported 6.8% of GE last in methane. Production of methane in the rumen is correlated with feed quality, feed digestibility, type and size of the animal and production level of the animal. While ruminants are capable of subsisting on relatively low quality forages and crop residues, the low digestibility of these feed sources contributes substantially to methane production by them and limits their production efficiency (Wang *et al.* 2002).

In a highly digestible ration (>70%), it would be expected that 4 to 6% of the total digestible energy would be converted to methane. As the digestibility of the diet decreases, the proportion of digestible energy that is converted to methane increases to as much as 15% in a diet having less than 50% digestibility. Diets with low digestibility produce substantially higher methane per unit of product. The increase in feed digestibility and the efficiency of its utilization can reduce methane emission substantially. Methane production during the feed fermentation is not only the loss of feed energy but methane causes global warning and depletion of ozone layer. Therefore attempts have been made to review the experimental results in respect of livesock productivity and methane production, methane production by Indian livestock, methane reaction in atmosphere and nutrient energy loss in methane.

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Methanogenesis and diet

Methane is produced during the fermentation of feed in rumen and guts, however, rumen fermentation resulted 87% (Murray *et al.* 1976) and gut fermentation contribute 13% of total methane produced (Moss *et al.* 2001). Looking into stoichiometry of hexose fermentation the following three type of fermentation is possible (Singh 1997) depending on the situation.

(i) $C_6H_{12}O_6 \rightarrow 2\ CH_3COOH + 2\ CO_2 + 8\ [H]$
(Methanogenic)

(ii) $C_6H_{12}O_6 \rightarrow 2\ CH_3CH_2COOH + 2\ CO_2 + 4\ [H]$
(Glucogenic)

(iii) $C_6H_{12}O_6 \rightarrow CH_3CH_2CH_2COOH + 2\ CO_2 + 4\ [H]$
(Methanogenic)

Thus 12[H] are produced, however, 4[H] are utilized for propionate formation and 8[H] are converted to methane or utilized for biohydrogenation of feed unsaturated fat.

$$4H_2 + CO_2 \rightarrow CH_4 + 2\ H_2O$$

This is a theoretical calculation and may vary from feed to feed. The molar percentage of volatile fatty acids (VFA) plays a key role because fibrous feed results in higher methanogenic VFA, ultimately higher methane, (Singh *et al.* 1993). In India and in most of the developing countries, cereal crop residues are the major source of feed for ruminants. These are poor source of nitrogen and minerals and energy present in the form of cellulose/hemicellulose, which on fermentation give rise to higher methanogenic VFA and produce more methane (Singh and Oosting 1992). Supplementation of highly cellulose diet (straw) with deficient nutrients optimize the rumen fermentation and reduce the methane production (Preston and Leng 1987). The increases of efficiency of growth and milk production was because of higher energy available for production function.

Feed of the animals

Quantity and quality of feed consumed by animal have a major effect on the nutrient utilization for productivity and methane production because the individual VFA proportion in rumen is influced by the quality and quantity of feed consumed and roughage: concentrate ratio (Fashey and Berger 1988). Methane emission would be less when grains are fed due to higher production of propionic acid. Johnson and Johnson (1995) reported drastically fall in methane emission from a level of 6 to 12% of energy intake when forages were fed at maintenance to as low as 2-3 % when high grain concentrates (>90% concentrate) were fed at near *ad lib.* intake level. Van Soest (1982) indicated that a high grain diet and / or the addition of soluble combabydrote shift the rumen fermentation to words propionate resulting in less methanogenic VFA. Methane production was higher for coarsely chopped than finally ground pilleted diets (Moss 1992, Hironake *et al.* 1996). According to Vagra *et al.* (1985), methane yield from leguminous forages were lower than from grass forages due quality and quantity of carbohydrates. Methane emission from animals fed forage based diets is influnced by stage of maturity, method of preservation, species and climate. Quantity of methane emission increased when low quality forages were improved by certain treatments like urea, ammonia, sodium hydroxide etc. but the amount of methane was decreased relative digestible organic matter intake (Mc Allister *et al.* 1996, Moss *et al.* 1994). Incorporation of concentrate mixture to paddy straw plus fodder based diet reduced the methane emission from 19.26 to 18.40 g/kgDM (Srivastava and Garg 2002). They also reported that the supplementation of urea molasses mineral block (UMMB) to paddy straw reduced the methane emission from cows.

Supplementation of nutrients to straw-based diet

In India and in most of the developing countries, cereal straws are the major feed for ruminants. These are poor sources of nitrogen and minerals and energy, because of being present in the form of cellulose/hemicellulose, which on fermentation give rise to higher methnogenic VFA, and produce more methane (Singh and Oosting 1992). Supplementation of straw diet with deficient nutrients however, optimizes the rumen fermentation leading to reduced methane and carbon dioxide production and increases the efficiency of growth and milk production.

Supplementation of UMM lick to crop residue diet

Percentage of methane in ruminal gases decreased from 41.3 to 38.2% in untreated wheat straw and from 38.6 to 35.4% in urea-treated wheat straw owing to supplementation of urea-molaases-mineral (UMM) lick. Thus methane in rumen gas reduced by 5.8 to 7.5% and 6.0 to 8.0/% on untreated and urea-treated straw, respectively. However, the percentage reduction of methane in rumen gas was 12-15 due to both supplementation of UMM lick and urea treatment. Molar percentage of acetate decreased significantly due to supplementation of UMM lick and urea treatment (Singh *et al.* 1995). Molar percentage of acetate decreased significantly due to supplementation of UMM lick to straw-based diet. The percentage increase of molar propionate decreased the methanogenic VFA (Singh *et al.* 1993).

Percentage of methane in rumen gas decreased from 42.2 to 35.5% due to supplementation of UMM lick to paddy straw-based diet, resulting in about 9% decrease of methane on untreated paddy straw, and from 39.7 to 35.5% on urea-reacted paddy straw, the reduction being to the extent of 11%. Methane production decreased from 2.76 moles/kg digestible dry matter (DDM) to 2.30 moles/kg DDM due to supplementation of UMM lick and urea treatment of paddy straw, resulting in 16.7% reduction of methane (Singh *et al.* 1995). Increase in propionate due to supplementation affects the methane because propionate acts as a hydrogen sink (Bever *et al.* 1993, Singh *et al.* 1995)

For the ruminants fed mainly on straw, the methane generated/kg meat is estimated about 2 kg methane/kg meat produced. However, by supplementing with urea, minerals and by-pass protein, methane production is 0.36 kg/kg meat due to increased efficiency of fermentation, digestion and faster growth (Preston and Leng 1989).

Concentrate roughage ratio in ruminant diet and methane production

Sicilliano-Jones and Murphy (1989) reported significant decrease in acetate and increase in propionate when steers diet was changed from alfalfa hay: concentrate feed of 4:1 to 1:4. On the other hand, Davis (1967) reported 67, 21 and 12% acetate, propionate and butyrate in VFA, respectively, on alfalfa : grain (1: 1.3) diet and 49%, 40% and 11% acetate, propionate and butyrate on alfalfa : grain (1: 6.6) diet. Beever *et al.* (1988) calculated the VFA and methane production on different types of diets:

(i) High forage diet

$$1 \text{ mol CHO} \rightarrow 1.34 \text{ mol } CH_3COOH + 0.45 \text{ mol } CH_3CH_2COOH + 0.11 \text{ mol } CH_3CH_2CH_2COOH + 0.61 \text{ mol } CH_4 + 4.62 \text{ mol ATP.}$$

(ii) High cereal diet

$$1 \text{ mol CHO} \rightarrow 0.90 \text{ mol } CH_3COOH + 0.70 \text{ mol } CH_3CH_2COOH + 0.20 \text{ mol } CH_3CH_2CH_2COOH + 0.38 \text{ mol } CH_4 + 4.38 \text{ mol ATP.}$$

(iii) High molasses diet

1 mol CHO → 0.94 mol CH_3COOH + 0.40 mol CH_3CH_2COOH + 0.33 mol $CH_3CH_2CH_2COOH$ + 0.54 mol CH_4 + 4.50 mol ATP.

However, the above results based on good quality roughage like alfalfa and grain-based feed are not applicable for Indian ruminants because their major roughage is straw and the concentrate mixture contains agro-industrial by-product.

One of the important methods of reducing the methane production is by increasing the concentrate mixture in diet, specially when animals are fed straw-based diet. Singh and Mohini (1999a) reported that propionate in VFA increased from 23.33% on concentrate-25: wheat straw-75 diet to 35.60% on concentrate-75: wheat straw-25 and 30% on concentrate-50: wheat straw-50. Methane production reduced from 40.9 to 28.0 lit/kg DDM due to the increase of concentrate mixture from 25% to 75% in wheat straw-based diet. Similar studies on 3 ratios of concentrate and paddy straw (25:75, 50:50 and 75:25) showed an increased propionate percentage in VFA acids (22.3%, 26.5% and 36.7%) and decrease in methanogenic VFA from 77.7% on concentrate-25: paddy straw-75 to 70.5% on concentrate-50: paddy straw – 50 and 63.3% on concentrate-75: paddy straw-25, respectively (Singh and Mohini 1999a). Thus, methane production was reduced by 19.5 to 31.5% because of increase of concentrate in wheat-straw-based feed. However, the reduction of methane production was between 20.4% and 26.6% when diet was on straw alone and when concentrate mixture was increased up to 75% in the feed based on paddy straw as roughage.

Green fodder in diet and methane production

The green fodder and grasses contain higher amounts of soluble sugars, which when fed to ruminants change their fermentation pattern towards more propionate and less methane production. *In vitro* methane production studies on different ratios of berseem and wheat/paddy straw resulted in 20-30% and 18.5-30% reduction in methane production depending on the ratio of berseem in diet (Das and Singh 1999, Singh and Mohini 1999b). In oat green fodder and wheat straw combinations, methane production reduced to the extent of 8-23%. Similarly feeding of green maize fodder in wheat straw diet decreased the methane in gas and increased the propionate percentage in volatile fatty acids (Singh and Mohini 1999c). Therefore, in India, methane production could be reduced to a significant extent by feeding green fodder to ruminants.

Feed additive for minimizing methane production and increasing energy availability in ruminants

A large number of inorganic, organic compounds and ionophores modify microbial activity to reduce methane production and increase the nutrient availability. The most promising and tested rumen fermentation modifier is momensin/rumensin. Ionophores are routinely used as feed additive in beef cattle feed in the US. Ionophores have little direct effect on methanogens, but they inhibit the growth of bacteria which produce hydrogen, the precursor of methane (Van Nevel and Demeyer 1977). Rumensin/momensin increases the feed utilization efficiency and this effect can be mediated by a decrease in methane production, with increase in propionate and ruminal pH (Russel and Strobel 1989). In a rusitec experiment, it was reported that feeding of 0, 2, 10 and 50 mg/day monensin resulted in 48, 30, 19 and 18 mol/day methane production, indication the effectiveness of monensin for control of methanogenesis (Wallace *et al.* 1981). Feeding of ionophores improved feed efficiency by 5-10% (Bergen and Bates 1984). Ionophores exert favourable actions including deamination (Kobayashi *et al.* 1996) and decrease the acetate : propionate ratio (Kook *et al.* 1999).

Feeding of 50 and 100 mg rumensin/day/animal increased the propionate production significantly and decreased the percentage of methane in gas and methane produced per unit digestible dry matter. The methane production was reduced by 14-23% on maintenance, 30-35% on medium milk production and 22-32% on high milk production feed conducting of concentrate and wheat straw due to rumensin feeding (Singh and Mohini 1996). Similarly on 3 types of feed consisting of concentrate and paddy straw, propionate production increased and methane produced per unit of digestible dry matter decreased (Singh and Mohini 1993). Reduction in methane production was 15-22% on maintenance production, 23-32% on medium production and 14-25% on high milk production diet due to feeding of 50 and 100 mg rumensin/day. On the basis of digestibility and methane production/kg DDM methane production by 400 kg cow was calculated at maintenance, medium and high production feeds and it was observed that the methane production reduced from 153.1-162.0 to 112.8-129.0 litre/day at maintenance level of feeding (concentrate-25: straw-75), from 178.0-183.3 to 119.0-127.9 litre/day at medium level of production ration feeding (concentrate-50:straw-50) and from 202.8-206.8 to 146.3-157.60 litre/day on high production ration (concentrate-75 : straw-25) feeding due to rumensin in the diet. Thus, the methane production by Indian ruminants is lower than the reported values (WRI 1990, Czerkawski 1969). De and Singh (2004) recommended 35 ppm rumensin in feeds of Indian cattle fed on crop residue based diet.

Animal production level and methane production

Substantial amount of methane is emitted by animals, which are merely maintaining themselves. Methane production per unit of product will fall as the productivity of animal increases. There is little doubt that increasing production can reduce methane emissions/kg of milk

Kirchgessner *et al.* (1995) suggested that doubling of milk production of dairy cows from 5 000 to 10 000 kg milk/year increased the methane production by 5% only (i.e. from 110 to 115 kg/year). Similaryly, Leng (1991) indicated that Holstein cattle fed a high quality diet produced only 15% as much methane/litre of milk as do native Indian cattle on traditional feed. Studies in developed countries have indicated a positive correlation between increased productivity and methane production in the US, with the increase in milk production from 3 195 kg to 7 000 kg over the 30–year from 1960 to 1990; methane emissions have been reduced from 24 to 17 g/kg of milk (EPA 1994). Report from National Dairy Research Institute, Karnal, indicated that the average methane production by Indian cattle and buffalo was about 80 to 96 g/day/animal (Singh 1997). However, methane production per unit milk decreased with an increase in milk yield due to dilution of maintenance energy requirement. Singh (2002) reported a decrease in methane production from 186.09 to 117.6 g/kg milk in 2000 due to increase in milk production. Earlier, Singh and Mohini (1996) reported that methane eminssion from Indian dairy animals varied in the range of 148-183 g/kg of milk; however, Aneja (1992) reported 240 g/kg milk methane production from Indian cattle. It is very interesting to note that as the total milk production in the country increased, total methane emission also increased, however, methane emission per unit milk reduced.

Energy loss in methane

Indian ruminant livestock losses 739.30 × 10^8 moles of ATP per day, and in term of K cal it is 405.75 × 10^8 or 0.406 Mcal per day (Singh 2001). However, loss of energy from cattle is major because of their number, followed by buffalo, goat and, sheep. This 405.75 × 10^8 Kcal or 0.406 Mcal of energy will be sufficient to meet the energy requirement of (i) 5 635 417 growing calves of 100 kg body weight with 500g growth rate, (ii) 1 334 912 lactating cows of 400 kg body weight yielding 10 kg milk/day with 4.5% fat, or (iii) 2 101 243 mature bulls of 500 kg (NRC 1989). Thus, country is loosing energy worth Rs 22 million/day in methane. Since methenogenesis is the intergral part of rumen fermentation and essential but wastefull process. Therefore, it is not possible to completely stop methanogenesis. However, if methanogenesis is reduced by 20%, which is possible, energy worth Rs 4.538 million/day can be saved.

Methane production and global warming

Atmospheric concentration of greenhouse gases is linked to increasing amounts of the radioactive solar energy being trapped in earth's atmosphere. If the current trend in growth of these emissions is allowed to continue, scientists predict that average world temperature will increase by 1° to 3° C during the 21st century due to global warming which would lead to rise in sea level owing to melting of glaciers and ice sheets (IPCC 1995). After carbondioxide which is emitted from the combustion of fossil fuels, methane is the second major greenhouse gas contributing to global warming. Though its contribution to the atmospheric budget is about 18%, it is 20-40 times more potent as a greenhouse gas than carbondioxide on a kg per kg basis (Dhiman *et al.* 1998). Methane is produced naturally by ruminants during the normal digestion process in the rumen.

Methane contribution of Indian livestock

Methane production by cattle is 76.74 g/day/animal and total methan production was 5.589 Tg per year. Similarly buffalo produced 97.01 g/day/animal and total production was 2.804 Tg per year. Sheep and goat produced 11.63 and 10.14 g/day/head, respectively, and total production was 0.194 and 0.408 Tg/year, respectively, in sheep and goat. Total methane production was 8.995 Tg/year, which is 0.028 Tg/year less than earlier estimate (Singh 1998). The present estimate is comparatively more precise than earlier one (Singh and Mohini 1996). The contribution of cattle, buffalo, sheep and goat to total methane emission is 62.0, 31.0, 2.0 and 5.0% respectively. The global average methane concentration is about 1.7 pmv and is increasing at about 0.8%/per year (World Bank 1992). However, Steele *et al.* (1992) reported, reduced rates of increase methane (0.6%) in atmosphere. Total methane production by Indian livestock has been reported by various groups of worker. World Resource Institute (1990) has reported 10.0 Tg annual methane productions by Indian livestock, while. USEPA (1994) reported that 10.4 Tg. methane emission, while Khan (1996) reported it as of 8.9 Tg per year. Methane production estimates of various worker along with animal are given in Table 1. No work has been done on the emission of methane

Table 1. Estimate of methane emission by various workers for Indian livestock (Tg/year)

Cattle	Buffalo	Sheep	Goat	Total
		USEPA (1994)		
5.59	4.0	0.27	0.55	10.41
		Singh and Mohini (1996)		
5.690	2.804	0.21	0.388	9.023
		Khan 1996		
5.80	2.40	0.20	0.50	8.90
		Singh (1998)		
5.59	2.80	0.19	0.41	8.99
		Garg and Shukla (2002)		
-	-	-	-	7.257
		Singhal and Mohini (2002)		
-	-	-	-	10.08
		WRI (1990)		
-	-	-	-	10.00

Methane production by camel (Tg/year): World, 0.90*; Indian, 0.07*; Indian, 0.06**.

*USEPA (1994), ** Singh (2002).

from 0.07 Tg methane emission from Indian camel and 0.9 Tg from world camel. Recent estimate indicated 0.06 Tg methane production from Indian camel because of decrease in camel population (Singh 2002). While Garg and Shukla (2002), reported 7.257 Tg annual methane production by Indian livestock, Singhal *et al.* (2004) reported a value of 10.08 Tg/year.

The overall review clearly indicated that white, ruminants are capable of subsisting on relatively low quality forages and crop residue, the low digestibility of feed resources contributes substantially to methane production and limit the efficiency of production. Increase in feed digestibility, improve the productivity of animal and reduce the methane production.

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