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Influence of Diet on Methane and Nitrous Oxide Emissions from Cattle Manure

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ABSTRACT

Livestock is one of the major contributors of greenhouse gases (GHGs). It accounts for 14.5% of the global GHGs emissions like methane (CH_4) from enteric fermentation and manure, nitrous oxide (N_2O) from manure and fertilizer. Since enteric emissions are a major contributor of CH_4 than that of manure emissions hence primary efforts were made on reducing enteric emissions, with minor attention to dung emissions. Many researches were conducted by dietary manipulation to mitigate enteric CH_4 emission. However dietary manipulation also had significant effects on manure GHGs emissions too. Several works proved that manure CH_4 emissions were increased with high level of concentrate supplementation despite reduction in enteric CH_4. Fat and CP content of the diet has shown inconsistent results on manure CH_4 emissions. Amount of concentrate in the diet has shown little effect whereas dietary CP content exhibited conflicting effects on manure N_2O emissions.

Key words: Methane, Nitrous oxide, Diet, Cattle, Manure

1. INTRODUCTION

GHGs are the gases which has the capability to absorb radiations and emit the same within the thermal limits. The major GHGs are carbon dioxide (CO_2), CH_4 and N_2O which contributes to the increasing temperature of the earth's surface. GHGs are involved in the catalytic destruction of the stratosphere i.e, ozone depletion. Total GHGs emissions from livestock supply chain are estimated to be 7.1 gigatonnes CO_2 eq/annum (FAO, 2013). CH_4 is the second most important greenhouse gas contributing about 15-20% of total GHGs. CH_4 remains in the atmosphere for 9-15 years and is about 21 times more effective in trapping heat in the atmosphere than CO_2 (FAO, 2006). The global warming potential (GWP) for CH_4 is suggested as 34 (IPCC-AR5, 2013). Global atmospheric concentration of CH_4 has increased from 720 [695 to 745] ppb in 1750 to 1803 [1799 to 1807] ppb in 2011 (IPCC, 2013). Anthropogenic activities like agriculture, fossil fuel use are the leading contributors for the increase in CH_4 concentration. N_2O is other potent GHGs with a long half life of 150 years in the atmosphere and large radioactive forcing potential which is about 310 times than that of CO_2. Besides, N_2O is also involved in the catalytic destruction of stratospheric ozone following its photolytic oxidation to nitric oxide (NO). The GWP for N_2O is suggested as 298 (IPCC, 2013). The global atmospheric concentration of N_2O has increased from 270 ppb in the preindustrial period to 324 ppb in 2011 (IPCC, 2013).

Livestock is one of the major contributors of GHGs. It accounts for 14.5% of the global GHGs emissions like CH_4 from enteric fermentation and manure, N_2O from manure and fertilizer (FAO, 2013). About 37% of anthropogenic CH_4 is attributed to enteric fermentation by ruminants as part of their normal digestive processes. India produces 12.45% of the total enteric CH_4 emissions (Chhabra *et al.*, 2013). Livestock manure management has also been a significant source of CH_4 with global emissions of 9.3 Tg/year (Scheehle and Kruger 2006) and 0.121 Gg/yr from Indian livestock (Mohini, 2010), respectively. Livestock also contributes to a small amount of N_2O emissions from animal waste management systems. In India N_2O emissions from livestock is about 0.075 Gg/yr (Mohini, 2010). CH_4 emissions from storage of dairy cow manure have been estimated as 12-23% of total CH_4 emission (Hindrichsen *et al.*, 2005). The proportionate emissions from manure storage, however, can vary widely depending on the storage type and climate, and might only represent about 1/3 of the potential yield.

Many factors like species, diet, storage temperature, type of storage, farming system influences the production of CH_4 and N_2O from manure. Among these the diet or ration of the animal is a major deciding factor for GHGs emissions from manure. Various researches has shown that composition of the diet fed to animals like concentrate, forage proportions, fat content, crude protein (CP) content and other feed supplements influenced CH_4 and N_2O emissions from manure. This article will be dealing with the effect of different types of diet on CH_4 and N_2O emissions from cattle manure.

2. MECHANISM OF CH_4 AND N_2O PRODUCTION FROM DUNG

In ruminants methanogenesis occurs in the rumen. Rumen is a complex anaerobic microbial ecosystem which converts fibrous plant materials to volatile fatty acids, CO_2, CH_4 and H_2 with the help of different types of bacteria, protozoa, fungi and methanogens. Methanogens from the domain archae bacteria is responsible for the production of CH_4. Some of the important methanogens are *Methanobacterium formicicum*, *Methanobacterium bryantii*, *Methanobrevibacter ruminantium* and *Methanomicrobium mobile*. Methanogens can produce CH_4 from acetate and also by reducing CO_2 with H_2. Production of CH_4 from dung also occurs by the same process.

N_2O production from dung takes place through a combined nitrification-denitrification of nitrogen contained in the dung. N_2O production requires an initial aerobic reaction and then an anaerobic process, it is theorized that dry, aerobic management systems may provide an environment more conducive for N_2O production. Nitrification is an aerobic process performed by a small group of autotrophic bacteria and archaea. *Pseudomonas*, *Thiobacillus* and *Micrococcus* are some of the bacteria involved in it. Nitrification is the biological oxidation of ammonia with oxygen, then into ammonium, then into nitrite followed by the oxidation of these nitrites into nitrates. Denitrification is the process of conversion of these nitrates to N_2 through a series of intermediate gaseous nitrogen oxide products like NO and N_2O.

3. CH_4 PRODUCTION POTENTIAL FROM DUNG

Safley *et al.* (1992) proposed a range of 0.10 to 0.24 m^3 CH_4/kg volatile solids (VS) for CH_4 production potential (Bo) of manures in dairy cattle and for non dairy animals the value range is 0.17 to 0.33 m^3 CH_4/kg VS. He has also estimated the Bo value for dairy and non dairy animals in Indian sub continent as 0.13 and 0.1 m^3 CH_4/kg VS respectively. Zeeman and Gerbens (1999) showed that the estimated Bo values of developed and developing countries were 0.25 and 0.14 m^3 CH_4/kg VS in case of dairy cattle.

CH_4 production from dung depends upon several factors like species, diet, storage temperature, storage type and farming system.

4. EFFECT OF DIETARY MANIPULATIONS ON CH_4 EMISSIONS FROM DUNG

4.1 Ratio of Concentrate and Forage in the Diet

Enteric CH_4 emission can be reduced by increasing the dietary concentrate proportion. A curvilinear relationship was found in between CH_4 production and proportion of concentrate in the diet. Higher levels of concentrate in diet increases the feed intake which in turn results in improved rumen fermentation and accelerated feed turnover which causes large modifications of rumen physico-chemical conditions and microbial populations. But several research works has proved that manure CH_4 emissions are increased with higher levels of concentrate supplementation despite its reducing effects on enteric CH_4 emissions.

As early as in 1981, Hashimoto *et al.* (1981) reported that when forage diet (92%) to concentrate diet by (7% forage) there was an increase in CH_4 emissions per unit of volatile solids in bovine manure. Lodman *et al.* (1993) underlined the above result by proving that feedlot steer receiving a high gain diet (11% forage) had higher CH_4 efflux from manure comparing to that receiving only forage diet. Kulling *et al.* (2003) also got similar result on using two different forage based rations (young grass and hay, hay and concentrate).

Boadi *et al.* (2004) had tested the effect of low and high forage diet on mbnure pack greenhouse gas emissions from feedlot steers and observed that CH_4 production (L/d) was 42% higher ($P < 0.05$) from steers fed the low forage: grain ratio (barley silage and barley grain) than from steers fed the high forage: grain ratio. Overall, CH_4 production (% of gross energy intake) ranged from 0.9 to 6.9% on the low forage: grain diet and from 0.7 to 4.9% on the high forage: grain diet. The effect of carbohydrate composition of concentrates on CH_4 emission from dairy cows and their slurry were studied by Hindrichsen *et al.* (2005) where they compared six different concentrate diets like oat hull, soybean hull, apple pulp, *Jerusalem artichoke*, molasses and wheat, respectively. The slurry originating from molasses diet showed maximum CH_4 emission at 14 weeks of storage. The proportion of CH_4 produced in the slurry compared to the amount totally emitted (enteric & slurry) ranged between 5.2 and 10.8% in the first 7 weeks and between 16.0 and 21.9% after 14 weeks of storage however the treatment effects were

Table 1. Influence of various dietary combinations on manure CH_4 and N_2O emissions.

Sl No.	Diet	Storage type	Dung CH_4	Dung N_2O	Reference
1	Grass (adlib) and Hay (2 kg/d) & Hay (adlib) and Concentrate (3kg/d)	Liquid manure Slurry Manure	13.6 and 16.1 μg/m^2 8.9 and 20.1 μg/m^2 15.5 and 12 μg/m^2	0.20 and 0.40 μg/m^2 0.01 and 0.03 μg/m^2 2.1 and 0.75 μg/m^2	Kulling *et al.*, 2003
2	Low forage: Grain (10: 90) and High forage: Grain (40: 60)	Manure bedding pack	11 and 17.7 g/pen/d	2.2 and 2.1 g/pen/d	Boadi *et al.*, 2004
3	Concentrate sources used Oat hulls Soybean hulls Apple pulp diet *Jerusalem artichoke* Molasses Wheat	Slurry	 17.6 g/cow/d 25.8 g/cow/d 28.1 g/cow/d 34.5 g/cow/d 44.7 g/cow/d 39.4 g/cow/d		Hindrichsen *et al.*, 2005
4	Hay: Grass silage (50: 50) Hay: Grass silage: Concentrate (25: 25: 50) Maize silage: Grass silage (50: 50) Maize silage: Grass silage: Concentrate (25: 25: 50)	Slurry	8.1 g/cow/d 20.1 g/cow/d 4.4 g/cow/d 5.5 g/cow/d		Hindrichsen *et al.*, 2006
5	Hay Corn silage Corn grain	Slurry	69.6 g/bull/d 61.2 g/bull/d 56.0 g/bull/d		Doreau *et al.*, 2011
6	Lauric acid (40 g/kg DM) in forage: concentrate 3: 2 and Stearic acid (40 g/kg DM) in forage: concentrate 3: 2	Complete slurry Urine rich slurry Farmyard manure	29.06 and 8.9 ppm 7.06 and 2.62 ppm 10.76 and 8.90 ppm	0.86 and 0.96 ppm 0.02 and 0.03 ppm 1.34 and 2.99 ppm	Kulling *et al.*, 2001
7	Rye grass Kale Lucerne	Slurry		14.23 kg N/ha 13.88 kg N/ha 10.84 kg N/ha	Cardenes *et al.*, 2007
8	Grass silage & hulled wheat (60: 40) Grass silage & concentrate (50: 50)	Solid manure	0.131g/kg manure 0.248 g/kg manure	0.012 g/kg manure 0.025 g/kg manure	Mathot *et al.*, 2012

not significant. In another work Hindrichsen *et al.* (2006) noticed on a sole forage diet the manure derived CH_4 was 6.6% of total CH_4 emission but when forage and concentrate were used in ratio of 1 : 1, manure derived CH_4 was 13% of total CH_4 emission. However the higher CH_4 emissions from slurry of cows supplemented with concentrates was partially compensated with the reduction in enteric CH_4 emissions, but the extent of reduction was about 22% on an average. The above results were supported by the works of Yohaness (2010). Mathot *et al.* (2012) noticed that diet had no significant effect ($P > 0.05$) but lower gases emissions were observed for a high concentrate diet than for a low concentrate diet when expressed as per kg live weight gain, but when expressed as per kg of fresh manure stored, the emissions were found similar for both the diets.

But on contrary, Doreau *et al.* (2011) found that hay diet (containing 41% hay and 49% corn grain) and corn silage diet (containing 63% corn silage and 21% corn grain) showed higher manure CH_4 production compared to sole corn grain diet (containing 70% corn grain). Hay and corn silage diet showed total CH_4 emissions of 202.7 and 213.5 g/d as compared to 118.3 g/d in case of corn grain diet. Aguerre *et al.* (2010) also observed that increasing the forage: concentrate ratio from 47 : 53 to 68 : 32 increased manure CH_4 emission from 538 to 648 g/cow per day.

4. 2 Effect of Supplementation of Dietary Fats to Ration

According to IPCC, use of a fat rich diet results in higher emissions of CH_4 during the storage of manure than other diets in case of all temperatures. Kulling *et al.* (2002) supplemented lauric acid, having anti methanogenic activity to early lactating dairy cows at the rate of 40 g/kg DM and found that faeces of cows supplemented with lauric acid had higher CH_4 emissions as compared to those supplemented with stearic acid. Faeces of cows supplemented with malic acid had higher proportions of undigested fibre. Overall, manure-derived CH_4 accounted for 8.2% and 15.4% of total CH_4 emissions after 7 and 14 weeks of storage, respectively. Moller *et al.* (2012) also got higher CH_4 values on using high fat concentrate (rape seed) when compared to low fat concentrate (maize). But storage of manure at lower temperatures of about 10°C, resulted in reduced CH_4 emissions for the fat supplemented group.

4. 3 Influence of Dietary Crude Protein on Manure CH_4 Emissions

The effects of varying levels of dietary crude protein content either in forage or in concentrate has shown inconsistent results on manure CH_4 emissions (Kreuzer and Hindrichsen, 2006). Kulling *et al.* (2003) observed that manure derived CH_4 was found to be decreasing with the use of high crude protein content in the forage instead of low crude protein. The manure carbon to nitrogen ratio is of more importance in case of manure CH_4 emissions and it increases with high carbon to nitrogen ratio.

5. INFLUENCE OF DIETARY VARIATIONS ON MANURE N_2O EMISSIONS

5. 1 Ratio of Concentrate and Forage in Diet

The amount of concentrate in diet will largely influence the amount of CH_4 emissions but there is not much effect on the N_2O emissions. Boadi *et al.* (2004) observed no significant difference among the manure pack N_2O emissions from low forage: grain and high forage: grain diet in feedlot cattle. Cardenas *et al.* (2007) analyzed three slurries applied to grassland soil which were derived from sheep fed on ensiled ryegrass (*Lolium hybridicum*), lucerne (*Medicago sativa*) and kale (*Brassica oleracea*), respectively. The resulting fluxes of N_2O and N_2 were measured, which were 14.23, 10.84 and 13.88 for ryegrass, lucerne and kale respectively. It was found that the largest amount of total N flux was generated by ryegrass slurry treatment. Later Mathot *et al.* (2012) studied the effects of high and low concentrate diets on N_2O emissions in cattle and found that there was no significant difference between the various groups.

5. 2 Effect of Supplementation of Fats on Manure N_2O Emissions

In general dietary manipulations have very little effect on manure N_2O production, but supplementation of fat had some variable effects on manure N_2O emissions. The effect of lauric and stearic acid supplementation (40 g/kg DM) on diet, noticed by Kulling *et al.* (2002) reported that manure N_2O emissions were twice more in stearic acid fed cows as compared to those fed lauric acid.

5. 3 Effect of Dietary Crude Protein Supplementation on Manure N_2O

Crude protein (CP) content in the diet has shown contrasting and inconsistent results for N_2O emissions. Külling *et al.* (2002) reported that there was decrease in N_2O emissions during simulated storage of manure from dairy cows which were fed low-protein diets. However the total GHGs emissions were not changed due to dietary protein content. In support of this statement Sauvant *et al.* (2011) and Dijkstra *et al.* (2011) stated that decreasing dietary protein concentration likely results in increased concentration of fermentable carbohydrates in the diet, which in turn likely increases CH_4 production. So these relationships must be considered for manipulating dietary nitrogen to reduce manure N_2O emissions. Mertens (1994) observed that diets which are having low rumen degradable protein (RDP) will result in reduction of total tract fibre digestibility. Hindrichsen *et al.* (2005) found that this reduced fibre digestibility result in increased fermentable organic matter in manure which might increase manure CH_4 emissions. Diets severely deficient in RDP will have a negative impact on microbial protein synthesis and animal productivity and therefore must not be recommended as a mitigation practice. Montes *et al.* (2013) reported that feeding protein close to animal requirements, including varying protein concentration with the productive stage of the animals (phase feeding), is recommended as an effective manure N_2O emission mitigation practice.

In contrast Arriaga *et al.* (2010) given 3 different types of protein diet (low CP 14.1%, medium CP 15.9 % and high CP 16.9%) to lactating Holstein cows and found no effect of dietary CP on N_2O emissions.

6. NITROGEN EMISSIONS THROUGH URINE

Nitrogen and CP content in the diet affects nitrogen emissions from manure. Total nitrogen emissions from manure were generally quantified as total gaseous nitrogen loss, NH_3 as well as N_2O. Kulling *et al.* (2003) observed that protein content in ration affects the N_2O emissions in an inconsistent manner and varied according to the storage type. Feeding of high CP grass significantly increased urinary nitrogen excretion. Kulling *et al.* (2001) from storage experiment (deep litter manure, slurry, urine rich slurry and farmyard manure) done on cow manure, fed with rations having different dietary protein content (175, 150 and 125 g CP/kg DM) concluded that reduction of nitrogen intake decreased daily nitrogen excretion and urinary nitrogen proportion and, on an average, led to 0·7-fold lower storage NH_3 emission rates. Total storage nitrogen loss was simultaneously reduced to the extent depending on urinary nitrogen proportion of the respective manures. A lower dietary protein content furthermore reduced N_2O emission rates in most manure types and the GWP of all manures was similar with low and high dietary protein content. Kulling *et al.* (2002) found that manure of cows fed lauric acid (C_{12}) showed less nitrogen loss as compared to stearic acid (C_{18}) fed cows. The C_{12} fed cows had lower nitrogen intake and nitrogen excretion and the proportion of urine nitrogen, which is rapidly converted to ammoniacal nitrogen in manure but was not varied with the type of diet. CP content of the diet which is a major factor in determining the urinary nitrogen percentage of total nitrogen was unchanged between diets. However, greater differences in gaseous nitrogen losses can be expected from diets which provide nitrogen far in excess than that of the animal's requirements.

Hindrichsen *et al.* (2005) compared the nitrogen excretion from dairy cows after feeding with different carbohydrate sources like oat hull, soyabean hull, apple pulp, *Jerusalem artichoke* tubers, molasses and wheat. Percentage of total nitrogen excreted via urine was significantly higher for cows fed the oat hulls diet compared to cows fed the molasses diet. The initial slurry nitrogen content was also significantly lower for cows fed the oat hulls diet compared to the other five diets. After 14 weeks of storage the N content of the slurry of this treatment was significantly lower as compared to cows fed the *Jerusalem artichoke* diet. Hindrichsen *et al.* (2006) found that concentrate supplementation resulted in increased urinary nitrogen excretion and the proportion of urinary nitrogen to total excreta nitrogen. They also concluded that concentrate supplementation increased the proportion of ammonia-nitrogen in the corresponding slurries, which resulted in significantly increased gaseous nitrogen loss (g/ cow/ d).

Phase feeding was found to have high effect in mitigating nitrogen excretions. Cole *et al.* (2006, 2005), Vasconcelos *et al.* (2007) observed significantly lower nitrogen excretions on reducing dietary protein concentration. Erickson and Klopfenstein (2010) reported lower nitrogen excretion and lower nitrogen volatilization losses of phase-fed cattle. Joachim and Heinz-Jürgen (2001) observed significantly reduced nitrogen excretion in four phase feeding compared to two phase feeding.

7. CONCLUSIONS

Rise in GHGs emissions from livestock leading to global warming is a matter of high concern now a day. Diet of the animal was found to play a prominent role in determining the CH_4 and N_2O productivity of dung of the animal. Amount of high concentrate in diet considerably reduces the enteric CH_4 emissions but it significantly increases the dung CH_4 and N_2O emissions. High fat in diet found to increase gas production from dung but the effect of crude protein was found to be inconsistent. Decreased nitrogen content in diet found to reduce nitrogen emissions from manure but increasing CH_4 emissions. Hence these relationships must be considered while manipulating dietary nitrogen to reduce manure nitrogen emissions. Feeding diets with balanced protein and fibre content will be most suitable for reducing emissions of GHGs from both enteric and manure sources. More research work is to be conducted in this field regarding effect of diets on GHGs emissions since most of the works showed more concern regarding mitigation of enteric CH_4 emission but efforts should be also taken to reduce emissions from dung.

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