# Nutritional and Management Strategies to Mitigate Animal Greenhouse Gas Emissions

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## Introduction

Animal production is a significant source of greenhouse gas (**GHG**) emissions worldwide. The current analysis (Hristov et al., 2013) was conducted to evaluate the potential of nutritional, manure and animal management practices for mitigating methane (**$CH_4$**) and nitrous oxide (**$N_2O$**), i.e. non-carbon dioxide (**$CO_2$**) GHG emissions from enteric fermentation and manure decomposition. These practices were categorized into enteric $CH_4$, manure management-based, and animal management-based mitigation practices. Emphasis was placed on enteric $CH_4$ mitigation practices for ruminant animals (only in vivo studies were considered) and manure management-based mitigation practices for both ruminant and monogastric species. Over 900 references were reviewed; simulation and life cycle assessment analyses were generally excluded. It is noted that in evaluating mitigation practices, the use of proper units is critical. Expressing enteric $CH_4$ energy loss on a gross energy intake basis, for example, does not accurately reflect the potential impact of diet quality and composition, or the impact of a mitigation strategy. Therefore, GHG emissions should be expressed on a digestible energy intake basis or per unit of animal product (i.e., Emission Intensity, Ei) because this reflects most accurately the effect of a given mitigation practice on feed intake and animal productivity.

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**Enteric $CH_4$ mitigation practices (Table 1):**

Increasing forage digestibility and digestible forage intake will generally reduce GHG emissions from rumen fermentation and stored manure, when expressed per unit of animal product, and are highly-recommended mitigation practices. For example, enteric $CH_4$ emissions may be reduced when corn silage replaces grass silage in the diet. Legume silages may also have an advantage over grass silage due to their lower fiber content and they provide the additional benefit of replacing inorganic nitrogen fertilizer. Effective silage preservation improves forage quality on the farm and reduces GHG Ei. Introduction of legumes into grass pastures in warm climate regions may offer a mitigation opportunity, although more research is needed to address the associated agronomic challenges and comparative $N_2O$ emissions with equivalent production levels when nitrogen fertilizer is applied.

Inclusion of lipids in the diet is an effective strategy for reducing enteric $CH_4$ emissions, but the applicability of this practice will depend on its' cost-effectiveness and its' effects on feed intake, productivity and milk composition. High-oil by-product feeds, such as distiller's grains, may offer an economically feasible alternative to oil supplementation as a mitigation practice, although their higher fiber content may have an opposite effect on enteric $CH_4$ emissions, depending on basal diet composition. Inclusion of concentrate feeds in the diet of ruminants will likely decrease enteric $CH_4$ emissions per unit of animal product, particularly when above 40 percent of dry matter intake. The effect may depend on type of concentrate and inclusion rate, production response, impact on fiber digestibility, level of nutrition, composition of the basal diet, and feed processing. Supplementation with small amounts of concentrate feed is expected to increase animal productivity and decrease GHG Ei when added to all-forage diets. However, concentrate supplementation should not substitute high-quality forage. Processing of grain to increase its' digestibility is likely to reduce enteric $CH_4$ production per unit of animal product. Caution should be exercised that concentrate supplementation and processing does not compromise digestibility of dietary fiber. In many parts of the world, concentrate inclusion may not be an economically feasible mitigation option. In these situations, improving the nutritive value of low-quality feeds in ruminant diets can have a considerable benefit on herd productivity while keeping the herd $CH_4$ output constant, thus decreasing Ei. Chemical treatment of low-quality feeds, strategic supplementation of the diet, ration balancing, and crop selection for straw quality can be effective mitigation strategies, but there has been little adoption of these technologies.

Nitrates show promise as enteric $CH_4$ mitigation agents, particularly in low-protein diets that can benefit from nitrogen supplementation, but more studies are needed to fully understand their impact on whole-farm GHG emissions, animal productivity, and animal health. Adaptation to these compounds is critical and toxicity may be an issue. Through their effect on feed efficiency, ionophores are likely to have a moderate $CH_4$ mitigating effect in ruminants fed high-grain or grain-forage diets. However, regulations restrict the use of this mitigation option in many countries. In ruminants on pasture, the effect of ionophores is not sufficiently consistent for this option to be recommended as a mitigation strategy. Tannins may also reduce enteric

$CH_4$ emissions, although intake and milk production may be compromised. Further, the potentially lower yields of tanniferous forages must be taken into account when they are considered as a GHG mitigation option. Data showing that tea saponins lower enteric $CH_4$ need to be confirmed. There is insufficient evidence that other plant-derived bioactive compounds, such as essential oils, have a consistent $CH_4$-mitigating effect. Some direct-fed microbials, such as yeast-based products, might have a moderate $CH_4$-mitigating effect through increasing animal productivity and feed efficiency, but the effect is expected to be inconsistent. Vaccines against rumen archaea may offer mitigation opportunities in the future, although the extent of $CH_4$ reduction appears small, and adaptation and persistence of the effect is unknown.

**Manure management-based mitigation practices:**

Diet can have a significant impact on manure (feces and urine) chemistry and therefore on GHG emissions during storage and following land application. Manure storage may be required when animals are housed indoors or on feedlots, but a high proportion of ruminants graze on pastures or rangeland, where $CH_4$ emissions from their excreta is very low but $N_2O$ losses from urine can be substantial. Decreased digestibility of dietary nutrients is expected to increase fermentable organic matter concentration in manure, which may increase manure $CH_4$ emission. Feeding protein close to animal requirements, including varying dietary protein concentration with stage of lactation or growth, is recommended as an effective manure ammonia and $N_2O$ emission mitigation practice. Low-protein diets for ruminants should be balanced for rumen-degradable protein so that microbial protein synthesis and fiber degradability are not impaired. Diets for all species should be balanced for amino acids to avoid feed intake depression and decreased animal productivity. Restricting grazing when conditions are most favorable for $N_2O$ formation, achieving a more uniform distribution of urine on soil and optimizing fertilizer application are possible $N_2O$ mitigation options for ruminants on pasture. Forages with higher sugar content (high-sugar grasses or forage harvested in the afternoon when the sugar content is higher) may reduce urinary nitrogen excretion, ammonia volatilization and perhaps $N_2O$ emission from manure applied to soil, but more research is needed to support this hypothesis. Cover cropping can increase plant nitrogen uptake and decrease accumulation of nitrate, and thus reduce soil $N_2O$ emissions, although the results have not been conclusive. Use of urease and nitrification inhibitors provide promising opportunities to reduce $N_2O$ emissions from intensive livestock production systems but can be costly to apply and result in limited benefits to the producer.

Overall, housing, type of manure collection and storage system, separation of solids and liquid, and their processing can all have a significant impact on ammonia and GHG emissions from animal facilities. Most mitigation options for GHG emissions from stored manure, such as reducing the time of manure storage, aeration, and stacking, are generally aimed at decreasing the time allowed for microbial fermentation processes to occur before manure application on land. These mitigation practices are effective, but their economic feasibility is uncertain. Semi-permeable covers are valuable for reducing ammonia, $CH_4$ and odor emissions during storage but are likely to increase $N_2O$ emissions when the effluent is spread on pasture or crops. Impermeable membranes, such as oil layers and sealed plastic covers, are effective in reducing gaseous emissions but are not very practical. Combusting accumulated $CH_4$ to produce electricity or heat is recommended. Acidification (in areas where soil acidity is not an issue) and cooling the stored manure are further effective methods for reducing ammonia and $CH_4$ emissions. Composting can effectively reduce $CH_4$ but can have a variable effect on $N_2O$ emissions and increases ammonia and total nitrogen losses.

Use of anaerobic digesters is a recommended mitigation strategy for $CH_4$. Management of digestion systems is important to prevent them from becoming net emitters of GHG. Some systems require high initial capital investment and, as a result, they may only be adopted when economic incentives are offered.

Decreasing nitrogen and carbon concentrations in manure through diet manipulation and preventing anaerobic conditions during manure storage are successful strategies for reducing GHG emissions from manure applied to soil. Separation of manure solids and anaerobic degradation pretreatments can mitigate $CH_4$ emissions from subsurface-applied manure, which may otherwise be greater than that from surface-applied manure. Timing of manure application (e.g. to match crop nutrient demands, avoiding application before rain) and maintaining soil pH above 6.5 may effectively decrease $N_2O$ emissions.

**Animal management-based mitigation practices:**

Increasing efficiency of animal production can be a very effective strategy for reducing GHG emissions per unit of livestock product. For example, improving the genetic potential of animals through planned cross-breeding or selection within a breed, and achieving this genetic potential through proper nutrition and improvements in reproductive efficiency, animal health and reproductive lifespan are effective and recommended approaches for improving animal productivity and reducing GHG emissions per unit of product. Reduction of herd size would increase feed availability and productivity of individual animals and the total herd, thus lowering $CH_4$ emission per unit of product. Residual feed intake may be an appealing tool for screening animals that are low $CH_4$ emitters, but currently there is insufficient evidence that low residual feed intake animals have a lower $CH_4$ yield per unit of feed intake or animal product. However, selection for feed efficiency will yield animals with lower GHG Ei. Breed differences in feed utilization efficiency should also be considered as a mitigation option, although insufficient data are currently available on this aspect. Reducing age at slaughter of finished cattle and the number of days that animals are on feed in the feedlot can also have a significant impact on GHG emissions in beef and other meat animal production systems.

Improved animal health, and reduced mortality and morbidity are expected to increase herd productivity, and reduce emission intensity in all livestock production systems. Pursuing a suite of intensive and extensive reproductive management technologies provides a significant opportunity to reduce GHG emissions. Recommended approaches will differ by region and species, but should target increasing conception rates in dairy and beef cattle and buffalo, increasing fecundity in swine and small ruminants, and reducing embryonic lossin all species. The result will be fewer replacement animals, fewer males required where artificial insemination is adopted, longer productive life and greater productivity per breeding animal.

## Conclusions

Improving forage quality and the overall efficiency of dietary nutrient use is an effective way of decreasing GHG emissions per unit of animal product. Several feed supplements have potential to reduce enteric $CH_4$ emission from ruminants, although their long-term effect has not been well-established and some are toxic or may not be economically feasible in developing countries. Several manure management practices have significant potential for decreasing GHG emissions from manure storage and after application or deposition on soil. Interactions among individual components of livestock production systems are very complex, but must be considered when recommending GHG mitigation practices. One practice may successfully mitigate enteric $CH_4$ emission, but increase fermentable substrate in manure and increase GHG emissions from land-applied manure. Some mitigation practices are synergistic and are expected to decrease both enteric and manure GHG emissions (for example, improved animal health and animal productivity). Optimizing animal productivity can be a very successful strategy for mitigating GHG emissions from the livestock sector in both developed and developing countries.

## Reference

Hristov, A. N., J. Oh, C. Lee, R. Meinen, F. Montes, T. Ott, J. Firkins, A. Rotz, C. Dell, A. Adesogan, W. Yang, J. Tricarico, E. Kebreab, G. Waghorn, J. Dijkstra, S. Oosting, P. J. Gerber, B. Henderson, and H. Makkar. 2013. Mitigation of Greenhouse Gas Emissions in Livestock Production: A Review of Technical Options for Non-$CO_2$ Emissions. FAO, Rome, Italy (in press).

**Table 1. Enteric methane mitigation potential of feed additives and feeding strategies**

| Category | Potential enteric methane mitigating effect[1] |
|---|---|
| **Inhibitors[2]** | |
| **Bromochloromethane and 2-bromo-ethane sulfonate** | High |
| **Chloroform** | High |
| **Cyclodextrin** | Low |
| **Electron receptors** | |
| **Fumaric and malic acids** | No effect to High |
| **Nitroethane** | Low |
| **Nitrate[3]** | High |
| **Ionophores[4]** | Low |
| **Plant bioactive compounds** | |
| **Tannins (condensed)[5]** | Low |
| **Saponins** | Low? |
| **Essential oils** | Low? |
| **Exogenous enzymes** | Low |
| **Defaunation** | Low |
| **Manipulation of rumen archaea and bacteria[6]** | Low |
| **Dietary lipids[7]** | Medium |
| **Inclusion of concentrate feeds[8]** | Low to Medium |
| **Improving forage quality** | Low to Medium |
| **Grazing management[9]** | Low |
| **Feed processing[10]** | Low |
| **Mixed rations and feeding frequency[11]** | ? |
| **Processing and supplementation of low-quality feeds** | |
| **Macro-supplementation (when deficient)** | Medium |
| **Alkaline treatment** | Low |
| **Biological treatment** | ? |
| **Breeding for straw quality** | Low |
| **Precision/balanced feeding and feed analyses[11]** | Low to Medium |

? A question mark indicates uncertainty due to limited research, variable results, or lack/insufficient data on persistency of the effect.

[1]High = ≥ 30 percent mitigating effect; Medium = 10 to 30 percent mitigating effect; Low = ≤ 10 percent mitigating effect. Mitigating effects refer to percent change over a “standard practice”, i.e. study control that was used for comparison. It is noted that most data used in this analysis are from short-term experiments. For most feed additives and mitigation strategies, long-term effects data are lacking.

[2]Some inhibitors are effective enteric methane mitigation agents, but also are environmentally unsafe (bromochloromethane, for example, is an ozone-depleting compound) and it has poor acceptability in many countries.

[3]Practicality of use is unknown. Caution must be exercised when feeding nitrate. Animals should be properly adapted and re-adapted if nitrate supplementation is discontinued for a period of time. Access to molasses blocks with nitrate should be limited so that nitrate intake does not poison the animal. This mitigation practice should not be used when diets have high N concentrations.

[4]Through improvement in feed efficiency, especially when diets contain concentrates; no effect when pasture is the sole diet. Most data are for monensin. Monensin does not appear to have a consistent direct effect on enteric methane production in dairy or beef cattle. Meta-analyses have shown improvement in feed utilization efficiency in beef cattle and dairy cows that may reduce enteric methane emissions per unit of product (meat or milk).

[5]Detrimental effects when dietary crude protein is marginal or inadequate or when condensed tannins are highly active in terms of protein binding capacity and are in high concentrations, but with adequate dietary crude protein some condensed tannins can have wide ranging benefits.

[6]Promising, but the technology is not yet developed or commercially available.

[7]Lipids are generally effective in reducing enteric methane production. They are recommended, when their use is economically feasible (high-oil by-products of the biofuel industries, for example). Their potential negative effect on feed intake, fiber digestibility, rumen function, milk fat content, and overall animal productivity must be considered. Maximum recommended inclusion rate in ruminant diets is 6 to 7 percent (total fat) of dietary dry matter. With the lack of incentive mechanisms to reduce enteric methane emissions, supplementing diets with edible lipids is questionable from an economic standpoint.

[8]Higher rates of concentrate inclusion may decrease intake and have a negative impact on rumen function, fiber digestibility, animal health, and productivity. Inclusion of small amounts of concentrate feed to all- or high-forage diets will increase animal productivity and reduce methane emission intensity. Although recommended (due to direct reduction in enteric methane emissions or indirect increases in animal productivity), the applicability of this mitigation practice will heavily depend on availability and price of concentrates.

[9]Results have not been consistent, but recommended on the basis that improving pasture quality should reduce methane emissions per unit of feed intake and product.

[10]Conditionally effective (if fiber degradability is not decreased and if safe to the environment). (Energy input may counteract GHG mitigating effect; cost benefit ratio has to be determined using life cycle assessment). Recommended (if economically feasible and does not jeopardize fiber digestibility).

[11]Even if direct methane mitigation effect is uncertain, precision/balanced feeding and accurate feed analyses will likely enhance animal productivity and feed efficiency and improve farm profitability (thus have an indirect mitigating effect on enteric and manure methane and nitrous oxide emissions).

# SESSION NOTES