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SCIENCE FOR SUSTAINABLE PRODUCTION

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Mitigation of Enteric Methane Emissions from Dairy Cows

Enteric Methane Emissions

Methane (CH_4) is a colorless and odorless gas that is released into the atmosphere from many sources, including the digestive tract of ruminant animals (mammals that have a stomach with four compartments that ferment food as a major part of the digestion process). Ruminant animals include cattle, sheep, and goats. Enteric methane is the methane resulting from the fermentation process within ruminant animals' digestive tracts, which allows them to obtain nutrients from feed resources high in fiber and thus not edible by humans (Figure 1).

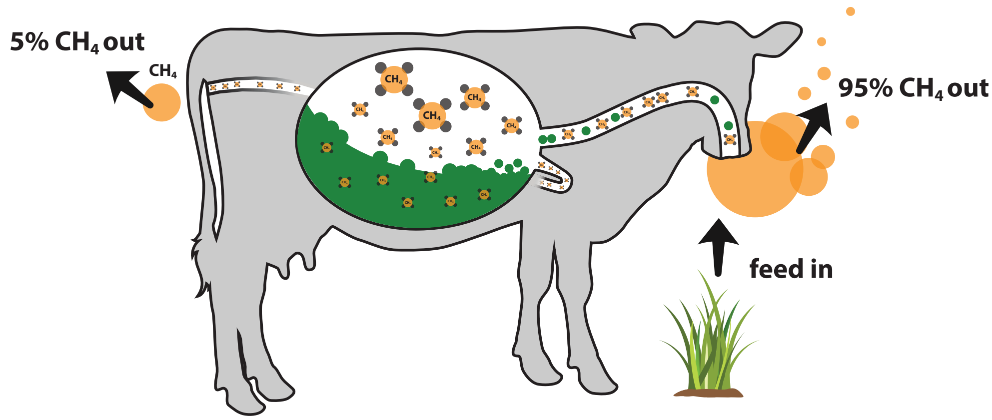

Figure 1. Formation and losses of enteric methane (CH_4) during a cow's digestive process.

Enteric methane from ruminant animals is one of the major contributors to global and United States (U.S.) agricultural greenhouse gas (GHG) emissions, making up 33% and 32%, respectively (IPCC 2014; USEPA 2017). At the farm level, enteric methane can represent 50% of GHG emissions (Aguirre-Villegas et al. 2015). Reducing these emissions is challenging, as it involves complex microbial interactions in the cow's rumen that are critical to the animal's basic function.

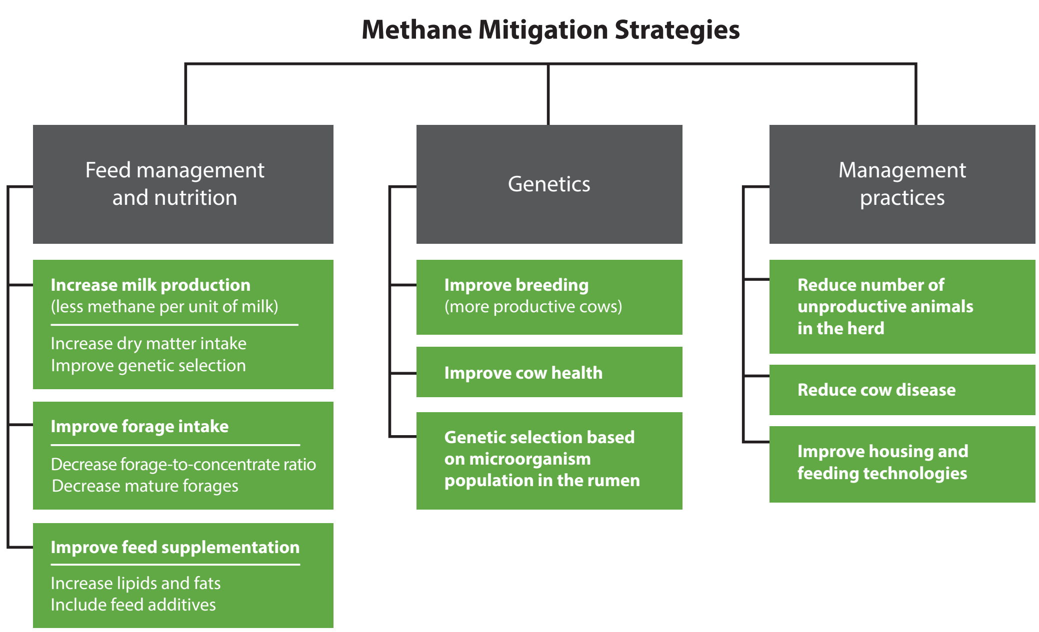

Figure 2. Summary of enteric methane mitigation strategies.

However, there are some strategies to reduce enteric methane emissions that include cow nutrition, genetics, and management (Figure 2).

Knapp et al. (2014) conducted a review of enteric methane mitigation options and concluded that reductions ranging from 5% to nearly 20% could be achieved by implementing individual mitigation approaches and 30% when combining approaches (Figure 3). However, some of the described strategies, such as genetic selection, have not been fully developed at the time of this articles publication to achieve these reductions in practice.

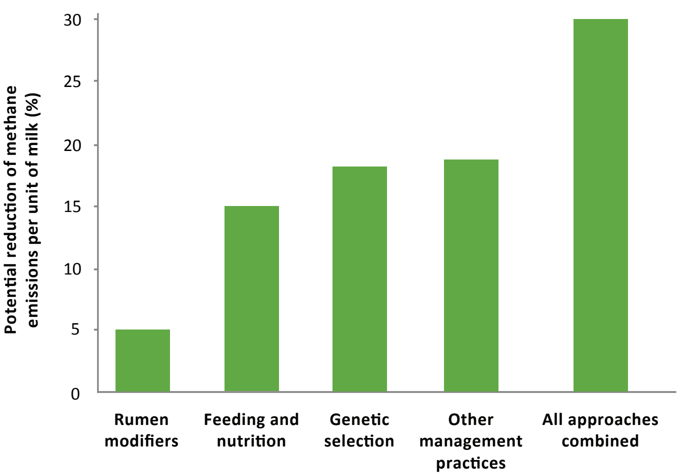

Figure 3. Summary of the maximum potential reduction of methane emissions that could be achieved by implementing some of the strategies described in this fact sheet. Other management practices include approaches to increase milk yield (e.g. reducing nonvoluntary culling and diseases, improving facility and equipment designs for cow comfort, and using enhancing performance technologies) (Knapp et al. 2014).

Feeding Management and Nutrition

A modern dairy cow in the U.S. may release as much as 1-1.4 pounds of enteric methane per day (Aguirre-Villegas et al. 2015). Feed quality and composition can affect enteric methane emissions by changing the conditions of the rumen (e.g. decreasing rumen pH) and thereby altering the microbial populations that produce methane. Improving feed efficiency with a resulting increase in milk production also results in lower emissions per unit of milk produced. Some common nutrition strategies that affect enteric methane emissions include the level of feed intake, the type of carbohydrate in feeds, and the quality and type of forage.

One of the most important factors affecting enteric methane is the level of feed intake (commonly measured as dry matter intake). As expected, total enteric methane produced per cow increases with feed intake as there is more material to be fermented (Moraes et al. 2014). However, when the cow has a greater feed intake it can also produce more milk. Therefore, when considering the emissions per total energy intake or per unit of milk production, enteric methane decreases with an increase in feed intake due to a coinciding increase in milk production. This indicates that enteric methane emissions increase at a slower rate than the conversion of dry matter intake to milk, making the cow more efficient per unit of milk produced in terms of methane emissions (Johnson and Johnson 1995).

There is a variation in feed efficiency and milk production per dry matter intake from cow to cow, which can be exploited to reduce methane emissions. Most farms usually feed totally mixed rations (TMR) to the entire herd, but this type of feeding will unlikely meet the individual requirements of each cow as TMRs are usually targeted for high producing cows. For example, cows in peak lactation require diets low in fiber and high in digestible starch. On the contrary, cows in late lactation require more fermentable fiber and less fermentable starch to maximize milk production (VandeHaar 2014). As a result, an increase in milk production, and a correspondent reduction in enteric methane emissions per unit of milk produced, could be achieved if diets are formulated targeting each specific group of cows.

Changing the diet by altering the forage quality and forage-to-concentrate ratio can affect enteric methane emissions. Forage feeds are high in cellulose, hemicellulose, and lignin (measured as neutral detergent fiber, or NDF), which are more difficult to digest than concentrates (NRC 2001). A slower digestion of a fibrous forage diet results in higher methane formation than a faster digestion of a grain-rich diet. Feed concentrates are high in starch, sugars, organic acids, and pectin (measured as non-fiber carbohydrates, or NFC), which are more digestible than NDF (NRC 2001). In general, a higher forage-to-concentrate ratio diet increases enteric methane emissions and may decrease milk production depending upon the quality (digestibility) of the forage (Knapp et al. 2014). Aguerre et al. (2011) found that enteric methane emissions increased by 20% when increasing the forage-to-concentrate ratio from 47:53 to 68:32. However, diets that have high concentrate contents (e.g. rich in grains) can be more expensive, may decrease milk fat content, and may result in metabolic disorders (Boadi et al. 2004).

Diets with more mature forages also result in higher enteric methane emissions, as the NDF in these forages is less digestible in the rumen due to higher lignin contents (Boadi et al. 2004). It is therefore important to select higher quality forages and harvest at the appropriate maturity, especially for dairy operations that use high forage diets. Processing forages through grinding, chopping, or pelleting can decrease methane emissions, as this size reduction enhances the speed of passage in the digestive system of the cow and has been associated with a reduction in methane emissions. However, any methane reduction will depend on the total composition of the feed and interactions between feed ingredients (Knapp et al. 2014).

High fat (lipid) diet supplements have also been studied as a strategy to reduce enteric methane emissions because lipids limit fermentation. Increasing the amount of certain types of fat in the cow's diet could therefore reduce methane formation. Martin, Morgavi, and Doreau (2010) found an average 3.8% methane reduction with every 1% addition of supplemental feeds rich in lipids. Some of these feeds include seeds (flax, sunflower, and canola) and oils (palm, coconut, and soybean). However, increasing fat ingredients could reduce milk production and increase the nutrient content excreted in manure, which could have negative environmental and economic impacts (Kulling et al. 2002).

In the laboratory, many rumen modifiers (e.g. monensin, sponins, and condensed tannins) have reduced enteric methane formation. They do this by interrupting or inhibiting the natural processes of the methanogens (methane producing microorganisms) in the rumen. However, in practice the effect of these additives when fed to cows has been small, as there are many groups of methanogens that have been able to adapt to them (Knapp et al. 2014).

A recent study showed promising results with an inhibitor known as 3NOP (3-nitrooxypropanol), which was able to reduce methane emissions by 30% without affecting milk production in an experiment conducted in Holstein cows (Hristov et al. 2015). Despite the possible positive effects, 3NOP is still under experimentation and its approval as a feed additive will take some time. In addition, including this or other additives in the dairy diet will likely be cost prohibitive and unrealistic with current regulations for farms with tight profit margins.

Genetics

Genetic selection through breeding may affect enteric methane emissions. Different cow breeds emit enteric methane at different rates, with Jersey cows being more efficient (emitting less methane) than Holstein cows due to higher feed conversion efficiencies (Halachmi et al. 2011). Thus, reducing animal size of high-emitting breeds without reducing milk yield is a potential strategy to improve efficiencies and reduce enteric methane emissions due to reduced maintenance energy requirements (VandeHaar et al. 2016). Genetic selection based on the microorganisms in the cow's rumen to reduce methanogens, or other microorganisms that aid in methane production, also has potential to reduce methane emissions. However, this approach still needs more research (Cottle, Nolan, and Wiedemann 2011).

Perhaps the most common genetic selection strategy to reduce emissions is improving the productivity of the cow. More efficient cows produce more milk per unit of feed they consume, and thus their methane emissions per unit of milk are lower. Any genetic strategy that will improve the cow's health and increase its lifespan will result in overall reduced methane emissions. For example, improving the resistance of cows to mastitis will increase milk production and thus reduce methane emissions (Knapp et al. 2014; Arndt et al. 2015). Increasing the cow's productive life will reduce the relative impact of the methane she emitted before she was able to produce milk (i.e. as a heifer), thus reducing the overall methane impact per unit of milk she produces.

Genetic selection, complemented with management practices, is behind the impressive milk yield improvements of 400% in the U.S. in the last 60 years (Capper, Cady, and Bauman 2009). The high milk production variability that still exists from cow to cow indicates that there is still potential to reach even higher yields in many herds.

Management Practices

Management practices have increased milk production and profitability of dairy operations for decades. Efficient management practices currently used to improve the animals' environment and feed efficiency also have an indirect impact on enteric methane emissions. Some strategies to improve lifetime feed efficiency include increasing cow longevity to four lactations, reducing the age at first calving to 22 months, and reducing calving intervals to 12 months (VandeHaar 2014).

More efficient management leads to a higher producing herd, which at the same time decreases enteric methane emissions per unit of milk produced. Some of these management practices include reducing disease and culling; improving equipment and housing facility designs; and improving feed delivery technologies. For example, heat stress affects milk yield, fertility, and reproduction, all of which reduce milk production and indirectly affect methane emissions (Knapp et al. 2014). However, strategies to improve efficiencies may have unintended consequences. In the previous example, while reducing heat stress in dairy cows may indirectly reduce enteric emissions per unit of milk, negative environmental implications may arise from the use of large amounts of water and energy. Reducing the number of dry cows and replacement animals in a herd is also a strategy to reduce overall methane emissions. This could be achieved by implementing good reproduction management to minimize the dry period and by selling any surplus calves at a younger age (Hristov et al. 2013).

Challenges of Reducing Enteric Methane

There are numerous strategies available to mitigate enteric methane emissions from the dairy sector, but challenges remain. Enteric methane reductions are difficult to measure and the variability in farm practices makes it difficult to implement strategies that will apply to all dairy farms. While the environmental benefits of reducing methane are clear, the direct benefits for the dairy farmer are not yet easily perceived. This limits adoption. In addition, strategies such as changing the herd diet can be costly and may reduce milk production. Reducing enteric methane emissions could create other concerns throughout the dairy farm, such as potential increases in nutrient excretion and emissions from manure management. These need further evaluation. Finally, some promising solutions, such as genetic selection, may take a long time to fully develop.

Summary

Enteric methane is the methane resulting from the fermentation process in ruminant animals as a major part of their digestion process. Enteric methane is a major contributor to global and U.S. agricultural GHG emissions and can represent 50% of a dairy farm's GHG emissions. Reducing these emissions is challenging, as it involves complex microbial interactions in cows' rumen that are critical to the animals' basic function. Strategies that can reduce methane emissions include nutrition and feed management to facilitate digestion; improved genetics to increase milk production; and management practices to increase productivity and cow comfort. Some of these strategies can achieve methane reductions of 5-20% and up to 30% when combined. One of the most important factors affecting enteric methane is increasing feed efficiency, as milk production also increases with greater feed efficiency. As a result, enteric methane decreases per total energy intake or per unit of milk production when there is an increase in milk production.

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