U.S. DEPARTMENT OF AGRICULTURE

May 2023

Nutrient Management Technical Note No. 190-NM-12

Feed and Animal Management for Greenhouse Gas Reduction

Acknowledgments

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Special thanks to Greg Zwicke, Air Quality Engineer, NRCS, West National Technology Support Center (WNTSC), Fort Collins, CO, Allison Costa, Air Quality Engineer, NRCS, WNTSC, Portland, OR and Charlotte Kirk Baer, NRCS, National Animal Husbandry Specialist, National Headquarters, Washington, DC, for their contributions.

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Feed and Animal Management for Greenhouse Gas Reduction

Introduction

Feed management is a Natural Resources Conservation Service (NRCS) practice for manipulating and controlling the quantity and quality of available nutrients, feedstuffs, or additives fed to livestock and poultry. Feed management is also the addition of dietary ingredients or additives to reduce nutrient losses, including greenhouse gases, to the environment. When feed management is implemented, NRCS can help producers conserve natural resources by decreasing excess nutrients that could contribute to soil, water, or air quality degradation. NRCS Conservation Practice Standard Feed Management (Code 592) helps producers achieve reductions in manure nutrients. NRCS also has a series of Nutrient Management Technical Notes on feed management for major species of livestock raised in the U.S. (See table 1). These technical notes are available at https://directives.sc.egov.usda.gov/.

Table 1: U.S. Department of Agriculture Natural Resources Conservation Service Feed Management Technical Notes

Number	Technical Note Title
001	Effects of Diet and Feeding Management on Nutrient Content of Manure
002	Feed and Animal Management for Beef Cattle
003	Feed and Animal Management for Swine (Growing and Finishing Pigs)
004	Feed and Animal Management for Poultry
005	Feed and Animal Management for Dairy Cattle
008	Animal Diets and Feed Management
010	Feed and Animal Management for Horses
011	Feed Management for Small and Organic Operations

Managing diets of livestock can have positive effects on conservation. Feed management for conservation is defined as: minimizing overfeeding of nutrients that become animal waste, feeding local and home-raised feedstuffs to minimize introduction and concentration of outside nutrients onto a property or into a watershed, minimizing feed waste, and balancing forage production to the anticipated number of animals to reduce or mitigate plant, soil and water degradation and erosion. Implementing several best management practices on the operation equates to conservation.

This technical note provides guidance for feeding practices and feed ingredients that may lead to a reduction in production of various greenhouse gases. This document is not meant to set limits or formulate feeds; the producer’s feed manufacturer or a consulting nutritionist should determine ration composition, amounts, and ingredients.

State of the Science

Rapid changes in climate and new policies and goals set by government and industries have brought the impact of livestock production on climate change into focus. There are several greenhouse gases produced by livestock. These include enteric methane (cow burps); methane and nitrous oxide from manure handling and management; and nitrous oxide from feed production. Ammonia is also emitted in livestock operations. While ammonia itself is not a greenhouse gas, it has major impacts on air quality and its interactions through the nitrogen cycle that affect levels of nitrous oxide.

While nitrogen is a major component of air, this form of nitrogen is relatively unreactive. Through the “nitrogen cycle,” nitrogen is converted into other, more reactive forms of nitrogen, that can be used by plants and animals. Atmospheric nitrogen is converted to nitrous oxide and ammonia naturally when lightning breaks nitrogen molecules apart. Nitrous oxide further dissolves in rain, forming nitrates that are deposited on the ground. Nitrogen is also converted to methane by bacteria that live in the soil or on the roots of legumes. Nitrifying bacteria converts ammonia to nitrites and then nitrates. Nitrates, which dissolve in water, can be used by plants to make proteins. Fungi and bacteria create ammonia through decomposition of dead plants and animals; the ammonia undergoes nitrification to nitrates, and denitrifying bacteria in soil convert nitrates to nitrogen, which is released to the atmosphere, thus completing the cycle.

By adding excess nitrogen to the natural system, such as using nitrogen fertilizers or certain feed ingredients, the global supply of nitrogen increases and affects the movement of the various forms of nitrogen through air and water. Compared to historic averages, much more nitrogen is now available in reactive forms. Generally, the more nitrogen that exists in reactive forms like ammonia, the more gaseous nitrogen, like nitrous oxide, is emitted. This can directly increase atmospheric concentrations of nitrous oxide and have other negative consequences on local air and water quality. Ammonia emissions can also affect the concentration of greenhouse gases indirectly, through interactions with methane and aerosols, but these impacts are small compared to those of nitrous oxide emissions. (1,2)

Agriculture contributes about 10% of total U.S. greenhouse emissions. Livestock contributes about 4% of total U.S. greenhouse gas emissions, excluding emissions from feed production and fuel use. Emissions of methane from enteric fermentation and manure management (direct emissions) represent about 41% of agriculture’s total greenhouse gas emissions, measured in carbon dioxide equivalents (the aggregation of all emissions). While direct livestock contributions to the U.S. total greenhouse gas emissions are relatively small, they are directly responsible for 38% of U.S. anthropogenic methane emissions and 4% of U.S. nitrous oxide emissions. (3) Ruminant livestock can produce from 250 to 500 liters of methane daily. (4)

Much of the science on greenhouse gas mitigation is relatively new, still being tested, or is in some stage of research and development. A great number of new ideas are presented every year, and at least some of them will be adopted as a partial solution. A lack of information has been especially true with methane mitigation, with much more information available on emissions tied to manure management and mitigation of nitrogenous compounds. Despite these weaknesses, we have multiple ways of quantifying reduction in methane emissions from livestock, and while challenges exist with each, there are options to overcome them. Thus, the benefits of the feed management approaches in this technical note can be validated. (5,6,7)

Limiting Nitrous Oxide and Ammonia

There are several approaches to limiting nitrous oxide and ammonia production by livestock. These approaches typically involve manipulating dietary components and selecting for efficient animals.

Limit protein to decrease nitrous oxide and ammonia. The protein fed to animals is primarily made up of amino acids. Each amino acid molecule contains nitrogen. If the protein being fed is more than what the animal needs for maintenance and meat, milk, or egg production, the nitrogen will be excreted as waste in the animal's urne (uric acid in poultry) and feces. Part of this nitrogen waste can be used as fertilizer if it is mixed with manure and bedding, but part will be given off to the air as ammonia, or as nitrous oxide. If protein in the diet is limited to the needs of the animal, it should reduce emissions from the urine and feces (primarily from urine). (8,9) In one beef cattle study, feeding 11.5% crude protein reduced nitrogen loss by 60-200% compared to a diet of 13% crude protein. In another study, dietary nitrogen inputs were reduced by 10-20% and resulted in a 15-33% reduction in nigrogen loss. (10)

Another study showed that dietary protein reduction decreased the environmental impact of beef production. Urinary nitrogen excretion was reduced by 40% when decreasing dietary protein (from 17-12%), without impairing performance. Decreasing dietary protein (for example from 17-12%) reduced anaerobic manure nitrogen losses. The study concluded that optimum dietary chlorinated paraffiin is 14.5% to reduce nitrogen and carbon losses aerobically and anaerobically. (11)

Zeolites. Zeolites are naturally occurring minerals made of silica, aluminum, and oxygen. Zeolites contain many pores which may absorb moisture and adsorb different elements and ions. The most important property of zeolites in relation to feed management is the potential to adsorb ammonia and ammonium. Zeolites in feed lessen the excreted nitrogen. Zeolites can reduce the odors of cattle and cattle facilities. This reduction in ammonia in turn decreases respiratory distress of cattle. Zeolite is a low-cost solution to high ammonia levels in animal operations. The Food and Drug Administration (FDA) lists zeolites as Generally Recognized as Safe though they limit the use to 2% of the total ration (21 CFR 582.2122, 2727, and .2729). (12)

Feed additives. (Adapted from: USDA/USEPA Agricultural Air Quality Conservation Measures Reference Guide for Poultry and Livestock Production Systems. Sept 2017). Many feed additives are regularly used to improve nutrient absorption from feed ingredients when added to animal diets. The additives can include various minerals, enzymes, antibiotics and other materials (e.g., beta-agonists, direct-fed microbials, metabolites). Improved nutrient absorption can improve nutrient utilization efficiency and reduce dietary nutrient content without compromising animal performance.

When minerals are used to meet dietary needs, caution should be taken to minimize potential negative effects. Although trace mineral sources are a very small part of the diet and thus provide relatively little sulfur to the system, inorganic mineral sulfates can increase the formation and emission of sulfurous compounds. The mineral sulfate sources (zinc, iron, manganese and copper) in diets may be replaced with carbonate, oxide and chloride sources to reduce sulfur emissions. Moreover, organic mineral forms are usually more efficiently absorbed, minimizing the number of additives needed and amount of minerals excreted; although these non-sulfate mineral sources may have lower mineral availability than mineral sulfate sources.

In swine production (figure 1), research has shown that adding small amounts of fiber (e.g., soybean hulls, sugar beet pulp, wheat bran) to the diet can reduce nitrogen excretion and lower the pH in swine manure. Lowering the manure pH can help prevent ammonium nitrogen in the manure from converting to ammonia and thus reduces the potential for ammonia emissions from the manure. Fiber sources, like soybean hulls, can reduce the proportion of nitrogen excreted in the urine, which reduces ammonia emissions, while also reducing emissions of hydrogen sulfide and odors. Other additives to reduce urinary pH for ammonia reduction include calcium-salts, calcium-benzoate, a combination of phosphoric acid and calcium sulfate, and a combination of monocalcium phosphate, calcium sulfate and calcium chloride.

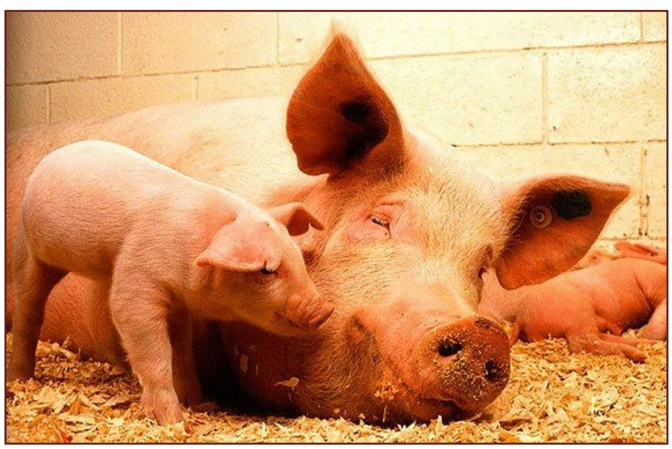

Figure 1: Swine.

In poultry production, the primary strategy for changing pH of excreta in laying hens involves replacing some of the limestone in the diet with calcium sulfate (i.e., gypsum - up to one third of the limestone can be replaced without affecting bird performance or shell characteristics), although the addition of calcium sulfate increases the sulfur content of the diet. Replacement of dietary limestone with calcium sulfate, in combination with zeolite and slight reductions in dietary crude protein, may result in a reduction of ammonia emissions, but at the expense of an increase in hydrogen sulfide emissions. This is an example where prioritizing emissions reductions becomes important. (13)

Breeding and production. By breeding and managing animals for the most efficient utilization of protein, the amount of excess nitrogen contributed to the waste stream can be minimized. In many cases, producers feed to maximize production from the least efficient animal in the operation. More efficient animals will be overfed excess nutrients that cannot be used, and those nutrients are expelled as waste. Breeding to minimize variation can allow the producer to provide the animals with the approximate amount of nutrients, thus minimizing the excess that is wasted.

The swine and poultry industries in particular, because of short generation periods and large population sizes, have been able to apply high degrees of selection pressure on their animals which has led to rapid changes in production efficiencies and minimization of variation in their animals. Because there is so little variation between animals in these industries, producers can feed a diet that is used more efficiently by the animals.

Other. Other things such as feed processing to decrease particle size, or to begin the breakdown of feed through steam, enzymatic, or chemical processing to improve digestibility makes the feed nutrients easier to absorb and digest. It also decreases the amount that can be given off as excreted nitrogen. Feeding according to production phase and/or sex or groups also can contribute to feed nutrients more exactly meeting the needs of the animal and decreasing the amount of excess that might be given off as excreted nitrogen.

Limiting Methane

When attempting to limit methane emissions from livestock, it is important to understand the sources of its production. As with nitrous oxide and ammonia, approaches to reducing methane production in ruminants focus on feeding and nutrition as well as animal selection and management (figure 2).

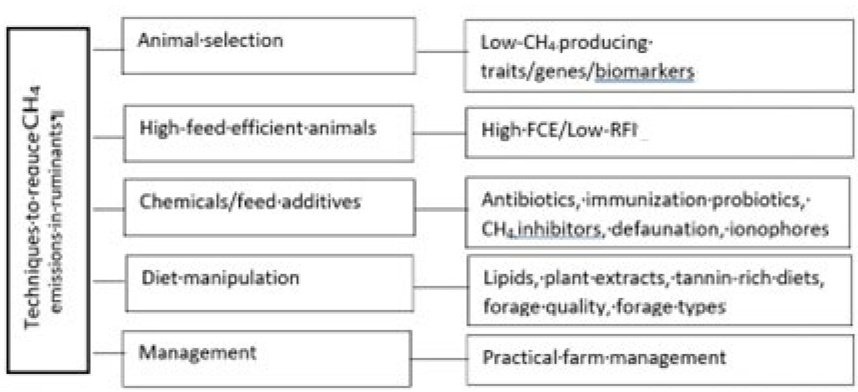

Figure 2: Techniques to reduce methane emissions in ruminants. Source: Byeng R. Min, Sandra Solaiman, Heidi M. Waldrip, David Parker, Richard W. Todd, David Brauer. Dietary mitigation of enteric methane emissions from ruminants: A review of plant tannin mitigation options. Animal Nutrition, Volume 6, Issue 3, 2020.

Where does methane come from? Methane is produced from the digestion of fiber into components that are useable by the animal. Most of the methane produced by the animal is given off as a gastric expulsion through the mouth of the animal. A small amount is given off as stored manure breaks down (See figure 3). The cellulose, hemicellulose, and pectin (forage) will ferment into acetate and butyrate, which releases hydrogen. Hydrogen production is what the archaea and other microbes use to produce methane. The type of carbohydrate in the feed will determine the amount of methane emitted. Concentrates will yield more propionate (from the starch) which consume hydrogen and lower methane emissions.

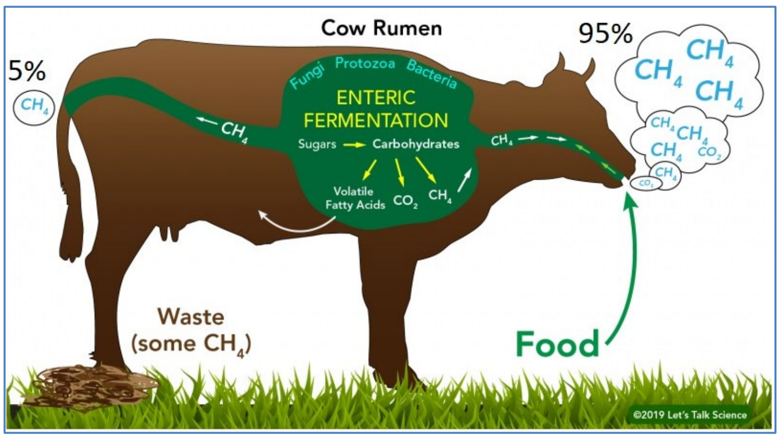

Figure 3: Drawing of a cow, with percentages shown for the amount of methane that is emitted from their body (i.e., 5% in manure and 95% by burps).

Increase feed quality to decrease enteric methane. There is a strong correlation between feed quality and its digestibility by the animal. Feed that is easier to digest will provide more available nutrients to meet the needs of the animal and will result in less emitted as waste products. Methane emissions can be reduced when corn silage replaces grass silage in the diet. Feeding legume silages can also lower methane emissions compared to grass silage due to the lower fiber concentration. (14) Enteric methane production in cattle feedlots is lower per unit of production than with cattle on pasture or range because the digestibility of the feed is higher for feedlot diets compared to grass. Changes in feed and forage can have a large effect on GHG production (See table 2).

Table 2: Summary of Effects of Various Dietary Strategies on Enteric Methane Production in Dairy Cows using Modeled Simulations

Strategy	CH_4 Variation (per unit of GEI)	CH_4 Variation (per unit of DE)
Increasing DMI	-9 to 23%	- 7 to 17%
Increasing concentrate proportion in the diet	-31%	-40%
Switching from fibrous concentrate to starchy concentrate	-24%	-22%
Increased forage maturity	+ 15%	-15%
Alfalfa versus timothy hay	+ 28%	-21%
Method of forage preservation (ensiled versus dried)	-32%	-28%
Increased forage processing (smaller particle size)	-21%	-13%
Ammoniated treatment of poor quality forage (straw)*	x 5	x 2
Protein supplementation of poor quality forage (straw)	x 3	x 1.5

Source: Bencxhaar et al. (2001), Table 12.

* Effects are due to significant in hay digestibility with no change in DM intake.

Early hay/multiple cuttings. As grass matures the proportion of lignin, the “woody” component of the grass, increases and the digestibility of the grass and availability of nutrients decreases. Harvesting hay early can increase the quality of the feed for cattle, since the hay is easier to digest, which will decrease the amount of methane emitted. Harvesting hay early and harvesting additional cuttings of hay increases the quality of the hay offered to the animals. Early harvesting keeps the grass in a state of growth of easily digestible, high-quality forage. In this case, increasing the quality of the forage by early harvesting not only decreases methane production but may also lead to more efficient production of the animals. All of this being said, it is important to protect the hay in some way (wrapping or storing inside or under a tarp) to keep weathering by the sun and rain from decreasing quality and availability of nutrients.

Pasture quality and quantity. High-quality pasture provides grass that is easy for animals to digest. As pasture quality and digestibility decrease, methane production increases. It is important for producers to ensure quality and quantity of grass provided to the animals will meet their physiological requirements; forage testing will assist the producer to determine the forage quality. Prescribed grazing, mob grazing, pasture irrigation, clipping, and replanting are all examples of management practices that can be used to maintain high-quality pastures and provide enough forage for livestock. To ensure the sustainability of forage plants, a balance needs to be met between the methane production goals of the animals with the amount of defoliation and recovery growth requirements of the forage plants in the pasture.

Grain and concentrates. Feeding grains and concentrates can decrease the relative amount of methane produced. Because grains and concentrates have "concentrated" feed nutrients and energy, with a more limited amount of fiber, feeding grains and concentrates can provide the nutrients the animal needs without the fiber that the animal will turn into methane. Cattle in feedlots and dairy cows generally receive a diet higher in grain and concentrates than do animals on range and pasture, and enteric methane production from these animals may be lower than those on range and pasture.

Feeding oils and oilseeds. Ruminants (figure 4) contribute to the emissions of greenhouse gas, in particular methane, due to the fermentation of feed in the rumen. The supplementation of ruminant diets with plant oils (such as: from sunflower or linseed), causes some favorable effects on the fermentation processes. The addition of vegetable oils to ruminant mixed rations will reduce methane production increasing the formation of propionic acid without affecting the digestion of feed in the rumen. Adding vegetable fats to ruminant diets seems to be a suitable approach to a long-term decrease of methane emissions by up to 30%. (15)

Figure 4: Ruminants grazing in field.

Ionophores. Ionophores are feed additives used in cattle diets to increase feed efficiency and body weight gain. They are compounds that alter rumen fermentation patterns. Ionophores can be fed to any class of cattle and can be used in any segment of the beef cattle industry. Similar to many other feed additives, ionophores are fed in very small amounts and supplied via another feedstuff as a carrier for intake. Ionophores decrease incidence of coccidiosis, bloat, and acidosis in cattle. Commercially available ionophores include monensin (Rumensin®), lasalocid (Bovatec®), and laidlomycin propionate (Cattlyst®). Over the growth stages of production of beef cattle, ionophores can increase production by from 10 to 15 %. (16) Supplementation of monensin in cattle diets can decrease enteric methane emissions by 27 to 30% for 2 to 4 weeks, depending on energy content of the diet, though methane production begins to return to pre delivery levels. (17)

Monensin is a feed additive that can be included in lactating and dry cow rations at 250 to 300 mg per day or 11 to 22 g per ton of ration dry matter (See figure 5). The benefit to cost ratio (5:1) and feed efficiency (2 to 4 %) responses to adding monensin are favorable. Monensin will also decrease methane production. (18) Monensin acts by interfering with the breakdown of glucose to carbon dioxide If it were available, carbon dioxide would combine with hydrogen to form methane and water ($CO2 +4H2 => CH4 + 2H2O$).

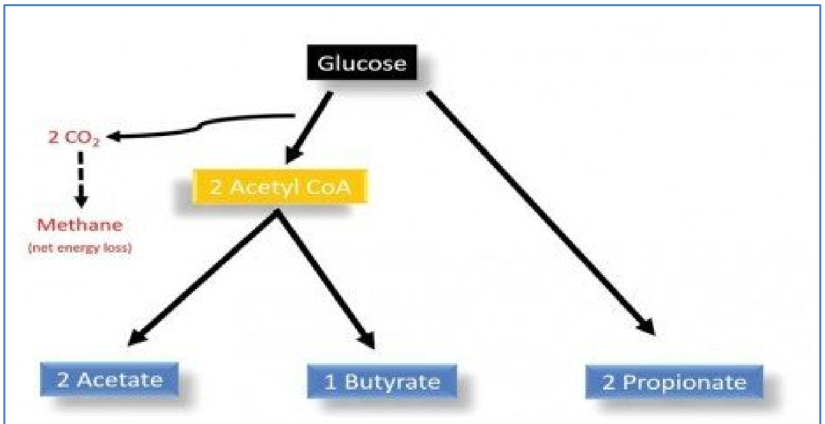

Figure 1. Adapted from Chap 31 Digestion: the Fermentative Processes from http://veteriankey.com/digestion-the-fermentative-processes/

Figure 5: https://extension.psu.edu/ionophores-a-technology-to-improve-cattle-efficiency.

Breeds, breeding and genetics. Raising livestock and focusing on breeds and varieties that most efficiently produce meat, milk or eggs can help reduce production of greenhouse gases. The most efficient livestock use most of the feed nutrients for production, and there are less nutrients excreted which results in less greenhouse gases that are emitted. Increasing feed efficiency has been a focus of all sectors in the livestock industry. In 2014, the U.S. National Dairy Herd produced twice as much milk with around 60% less cows than 90 years ago. This has halved the enteric methane emissions per unit of milk produced in the U.S. (19).

The poultry (figure 6) industry has improved in multiple areas: egg production per bird has increased by about 25%, broiler meat production to 7 weeks of age doubled, and feed per unit of production decreased by about 25% in the last 50 years. According to a UK report, commercially raised broilers have the lowest greenhouse gas emissions per kilogram of meat produced of all the meat-producing livestock species. Genetic selection of broilers over the last 20 years has led to this success and resulted in approximately 25% reduction of greenhouse gas emissions. (20)

Figure 6: Commercially raised chickens.

In all the animal industries, similar productivity gains have been achieved through continuous improvements in animal genetics, nutrition, and management.

Young vs. old animals. Healthy young animals produce much more efficiently than do mature animals. Most of the feed consumed by young animals is used for growth and production, whereas in older animals most feed is used for maintenance of the body, or development of an embryo. Feed efficiency typically declines throughout the growth of the animal until a mature weight is reached. After that, feed in addition to that needed for maintenance or embryonic development will either be assimilated by the animal as fat or wasted and excreted in the manure. The livestock industry can minimize greenhouse gas production by keeping as few older animals as possible (mainly for breeding). This means selecting breeding stock for fast growth and early maturity of their offspring and marketing those animals at an earlier age. Animals will be marketed at an age where they are still at a stage of relatively efficient growth.

Novel Technologies

Vaccines. In the science of feed management for greenhouse gas reduction, there are several new areas being explored for successful long-term solutions. Beginning in the early 2000s researchers in New Zealand began to look at vaccines to kill methane-producing bacteria in the rumen. (21) This met with partial success as populations of methanogens were eliminated, but methane levels returned to pre-vaccination levels as methanogen varieties not killed by the vaccine began to flourish. This method of methane reduction has seen further research but has not become the solution that many had hoped for, though potential exists.

Seaweed. Around the year 2020, research in Australia and the U.S. pointed to the feeding of small amounts of particular species of red seaweed as having potential for major reductions of enteric methane production in cattle of around 80%. (22) These methane reductions are substantial and sustained. This method has a great deal of potential and has been approved for commercial use as a supplement in California. (23) Apparent problems with palatability, and high levels of bromine and iodine of the product may need to be overcome. Other challenges may be presented by learning how to produce, harvest, and process the large amount of seaweed that will be needed to significantly affect enteric methane production. A great deal of additional research and development is likely to take place over the next several years on this topic.

Additives. Research is currently (2022) being done on several feed additives that may decrease enteric methane or ammonia gas production. One that holds promise is called 3-nitrooxypropanol. (24) This product has been shown to cause a sustained decrease of enteric methane of 20-30%.

Regulatory authorities have approved 3-nitrooxypropanol for use in Brazil and Chile. It has received a favorable opinion from the scientific panel of the European Food Safety Authority, and it is currently under review by the Food and Drug Administration. If 3-nitrooxypropanol is approved by the Food and Drug Administration, it should quickly become a tool for use by the cattle and dairy industries.

Other feed additives are being developed to decrease the production of ammonia gas. A product called "Experior" was approved by the Food and Drug Administration for ammonia gas emission reduction from animals or their waste. Ammonia gas emissions can come from many sources, including the manure of beef cattle. Studies of Experior indicated that the product partially reduces ammonia gas emissions from manure from an individual animal or a pen of animals in semi-controlled conditions in enclosed housing. (25)

Delivery on pasture and range. Many of the cattle in the U.S. spend at least part of their lives on pasture and range (figure 7). Enteric methane production can be affected by the condition of the forage available. Animals on pasture and range with poor quality forage will likely produce a larger amount of methane per unit of production than those cattle raised in a feedlot or dairy situation. Delivery of any sort of feed additive to animals on pasture or range is much more difficult, particularly if those animals do not receive any supplemental feedstuffs like silage, haylage, range cubes, or mineral blocks. The delivery problem is one that the industry will have to focus on to solve before many successes can be achieved in mitigating enteric methane in a pasture or range setting. For now, science indicates improving forage quality with low lignin and high digestibility content can reduce enteric methane. Another option could be seeding a mix of forages with higher tannin content into the pasture. When attempting to mitigate enteric methane on pasture and rangelands it's important to balance the amount of plant defoliation and recovery requirements with mitigation goals to ensure long term sustainability of the forage base.

Figure 7: Cattle grazing in pasture

Summary

Animal industries have focused on reducing greenhouse gases as climate change has become one of the major challenges of our time and consumers have demanded action. In some instances, changes to management are effective, and in others changes to diet and feed can have a significant effect. More and more research is being conducted and published that will allow animal producers to determine what needs to be done; what works and what does not.

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