Environmental Responses to Dietary Monensin in Lactating Dairy Cows

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Species: Dairy
Use Area: Animal Housing
Technology Category: Diet Modification
Air Mitigated Pollutants: Methane, Nitrous Oxide, Carbon Dioxide, Methanol, Ethanol

Description:

Paramount amongst the problems currently facing the dairy industry is the impact the dairy industry has on the environment. A main environmental concern associated with the dairy industry is the emission of volatile organic compounds (VOC) and greenhouse gases (GHG). Volatile organic compounds interact with oxides of nitrogen in the presence of sunlight to form ozone (O_3). The major VOCs produced on dairies are methanol (MeOH) and ethanol (EtOH) (Shaw et al., 2007; Sun et al., 2008). Both of these alcohols are produced in the rumen and in the fresh waste primarily by gram-positive bacteria including *Streptococcus bovis* and *Ruminococcus albus* (Shaw et al., 2007). In 2004, California dairy cows and their waste were estimated by air quality agencies to contribute similar amounts of smog-forming VOCs as light/medium duty trucks or light passenger vehicles within the state (SJVAPCD, 2006).

Greenhouse gas emissions associated with dairies are also a significant challenge. The primary GHGs are methane (CH_4), nitrous oxide (N_2O), and carbon dioxide (CO_2). Livestock is considered a significant source of global CH_4 and N_2O emissions from enteric fermentation and their manure (IPCC, 2001). Contributions of CH_4 and CO_2 from lactating dairy cows were determined to be primarily derived from enteric fermentation and respiration (Jungbluth et al., 2001), and to a lesser extent from stored manure (Shaw et al., 2007). Livestock respiration contributes significant amounts of CO_2, approximately half of total CO_2 emissions from both humans and animals worldwide. Under the Kyoto Protocol, livestock contributions of CO_2 are not considered a net source because the plant matter being consumed previously sequestered atmospheric CO_2 (FAO, 2006).

Feed additives have been thought to improve cattle health and productivity, and have been used for these reasons for decades. One such additive, the ionophore monensin (trade name Rumensin®), has been shown in most studies to improve feed efficiency, improve rate of weight gain, and most recently, improved milk production efficiency (milk output per feed input), but with much inconsistency. These improved efficiencies result from changes in rumen bacterial populations and the sparing of metabolites used for production. Any improvements in production efficiencies serve to decrease emissions from cattle per unit produced (milk, rate of weight gain) relative to feed consumed.

Mitigation Mechanism:

Feeding the ionophore monensin to dairy cattle has the potential to alter CH_4 production in the rumen because it selectively reduces the levels of gram-positive bacteria. This is achieved because monensin inserts into the bacterial cell membrane of gram-positive bacteria and functions as an antiporter, translocating extracellular sodium (Na^+) or hydrogen (H^+) for intracellular potassium ions (K^+) (Russell and Houlihan, 2003). Destroying chemi-osmotic gradients across the bacterial membrane result in the inability of the bacterium to synthesize adenosine tri-phosphate (ATP), causing eventual cell death (Tedeschi et al., 2003). Because gram-positive organisms are more likely to produce H_2 and acetate as their fermentation end-products than gram-negative bacteria, cows fed monensin should produce less H_2 and acetate during enteric fermentation. Although monensin has little or no direct effect on methanogenic archaea, methanogenesis should be reduced due to the lower quantities of methanogenic substrates (i.e. H_2 and acetate) (Russell and Houlihan, 2003). The effect of monensin on N_2O and VOC emissions has not been previously reported.

Applicability:

Monensin is currently approved by the FDA to prevent and control coccidiosis, improve rate of weight gain, improve feed efficiency, and increase milk production efficiency in cattle. It can be utilized in beef, dairy, and calf operations. Increasing the efficiencies of the animal, both in health and productivity, serves as the best application for this feed additive. Potential reductions in VOC and GHG emissions should be considered secondary benefits.

Monensin has been reported to affect animal performance. Increased milk production was found by Sauer et al. (1998) and Gallardo et al. (2005) but other workers found no effect of monensin on milk production (van der Merwe et al., 2001, Erasmus et al., 2005, Benchaar et al., 2006, Odongo et al., 2007). Thus additional studies are needed to determine the effect of monensin on milk production. Similarly the effect of monensin on dry matter intake (DMI) has varied across studies. In several recent studies DMI did not differ when cows were supplemented with monensin compared with unsupplemented control groups (Erasmus et al., 2005, Gallardo et al., 2005, Benchaar et al., 2006). However, a review of 228 trials including 11,274 cattle (Goodrich et al., 1984), DMI decreased by 6.4 ± 5% when monensin was added to the diet (average 246 mg day^{-1}) indicating considerable variability in response to monensin, again suggesting that additional studies are needed.

The effect of monensin on GHG emissions, specifically CH_4, has been studied with varied results. Odongo (2007) reported a 7% reduction for CH_4 emissions over a six-month period when cows were fed monensin ranging from 307.3 to 708.1 mg day^{-1}; however, the difference in CH_4 emissions was not significant until the fourth month of their study. Thus a decrease in CH_4 emissions in response to dietary monensin might occur only long term. Short-lived (3-6 weeks) reductions of CH_4 emissions in beef steers were reported in the literature, but emissions eventually returned to pre-ionophore feeding levels (Guan et al., 2006). Short-lived CH_4 decreases in steers with emissions returning to control levels after 9-12 days were also reported (Carmean and Johnson, 1990, Rumpler et al., 1986).

Previous studies reported varied results for CH_4 reductions when cows were fed high dry matter diets, similar to those in our study (see below), and high moisture diets that primarily consisted of corn silage. It is not clear if the type of diet is the chief factor in determining the effects of monensin on GHG reductions.

In our study, monensin did not affect emissions of the GHGs (CH_4, N_2O, and CO_2), as well as smog-forming VOCs (MeOH and EtOH). In the recently conducted study in our lab, monensin fed at 600 mg head^{-1} day^{-1} with an alfalfa hay-based total mixed ration did neither effectively reduce GHG and VOC emissions, nor impact animal performance or the microbial population structure of animal feces.

It is evident, due to such varied responses reported in the literature, that more research in this area is needed to determine the potential of monensin as a mitigation strategy.

Limitations:

Since ionophores are classified as drugs, the primary limitations associated with ionophores are the minimum and maximum feeding levels and intended uses as defined by the FDA. Feeding levels are specific to species and the type of operation (dairy, beef, calf), as well as the specific intended use (improved milk production efficiency, improved rate of weight gain, etc.). Current approved minimum and maximum feeding levels for dairy cows for increased milk production efficiency are 185 to 660 mg head^{-1} day^{-1}. Secondary limitations include, but not limited to, cost to profit ratios which are determined by quality and cost of feed, and by current milk prices received by the producer per one hundred pounds of milk (cwt).

Directly measuring the impact of ionophores on air emissions can prove difficult, if not impossible for many producers. Therefore measurements have to be based on improvements of efficiencies of unit output per unit input. Potential improvements in efficiencies in response to the use of ionophores can help to amplify this reduction of emissions per unit of output.

Cost:

Feed costs can represent approximately 50-55% of total operation costs on a dairy. This trend continues to increase resulting in decreased profit margins. In the western United States, there is a trend toward less dependence on concentrate feedstuffs because of price, while dairy producers are attempting to maximize their use of farm owned feeds (silages and hay). As the percent of roughages in the ration increase, the quality of the forage should be considered before the potential use of feed additives that claim improve feed efficiencies.

Monensin is most commonly delivered to the animal in a mineral or grain premix. Depending on the type of premix, inclusion level of monensin, and cost of transportation, costs can vary widely. Depending on the method of delivery to the animal, the cost of the raw drug form of monensin (Rumensin® R80, 80 g lb^{-1}) can range from approximately \$0.0145 to \$0.072 cow^{-1} day^{-1}, delivering 185 to 660 mg head^{-1} day^{-1}, respectively.

Implementation:

Monensin has been widely used in beef cattle operations for the past 30 years, as well as in US dairy operations since its approval in 2004 for use in lactating cows. The use of monensin is strictly determined by the definitions set by the FDA. Additionally, mixing of the raw drug form of monensin into feed is prohibited unless a license has been granted to the mixing facility by either state or federal government.

Technology Summary:

Feeding ionphores is believed to be a method to improve feed efficiency. Additionally, some studies have shown mitigation effectiveness for GHG emissions. Improvements in feed efficiencies for rate of weight gain and milk production equate to reductions of emissions per production unit. Increasing the efficiency of the animal will reduce the amount of emissions per unit of input. The use of ionophores has been shown to improve efficiency in the animal, although with inconsistent results. Many variables can impact the effect of ionophores including the type of diet and stage of production. Our study conducted in 2007, did not prove monensin to reduce emissions of the GHGs methane (CH_4), nitrous oxide (N_2O), and carbon dioxide (CO_2), as well as smog-forming VOCs methanol (MeOH) and ethanol (EtOH) when fed at 600 mg $head^{-1}$ day^{-1} with an alfalfa hay-based total mixed ration. Additional work is needed to evaluate the impact of monensin on feed efficiency, dry matter intake, milk production, and emissions of both GHG and VOC in lactating cows using different diets, particle size of feed, and quality of the forage.

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