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Effect of increasing levels of corn silage in an alfalfa-based dairy cow diet and of manure management practices on manure fugitive methane emissions

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ABSTRACT

The main objective of this study was to assess the effect of dairy cow diets and manure storage management practices on manure fugitive CH_4 emission in order to precisely establish the carbon footprint of Canadian milk products. The specific objectives of this study were to investigate the effect of incorporating 50 and 100% corn silage (CS) as starch sources in dairy cow diets and the effect of complete removal of residual sludge in the manure storage tank and of storage emptying frequency on manure fugitive CH_4 emissions. Alfalfa silage based diets were formulated as follows: 0% corn silage (0% CS, considered as the control diet); 50% corn silage (50% CS); and 100% corn silage (100% CS). Canadian summer manure storage conditions were simulated in laboratory-scale storage structures located in a controlled-environment chamber operated at 20 ± 1 °C. The incorporation of 50 and 100% CS in dairy diets was associated with significant increases of 39 and 79%, respectively, in fugitive CH_4 emissions expressed in L day^{-1} cow^{-1} from manure storage with residual sludge over a 120-day storage period. The complete removal of residual sludge in the manure storage tank resulted in fugitive methane emission reductions exceeding 97.0% irrespective of the diet composition. Emptying of the manure storage tank 2 times and 4 times over the summer period reduced fugitive CH_4 emissions on average by 40 and 80%, respectively. The complete removal of the manure storage residual sludge and the increase in manure storage tank emptying frequency over the summer can be adopted as low-cost best management practices (BMPs) for substantially reducing the fugitive CH_4 emissions from manure storages.

1. Introduction

The dairy sector is an important emitter of greenhouse gas (GHG) emissions. Environmental legislation and public concerns about the environmental footprint of livestock production operations have increased pressure on producers to adopt measures to reduce atmospheric and environmental pollution. Manure generated by livestock operations contributes to greenhouse gas (GHG) emissions. Methane (CH_4), one of the principal agricultural greenhouse gases, is produced by enteric fermentation in ruminant animals (Kebreab et al., 2006; Kraatz and Berg, 2010) and by fugitive methane emission that occurs during anaerobic degradation of manure in livestock buildings and manure storage facilities (Husted, 1994; Massé et al., 2008; Chadwick et al., 2011; Moller et al., 2004; Sommer et al., 2000). The level of uncontrolled fugitive CH_4 emission during manure storage is affected by environmental factors such as storage temperature (Khan et al., 1997; Massé et al., 2003; Park et al., 2006; Møller et al., 2004a,b), storage duration (Massé et al., 2008), manure composition and bedding content (Chen et al., 1988; Dinuccio et al., 2008; Massé et al., 2014).

It is widely recognized that diet modifications (quantity and type of starch, fiber and protein) strongly affect enteric fermentation and ruminant performance (Johnson et al., 1993; Moss et al., 2000; Külling et al., 2002; Hindrichsen et al., 2005). For example, an increase in the level of starch lowers ruminal pH, enhances propionate production, which reduces the acetate and hydrogen concentration in the rumen and therefore enteric methane (CH_4) formation (Monteny et al., 2006; Beauchemin et al., 2009). However, the effect of starch level in the diet on fugitive CH_4 emissions from manure has not been extensively studied. In order to successfully develop effective CH_4 mitigation strategies in the animal production sector, an integrated, system-wide approach should be implemented to assess the effectiveness of best management practices (BMPs) (Demeyer and Van Cleemput, 1996). One way to reduce emissions from barns and indoor

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storage structures is to remove manure more frequently and completely (Osada et al., 1998). Limited data are available on the effect of the complete removal of storage tank's residual sludge and of storage tank's emptying frequency on fugitive CH_4 emissions under cool climatic conditions. The main objective of this study was to obtain scientifically sound data on fugitive CH_4 emissions during storage as a function of animal diets and manure management practices, specifically for regions with cool climatic conditions like those in Canada. This R&D initiative is required to provide sound advice to farmers on the effectiveness of BMPs for reducing the carbon footprint of Canadian milk products. The specific objectives of this study were to investigate the effect of adding 50 and 100% corn silage as starch sources in an alfalfa silage-based dairy cow diet and of the effect of complete removal of storage tank's residual sludge and storage tank emptying frequency on fugitive CH_4 emissions.

2. Materials and methods

2.1. Experimental design

As part of an integrated research project to assess the carbon footprint of milk products in Canada, two experiments were conducted: (1) an animal experiment to evaluate the impact of the level of corn silage as a starch source in Holstein cow diets on enteric CH_4 emissions and on milk yield and composition (Hassanat et al., 2013). Nine ruminally cannulated lactating cows were used in a replicated 3×3 Latin square design (32-d period) and fed (ad libitum) a total mixed ration (TMR) alfalfa based diet with different corn silage content (0% CS, 50% CS and 100% CS in the TMR). Increasing the CS proportion (i.e., at the expense of alfalfa silage) in the diet was achieved by decreasing the corn grain proportion and increasing that of soybean meal (Hassanat et al., 2013). The diets composition is provided in Table 1. As per the 3×3 Latin square design, the animal trial included three 32-d periods. (2) A fugitive manure methane emission assessment experiment which is reported in this paper. Due to the infrastructure limitation, the effect of diet on fugitive CH_4 emission was studied only for the first period of the animal trial. Therefore, 3 pairs of duplicate storage structures with residual sludge simulating the current manure storage practice and another 3 pairs of duplicate storage structures without residual sludge simulating the complete removal of manure storage residual sludge have been used in the fugitive CH_4 emission study.

Table 1
Composition of the diets for the three periods of the animal trial (Hassanat et al., 2013).

	0% CS[a]	50% CS	100% CS
Diet ingredient (% DM)			
Alfalfa silage (AS)	56.4	28.2	0.0
Corn silage (CS)	0.0	28.2	56.4
Corn grain, ground	25.5	19.2	12.4
Soybean meal	2.2	9.2	16.2
Soybean hulls	5.9	5.8	5.8
Timothy hay	3.2	3.2	3.2
Corn gluten feed	2.1	2.6	3.0
Rumen inert fat	2.0	1.0	0.0
Urea	0.0	0.1	0.2
Calcium carbonate	0.5	0.4	0.6
Potassium carbonate	0.0	0.0	0.4
Mineral and vitamin supplement	2.3	2.4	1.8
Diet composition (% DM)			
Organic matter (OM)	91.7	92.8	94.2
Crude protein (CP)	16.8	16.2	15.6
Neutral detergent fiber (NDF)	30.7	29.7	28.6
Acid detergent fiber (ADF)	23.4	20.2	17.0
Starch	17.0	22.8	30.0
Crude fat	7.02	5.48	3.40

[a] CS stands for corn silage in the different diets (0% corn silage/100% alfalfa silage; 50% corn silage/50% alfalfa silage; 100% corn silage/0% alfalfa silage).

2.2. Manure fugitive methane emission assessment experiment

2.2.1. Effect of diet on fugitive methane emission from manure storages with residual sludge

Total collection of feces and urine was performed by fitting cows with harnesses and tubes, allowing the collection of feces and urine separately. Feces and urine were collected over the 6-day experimental period as described in Hassanat et al. (2013). After each collection day, feces and urine were pooled in a larger container and then stored at 4 °C. At the end of the collection period, manure slurries were homogenized and subsamples were taken for analysis. Manure slurries collected from the first period of the animal trial have been used for fugitive CH_4 emission experiment. Storage simulations were performed over a 4-month period in duplicate 54-L Plexiglas storage structures located in a controlled-environment chamber operated at 20 ± 1 °C, in order to simulate the monthly average temperature reached in commercial manure storage structures in cold regions like Canada over the 120-day storage period (late spring, summer and early fall). The methodology is also described by Massé et al. (2014).

A total of fourteen storage structures were used to assess the fugitive methane emission from three diets containing three different levels of corn silage (control 0% CS, 50% CS and 100% CS diets). Six storage structures contained raw manure and storage residual sludge, six manure storage structures without manure storage residual sludge simulating completely clean manure storages and two storage structures contained only manure storage residual sludge.

In Canada, manure storages have a flat bottom without a sludge pit that would be required to receive the residual sludge before it is picked up by the suction of the pump. Therefore the current manure removal equipment cannot remove all the manure slurry. There is always about 30 cm of manure residual sludge left at the bottom of the tank. The residual sludge to raw manure ratio changes with time. When the producer starts to fill the manure storage in early may, the ratio of residual sludge to raw manure is very high (around 8). With the continuous addition of raw manure to the storage over the summer the ratio of residual sludge to raw manure decreases. At the end of the summer the ratio of residual sludge to raw manure could be as low as 0.125. For this experiment, an average ratio of 1.0 has been selected and it is representative of commercial scale operation. This methodology is also described by Massé et al. (2014). The physico-chemical characteristics of the storage tank's residual sludge are given in Table 2. The three sets of storage structures, simulating standard commercial storages with

Table 2
The physico-chemical characteristics of the storage tank residual sludge.

Parameter	Concentration	
	% DM	$g\,kg^{-1}$ of residual sludge
Dry matter (DM)		50.0
Volatile solids (VS)	74.0	37.0
Fixed solids	26.0	13.0
Soluble chemical oxygen demand (SCOD)	17.8	8.9
Volatile fatty acids (VFAs)	0.76	0.38
pH (unit)		7.57
Total chemical oxygen demand (TCOD)	119.4	59.7
N-ammonia ($N\text{-}NH_3$)	4.0	2.0
Total Kjeldahl nitrogen (TKN)	6.6	3.3