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Comparison of greenhouse gas emissions from corn- and barley-based dairy production systems in Eastern Canada☆

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ABSTRACT

In Canada, corn silage is increasingly fed to lactating dairy cows at the expense of barley silage and other forages, as its high-energy content can improve animal performance. Moreover, corn silage is known to reduce methanogenesis in the rumen compared to barley silage. A life cycle analysis was conducted to compare whole farm total GHG emission and greenhouse gas (GHG) intensity (kilogram CO_2-equivalent per kilogram of milk) of corn- (CS) and barley- (BS) based dairy production systems. For this purpose, a virtual farm representative of typical dairy production systems in Quebec was used to simulate the 6-year lifespan of a dairy cow, from calving to culling. Diets fed to lactating cows consisted of 54.4% corn or barley silage, 5.5% grass hay and 40.1% concentrate (dry matter basis). The impact of silage digestibility (measured as total digestible nutrient [TDN] content) on total GHG emissions of the dairy production system was also assessed. From prior experimental data, milk production was assumed to average 34.7 and 31.9 kg/day for lactating cows fed corn and barley silages of medium TDN content respectively. Milk production was also assumed to be positively correlated with the TDN content of diets. To compensate for differences in milk production per cow, the number of cows was adjusted to obtain similar total fat- and protein-corrected milk production between farms. Forage (silage and hay) and grain (barley or corn) were cultivated on-farm whereas all other feed ingredients were purchased. Greenhouse gas emissions were estimated with the Holos model using a “cradle-to-farm gate” approach. Methane (enteric fermentation and manure storage), CO_2 (farm operations, production and transportation of purchased feed) and N_2O (N degradation from crop residue, manure, N leaching and volatilization) emissions were taken into account. Enteric CH_4 was predicted from animal energy requirements and diet composition. Percentage of energy intake lost as CH_4 was assumed constant regardless of silage TDN content. When silages having medium TDN content were used, total GHG emission was reduced by 13% with CS compared to BS, despite the fact that the reduction of enteric CH_4 emissions with corn silage was partially offset by increased CO_2 emissions from the additional purchased feed protein sources (+9%). Within a forage type, increasing silage TDN content reduced GHG intensity. Finally, the GHG intensity of dairy production systems was lower with high digestible barley silage compared to low digestible corn silage showing the importance of producing forages with high digestibility that maximize milk production.

1. Introduction

Ruminants are an important food source in human diets, supplying almost the totality of milk products and one third of meat consumed globally (Gerber et al., 2013b). Unlike monogastric animals, ruminants can make use of forages because of their unique digestive system, reducing the competition for grain used in human nutrition and maintaining various ecosystem services associated with forage cropping (Guyader et al., 2016). Corn and barley silages are the main annual forage sources in Canada. Because of a shorter growing season, barley silage is mostly produced in Western Canada whereas corn silage is widely grown in Eastern Canada. With climatic warming and the development of short-season corn hybrids, corn silage cultivation areas are progressively increasing throughout the country (Addah et al., 2011). Corn silage is particularly attractive to farmers as it improves performance of animals due to its higher total digestible nutrient (TDN) content in comparison to barley silage attributed to its higher starch content (20–40% of DM for corn silage, Bal et al., 1997; 10–30% of DM for barley silage, Hargreaves et al., 2009). Also, it is well documented that high-starch diets reduce methane (CH_4) production from ruminants as shown by

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Benchaar et al. (2014) who reported a 14% reduction in enteric CH_4 from lactating dairy cows fed a corn silage-based diet compared to cows fed a barley silage-based diet.

In Canada, enteric CH_4 production by ruminants accounts for 38% of greenhouse gas (GHG) emissions within the agricultural sector (Environment Canada, 2012). Modification of forage source is among the best potential strategies to improve CH_4 efficiency of ruminants, expressed as the ratio between CH_4 and food production (Gerber et al., 2013a). Indeed, unlike some direct CH_4-mitigating agents, modification of dietary composition offers the double advantage of reducing CH_4 production while improving production efficiency. Moreover, on-farm adoption of alternative forages and forage harvesting management are relatively simple, albeit limited by local agronomic constraints, in contrast to feeding CH_4-suppressants that are experimental and not yet registered for feeding commercially. However, modification of silage source requires a major shift in the cropping system of the farm.

Thus, prior to recommending corn rather than a barley feeding system as a CH_4 mitigation strategy, it is essential to assess the net impact of corn-based dairy production systems on GHG intensity of milk production to ensure that corn silage does not reduce enteric CH_4 emissions at the expense of other GHG sources (carbon dioxide [CO_2] and nitrous oxide [N_2O]). In addition, this study is the first to report the GHG intensity of a barley-based dairy production system using barley silage as the main forage source. Therefore, the objective of this life cycle assessment (LCA) was to compare the GHG intensity of milk production of a corn-based dairy production system (CS) with a barley-based system (BS). As nutrient content and yields of forages are subject to environmental conditions including geographical location and climate (Bal et al., 1997; Hargreaves et al., 2009), the effects of varying silage TDN content and biomass yield of these two forages on GHG intensity of dairy production systems was also explored.

2. Materials and methods

Input data were based on the study of Benchaar et al. (2014) conducted in Quebec, thus the model dairy farms were located at Napierville in the Montérégie region, Quebec, Canada with a fine loam soil texture cultivated under reduced tillage practice. The farms were located in Ecodistrict 541 in the Mixed Wood Plains Ecozone. Precipitation and evapotranspiration during the growing season (May–October) averaged 559 and 529 mm, respectively (Marshall et al., 1999). The LCA followed the baseline scenario for the dairy production system in this province developed by Mc Geough et al. (2012).

2.1. Animal management

2.1.1. Herd dynamics

The LCA started with the birth of 40-kg female calves that successively passed through the entire 6-year dairy production cycle (Fig. 1). The number of initial female calves and heifers was estimated accounting for calf death losses (7.8 and 1.8% between 0 and 3 and 3–6 months, respectively; USDA, 2010). The sex ratio of new-born calves was assumed to be 51:49 (male:female). Veal calves were grown as young veal calves for 3 months (40–107 kg) before being finished for 3.5 months (107–273 kg). Consistent with the average replacement rate (31.9%) and number of lactations (2.75) of cows in Quebec (Valacta, 2009), 25% of the cows were removed from the herd (i.e., assumed to be sent to the abattoir) at the beginning of their third lactation with the remainder slaughtered after giving birth to their fourth calf. In commercial practice, however, the culling of cows would be spread out over the production cycle. A single culling time was used to represent the average number of lactations, replacement rate, and dynamics of the herd to simplify the calculations, recognizing this approach would have no impact on the net emissions over the entire cycle.

2.1.2. Feeding system

Diets fed to calves were similar between CS- and BS-dairy production systems and mainly consisted of milk replacer for young females and veal calves, grass-legume hay for older female calves, and corn grain for older veal calves (Mc Geough et al., 2012; Table 1). Heifers and non-lactating (dry) cows received a diet containing grass-legume hay supplemented with either corn or barley silage, and dietary crude protein (CP) content and yield of enteric CH_4 (Ym, defined as MJ of CH_4 produced per MJ feed DM consumed) were predicted from diet composition (NRC, 2001; Little et al., 2013). Lactating animals were offered a corn or barley silage-based diet where ingredient composition and Ym were those reported by Benchaar et al. (2014). Because corn silage was lower in CP (−2% of DM) and NDF (−15%) content, the CS-based diet contained additional sources of nitrogen (N; corn gluten feed and urea) and fiber (soybean hulls) in order to obtain similar nutrient content between diets.

The effect of corn and barley silage digestibility on total GHG emissions at the system level was evaluated by changing the TDN content of silage offered to cows and heifers. For each silage, the TDN content was varied from low (LD; 65 and 55% for CS and BS, respectively), medium (MD; 70 and 60% for CS and BS, respectively), and high (HD; 75 and 65% for CS and BS, respectively) (NRC, 2001; Table 2). Diet CP content and Ym were assumed to be constant regardless of silage digestibility.

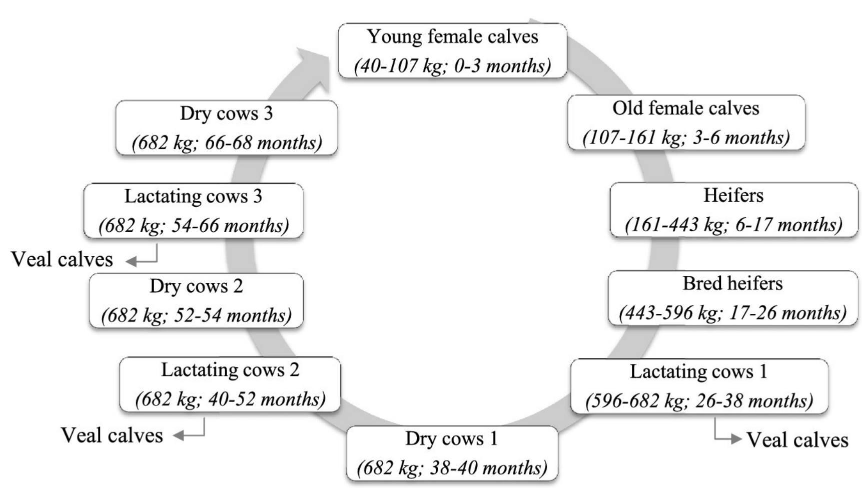

Fig. 1. Dairy production cycle and characteristics of animal categories.