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Greenhouse gas emission of Canadian cow-calf operations: A whole-farm assessment of 295 farms

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ABSTRACT

The Canadian beef industry is a major contributor of greenhouse gas (GHG) emissions from the agricultural sector. The industry is diverse geographically as well as in operation scale and management, suggesting there may be opportunities to reduce GHG emissions through identification and adoption of selected management practices. The objectives of the study were to: i) estimate variation in emission intensity [total farm GHG emissions (kg carbon dioxide equivalents, CO_2e) per kg total live weight (LW) sold] among cow-calf farms by categorizing farms into low-and high-emitting groups, and ii) identify management attributes that significantly impact whole-farm GHG emissions. Farm survey data from 295 beef cow-calf farms were used to estimate farm GHG emissions using a whole-farm model, Holos. Emission estimates included methane from enteric fermentation and manure, nitrous oxide from soils (crop, forage, pasture, range) and manure, and carbon dioxide (CO_2) from on-farm energy use and production of farm inputs. Farm boundary was delineated at the farm-gate and included all the processes of the farm until weaned calves and culled cows left the farm. Overall, our study indicated that large variation in emission intensity existed among cow-calf operations, regardless of the size (expressed as number of cows or land area) or location of the farms in Canada. Emission intensity averaged 23.9 (range of 16.3 to 37.8) kg CO_2e kg^{-1} LW sold and 2178 (range of 266 to 9782) kg CO_2e ha^{-1}. Most of the total farm emissions were associated with enteric fermentation (65%) and manure storage (23%). The quartile of low-emitting farms produced an average of 19.9 (range of 16.3 to 21.4) whereas the quartile of high-emitting farms averaged 28.7 (range of 26.3 to 37.8) kg CO_2e kg^{-1} LW sold. Low-emitter farms produced calves more efficiently (calved earlier in the year, higher calf average daily gain), provided diets with higher digestible energy and crude protein, grew fewer annual crops for feed relative to perennial forage, had higher culling rate, and did not compost manure. Our study indicated that improving management efficiency can reduce average emission intensity by 31% on Canadian cow-calf production systems.

1. Introduction

Beef cattle are raised in all provinces of Canada and make a significant contribution to the overall Canadian economy, generating $13 billion to the country's gross domestic product in 2012 (Kulshreshtha et al., 2012). The sector also accounts for 43% of all agricultural greenhouse gas (GHG) emissions (Environment Canada, 2015). Several studies reported that the carbon footprint of beef (kg carbon dioxide equivalent (CO_2e) kg^{-1} product) is larger than that of other livestock products such as pork, lamb, poultry, eggs and milk (Dyer et al., 2010; Lesschen et al., 2011; Browne et al., 2011). Therefore, it is important to identify management strategies that reduce GHG emissions from Canadian beef cattle farms.

National characteristics of the beef sector are captured through: government censuses (e.g., Statistics Canada, 2015), comprehensive farm surveys conducted occasionally (e.g., Sheppard et al., 2009; Sheppard and Bittman, 2011, 2012) and the Agriculture and Agri-Food Canada National Farm Surveys conducted periodically (Statistics Canada, 2011). Recently, Sheppard et al. (2015) surveyed 1009 beef cattle producers (1.6% of the beef farms in Canada; Beef Info, 2013) to characterize current management practices used on cow-calf, backgrounding and finishing operations. Of the respondents, 91% described themselves as cow-calf (specialized in marketing weaned calves), 38% as backgrounder or stocker (specialized in feeding weaned calves until they are ready for finishing), and 13% as feedlot operators (finishing mostly steers and heifers to market weight). The majority of farms reported raising cattle

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in more than one of these categories. In Canada, cow-calf operations are typically low input, forage-based systems where cows are naturally bred and generally kept with calves on summer pasture. Pregnant cows have traditionally been overwintered in confined feeding areas where they are fed hay and/or straw and provided with bedding. However, cows are increasingly overwintered in open fields (Sheppard et al., 2015) where they are offered round bales, swathed cereals or stockpiled forage to reduce production costs related to harvesting, storage, feeding, feed processing and manure handling (Kelln et al., 2011; Baron et al., 2014) and GHG emissions (Alemu et al., 2016a). This differs from finishing operations in which confined feeding is typical and hence more stored feeds with high energy density are used until the animals reach market weight.

Measuring GHG emissions from beef cattle production systems is complex because of the need to include the animal, facilities and land components. Many studies of GHG fluxes from cattle systems tend to focus on one gas from a single source, such as methane (CH_4) emissions from enteric fermentation either from individual animals (Boadi et al., 2002; Beauchemin and McGinn, 2005), grazing herds (McGinn et al., 2015), or group of animals managed in pens (Laubach et al., 2008; McGinn et al., 2009). In addition to CH_4, other GHG emissions including nitrous oxide (N_2O) and carbon dioxide (CO_2) from cattle-forage systems (Maas et al., 2013; Merbold et al., 2014) and manure, as well as on-farm energy use must also be considered to assess the impact of management practice on net emissions. Measuring net emissions is a difficult task given the scale of beef cattle operations, which are often very large and both temporally and spatially variable.

Whole-farm models are useful for estimating GHG emissions from entire farms (e.g., Little et al., 2008; White et al., 2010; Rotz et al., 2011; Foley et al., 2011). These models have been used to ascertain the main sources of emissions (Beauchemin et al., 2010), evaluate effects of change in management practices (Alemu et al., 2015), or suggest mitigation measures (Beauchemin et al., 2011). Beauchemin et al. (2010) previously modelled GHG emissions from Canadian beef production systems and determined that of the total GHG emissions (soil carbon (C) excluded), 80% came from cow-calf operations. Furthermore, of the total CH_4 from enteric fermentation, 84% was from mature cows, indicating the importance of mitigation in this sector. The main objective of our study was to assess GHG production from a cross section of cow-calf operations to determine farming practices that favour low GHG emissions. Specifically, we i) estimated the variation in GHG emission intensity [total farm emissions (kg CO_2e) per kg total live weight (LW) sold from weaned calves and culled cows] among cow-calf operations across Canada based on recent farm survey data and ii) identified production practices common to low- and high-emitting farms.

2. Methods

2.1. The database: Canadian beef survey of cow-calf operations

A survey of 1009 beef cattle operations was conducted in 2012 across Canada on farming practices for a one-year period (November 2010 through October 2011). The survey gathered comprehensive information on farm structure, herd management, feeding and grazing management, land use, and manure management (Sheppard et al., 2015). From the 1009 farms surveyed, we identified 295 cow-calf operations that maintained breeding stock and weaning-age calves with sufficient information to quantify whole-farm GHG emissions. Operations that also backgrounded and/or finished beef cattle were excluded to create a more homogeneous data set.

The farms were distributed across Canada and had a wide range of farm characteristics (Table 1). While nine of ten Canadian provinces (Newfoundland excluded) were represented in this population, 79% of the farms were from the four western provinces [Alberta (100 farms), Saskatchewan (79 farms), Manitoba (35 farms), British Columbia (18 farms)] where the majority of Canadian beef farms are situated (Statistics Canada, 2015). The cohort averaged 79 cows (median = 60, range of 3 to 500) with an average land size of 347 ha (median = 219 ha, range of 15 to 4399 ha), and a stocking rate of 0.71 animal unit (AU) per ha (median = 0.64, range of 0.11 to 2.7 AU ha^{-1}; Table 1). Standard AU was defined as one mature 453.6 kg cow with a calf, or equivalent, and was based on the average daily forage intake of 11.8 kg (Iwaasa et al., 2012). Calving typically occurred between March and June and average calving and weaning weights for the cohort were 39 (median = 39) and 278 kg (median = 272), respectively. The mean daily weight gain for calves (1.1 kg day^{-1}) was calculated based on reported birth and weaning weights and an average weaning age of seven months (Beauchemin et al., 2010). An average culling (replacement) rate of 17.5% (median = 14.8) for this cohort was within the range reported for Canada, 4 to 18% (Canfax Research Service, 2014). As specific information regarding the nutritional quality of the diet was lacking, we inferred this from management data including type of feed/diet provided, inclusion rate of forages and supplements, proportion of legume in perennial forages used for hay and pasture, stage of maturity at harvest, harvest frequency for perennial forages, and type of feed storage (Sheppard et al., 2015). Feed composition values from literature, national and provincial feed composition databases (National Research Council, NRC, 1982; Beef, 2015; Alberta Agriculture and Forestry, 2015a) and beef National Research Council (NRC) (2000)were used to estimate nutritional quality. Canadian beef cattle ration balancing software, CowBytes5© (Alberta Agriculture and Forestry, 2015b), was used to estimate dry matter (DM) intake for all cattle types on each farm based on animal and diet information from the survey.

Our analysis included farm inputs such as synthetic fertilizers, pesticides, fuel and purchased feeds (forage, grain, supplements). Some farms produced all required feed whereas others imported much of their feed (Table 1). About 43% of the farms did not grow annual crops and 4% did not produce perennial harvested forage (hay and silage). Pasture area was highly variable with 4% of the farms having >1000 ha of pasture area and about 8% having no pastureland. Nitrogen (N) fertilizer was more often applied on annual crops than on tame/seeded and native pasture. For the 57% of farms that grew annual crops for feed, the N fertilizer application rate ranged from 19 to 123 kg N ha^{-1} whereas for the 29% of farms that applied N fertilizer on perennial forage, the application rate ranged from 10 to 105 kg N ha^{-1}. Manure produced during confinement was applied either on farm land immediately following clean out of pens (mainly on cereal grain and forage fields) or temporarily stockpiled (in a static pile) before land application (in spring and fall) or composted (intensive and/or passive). However, on farms with cattle grazing for a significant portion of the year, most of the feces and urine were deposited directly on pasture.

2.2. Modelling GHG emissions

2.2.1. The Holos model

Greenhouse gas emissions were estimated using Holos (V2.1, Research; www.agr.gc.ca/holos-ghg), developed by Agriculture and Agri-Food Canada (Little et al., 2008; Kröbel et al., 2016). Holos is an empirical model based on the IPCC Tier 2 methodology (Intergovernmental Panel on Climate Change, IPCC, 2006), modified for Canadian conditions and farm size and used for Canadian national GHG inventory (Environment Canada, 2015). The model estimates GHG emissions on an annual time step for cropping system, land use and management changes and on a monthly time step for livestock operation. The model requires the user to select a farm location using ecodistrict numbers, a subcategory of the National Ecological Framework of Canada (Marshall et al., 1999). Specific farm location (ecodistrict number) was identified in the survey and used in our analysis however, farm confidentiality was maintained. The model has been tested for farm GHG emissions from both beef (Beauchemin et al., 2010, 2011; Bonesmo et