



## Assessment of grazing management on farm greenhouse gas intensity of beef production systems in the Canadian Prairies using life cycle assessment



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### ABSTRACT

Grazing is a common practice in the beef cattle industry and is an integral component of pasture and rangeland management. The objective of this study was to evaluate impacts of grazing management scenarios on greenhouse gas (GHG) intensity [kg carbon dioxide equivalents (CO<sub>2</sub>e) kg<sup>-1</sup> beef] at the farm-gate for beef production systems in western Canada using life cycle assessment. A life cycle assessment over an 8-year period was conducted on a hypothetical but typical beef farm that managed 120 cows, 4 bulls, and their progeny. Calves were backgrounded (raised) on rangeland and market cattle were finished on grain for an average of 134 ± 11 d. Four grazing management scenarios were examined: i) light continuous grazing (LC) for all cattle, ii) heavy continuous grazing (HC) for all cattle, iii) light continuous grazing for cow-calf pairs and moderate rotational grazing for backgrounded cattle (LCMR), and iv) heavy continuous grazing for cow-calf pairs and moderate rotational grazing for backgrounded cattle (HCMR). Greenhouse gas emissions from various sources within the farm were estimated using the whole-farm model, Holos. Soil organic carbon (C) change due to each grazing management scenario was estimated using the Introductory Carbon Balance Model. Primary model inputs came from short- and long-term grazing management studies. Greenhouse gas intensity of beef varied among grazing management scenarios, ranging from 14.5–16.0 kg CO<sub>2</sub>e kg<sup>-1</sup> live weight and 24.1–26.6 kg CO<sub>2</sub>e kg<sup>-1</sup> carcass weight. Greenhouse gas intensity decreased with increasing stocking rate: that of HC grazing management was 9.2% lower than that of LC treatment (14.5 vs 16.0 kg CO<sub>2</sub>e kg<sup>-1</sup> live weight, respectively). Greenhouse gas intensity was similar (< 3%) between LC and LCMR or between HC and HCMR, indicating that the use of moderate rotational grazing for the backgrounding operation in LCMR and HCMR had no effect on overall intensity estimates. However, LCMR management had 7% higher GHG intensity than HCMR (15.6 vs 14.6 kg CO<sub>2</sub>e kg<sup>-1</sup> live weight, respectively). Average farm production efficiency (kg beef per unit land area) was 17–25% higher for the HC and HCMR grazing management scenarios than the LC and LCMR scenarios. Regardless of grazing management, methane emission from enteric fermentation was the major source of emissions (67–68% of total), followed by nitrous oxide (14–16% of total) from manure management. The rate of soil C sequestration ranged from 0.01 Mg C ha<sup>-1</sup> yr<sup>-1</sup> for rangeland under HC to 0.46 Mg C ha<sup>-1</sup> yr<sup>-1</sup> for a triticale field used for swath grazing. When soil C sequestration was included in the total emission analysis, GHG intensity estimates decreased by 12–25%, and there was no difference in intensity estimates among the scenarios. The largest reduction in GHG intensity arising from soil C sequestration was observed for LC (22%) and LCMR (25%) because they sequestered more C than HC and HCMR. Overall, results of our study indicated that grazing management impacted GHG intensity of beef production by influencing diet quality, animal performance and soil C change. It also emphasizes the importance of accounting for all emission sources and sinks within a beef production system when estimating its environmental impacts.

### 1. Introduction

Globally, more than 10% of the anthropogenic greenhouse gas

(GHG) emissions (Smith et al., 2007; O'Mara, 2011) come from livestock farming primarily due to emissions from ruminants (Clark, 2009). The beef cattle industry is under increasing scrutiny by the public

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because of its GHG emissions, mainly in the form of enteric methane (CH<sub>4</sub>, Dyer et al., 2010; Lesschen et al., 2011). Enteric CH<sub>4</sub> accounts for more than 53% of total farm emissions for beef production systems in Canada (Beauchemin et al., 2010; Basarab et al., 2012). The Canadian beef cattle industry contributes about 43% of total national agricultural emissions (Environment Canada, 2015).

Management practices such as feed supplements, feeding management, manure management and improving animal husbandry by enhancing animal fertility and productivity have been proposed to decrease GHG emissions from animal agriculture (Hristov et al., 2013). However, manipulation of the soil-plant-animal ecosystem through grazing management and its impact on farm GHG emissions has rarely been studied (Liebig et al., 2010; Wang et al., 2015). Effective grazing management scenarios and innovations in rangeland management allow farmers to better use rangeland and pasture resources for beef production as well as improve rangeland ecosystems, which provide diverse ecological goods and services (Dodds et al., 2008).

Several studies have reported impacts of grazing system and stocking rate on specific farm components such as forage quality and productivity (Pitts and Bryant, 1987; Reeder and Schuman, 2002; Schellenberg et al., 2012), animal productivity (Willms et al., 1986), soil nutrient and water cycling (Baron et al., 2002; Naeth and Chanasyk, 1995; Li et al., 2010; Teague et al., 2011) and soil GHG emissions and soil carbon (C) sequestration (Haferkamp and Macneil, 2004; Soussana et al., 2007, 2010; Liebig et al., 2010; Wang et al., 2014). However, information on the influence of grazing system and stocking rate on total farm GHG emissions is limited. For example, Soussana et al. (2007) measured net ecosystem exchange at nine sites in Europe and reported managed grasslands to be a sink of atmospheric carbon dioxide (CO<sub>2</sub>). However, when C exports (through grazing or harvest) and other emissions including CH<sub>4</sub> and nitrous oxide (N<sub>2</sub>O) were included, the same grasslands exhibited net GHG emissions not significantly different from zero. This implies the importance of a whole-farm approach to evaluate impacts of change in farm management practices aimed at decreasing environmental impacts of beef production systems. The beef cattle industry in North America relies heavily on grazing of rangeland and pasture that sequester soil C through photosynthesis, yet C sequestration is not part of most whole-farm GHG studies (Crosson et al., 2011). In our study, we estimated both GHG emissions and C sequestration for a simulated farm, under various grazing management scenarios.

In Canada, grazing is an important component of feeding practices for the beef cattle industry, especially for cow-calf and backgrounding operations (raising weaned beef cattle in preparation for finishing in a feedlot). More than 80% of Canadian beef cattle farms manage cattle on natural rangeland or seeded pasture during the summer grazing season and 58% practice winter grazing on bales, stockpiled forages or swathed cereal crops (Sheppard et al., 2015). Traditionally, these farms practice either continuous (season-long) grazing or intensive rotational grazing with varying stocking rates (Western Beef Development Centre, 2015). Recommended stocking rates vary by region and type of rangeland and pasture. For example, in the Canadian Prairies, stocking rates range from 0.22 animal unit months (AUM) ha<sup>-1</sup> for dry mixed-grass prairie regions to 1.6 AUM ha<sup>-1</sup> for the foothills fescue prairie regions (Bailey et al., 2010). Animal unit month is the amount of forage required by one animal unit (mature cow weighing 453.6 kg) for one month based on a forage allowance of 11.8 kg per day. Several studies (e.g., Willms et al., 1986; Naeth et al., 1991; Manley et al., 1997; Li et al., 2012) have evaluated impacts of grazing strategy (continuous, rotational) and stocking rate for beef production systems, but their results were inconclusive. For example, Willms et al. (1986) reported that increasing stocking rate reduced forage production and weight gain per animal but increased total weight gain per unit area. However, Pitts and Bryant (1987) reported no difference in steer performance as well as forage quality and availability between continuous and rotational grazing with different stocking rates.

The objective of our study was to evaluate impacts of grazing management strategy and stocking rate on farm GHG intensity [kg CO<sub>2</sub> equivalents (CO<sub>2</sub>e) kg<sup>-1</sup> beef] of Canadian beef production using life cycle assessment (LCA). Primary data from short- and long-term grazing studies were used to evaluate four grazing management scenarios: i) light continuous grazing (LC) for all cattle (low stocking rate), ii) heavy continuous grazing (HC) for all cattle (heavy stocking rate, the most commonly-used grazing management strategy; Smith and Hoppe, 2000), iii) light continuous grazing for cow-calf pairs and moderate rotational grazing for backgrounded cattle (LCMR), and iv) heavy continuous grazing for cow-calf pairs and moderate rotational grazing for backgrounded cattle (HCMR). A deferred-rotational system that involves dividing the rangeland into at least two paddocks, each of which receives deferment, was used as the rotational grazing strategy. In all scenarios, cow-calf pairs grazed natural rangeland (Rough Fescue Prairie), while backgrounded cattle grazed re-established rangeland (established in 2001 by seeding a mixture of native cool- and warm-season grasses, native legume and native shrub species).

## 2. Methods

### 2.1. Farm boundary and functional unit

The study used International Organization for Standardization (ISO)-compliant LCA to compare cradle-to-farm gate cumulative GHG emissions associated with beef production systems practicing different grazing management scenarios. Thus, all emissions related to production of feed and beef until the time that animals left the farm (farm-gate) were included, but emissions related to transport of animals to slaughter or subsequent processing and transport to the consumer were excluded. Furthermore, energy use emissions associated with acquisition of raw materials and manufacturing of machinery and emissions related to buildings were not included. All emissions were expressed as CO<sub>2</sub>e, where: CO<sub>2</sub> = 1, N<sub>2</sub>O = 265 and CH<sub>4</sub> = 28 on a mass basis (Myhre et al., 2013). Results were expressed as GHG intensity calculated as total farm GHG emissions per unit beef (live weight or carcass weight). Because soil C change varies among sites, farm GHG intensity was estimated with and without soil C change estimates to show the range of possible responses.

### 2.2. Description of beef production system and simulated farm

Beef production in Canada is a three-phase system with cow-calf, backgrounding and finishing operations (Sheppard et al., 2015; Western Beef Development Centre, 2015). The cow-calf operations maintain breeding stock that includes mature cows, breeding bulls, replacement heifers and newborn calves (Table 1). After weaning, some of the progeny are maintained on the farm to replace culled cows, whereas others are moved to backgrounding and/or finishing operations. Backgrounding is a period of growth between weaning and finishing, when weaned calves are further grown on high-forage diets and/or rangeland before entering the finishing phase. For commercial beef operations, the length of backgrounding varies with animal weight gain, market prices of feed and cattle and feed availability and quality (Sheppard et al., 2015). In our study, calves weaned in the fall entered the finishing phase after they were backgrounded on forage-based diets (mixed hay) over winter followed by grazing on re-established rangeland the following summer (Fig. 1). In the finishing phase, animals received a high-grain diet until slaughter. Although grazing management scenarios studied differed only in the cow-calf and backgrounding operations, we included the finishing operation as well to capture impacts of rangeland management throughout the entire production cycle.

#### 2.2.1. Description of the simulated farm

A simulated farm was designed to represent a typical beef cattle farming system in western Canada to assess impacts of grazing

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