

Investigating the Carbon Footprint of Cattle Grazing the Lac du Bois Grasslands of British Columbia

John S. **Church***, Allan F. **Raymond**, Paul E. **Moote**, & Jonathan D. **Van Hamme**, Thompson Rivers University; Donald J. **Thompson**, Agriculture and Agri-Food Canada

* Corresponding Author

Abstract

Greenhouse gas emissions from cattle have been increasingly recognized as an important anthropogenic source. We investigated the impact of cattle ranching on these emissions in British Columbia in order to determine the overall carbon footprint. The grazing activity within the Lac du Bois grasslands of British Columbia was examined, with emphasis on identifying point sources and removals of greenhouse gas emissions from cattle ranching. Enteric methane emissions were empirically measured at two elevation gradients in the spring and fall of 2010. Cattle emitted on average 370 L CH₄ per day; these measurements on native grasslands are comparable to work on tame pastures. A life cycle analysis was conducted with a validated HOLOS model based on empirical measurements. The following grassland improvement strategies were evaluated: reducing stocking density; and re-seeding/interseeding grass and legumes with and without synthetic fertilizer additions. Reseeding was the most effective at reducing the carbon footprint of cattle ranching on the Lac du Bois grasslands. Reseeding initiatives could theoretically result in soil carbon sequestration rates of 2.12 Mg CO₂ equivalent per hectare. A combination of reductions and removals should be implemented in the future to reduce the overall carbon footprint of cattle ranching in British Columbia.

KEYWORDS: beef cattle; carbon sequestration; grazing; life cycle assessment; methane; modelling

Introduction

Methane (CH₄) is a greenhouse gas (GHG) whose atmospheric concentrations have increased dramatically over the last century. The rising concentration of CH₄ is strongly correlated with increasing populations, and currently about 70% of its production arises from anthropogenic sources (Intergovernmental Panel on Climate Change 2006). Methane released to the atmosphere by domestic ruminant livestock is considered to be one of the three largest anthropogenic sources (Steinfeld & Wassenaar 2007). Globally, ruminant livestock emit roughly 80 Tg (1 Tg = 10¹² g = 1 million metric tonne) of methane annually, accounting for about 8–10% of the global anthropogenic CH₄ emissions, and roughly 18% of the total atmospheric when additional emissions from land use change are used in the analysis (Beauchemin & Mc Geough 2012). Methane is considered by many to be one of the largest potential contributors to climate change (Yusuf et al. 2013). Methane

is a concern for livestock production because it is generated by ruminant animals in large quantities during the normal process of feed digestion (Beauchemin et al. 2008). In a life cycle assessment of beef production in western Canada, Beauchemin et al. (2011) determined that enteric CH₄ was the largest contributing source of GHG from the beef industry, contributing 63% of total emissions. They further determined that the cow/calf sector accounted for approximately 80% of total industry emissions, with 84% of enteric CH₄ coming from mature cows.

Many governments have implemented strategies and policies to reduce GHG emissions from agriculture, and significant efforts are being directed towards developing animal husbandry methods that lower enteric methane emissions (O'Mara 2011; Beauchemin et al. 2008). In addition to GHG issues, methane emissions from cattle represent a carbon loss pathway that results in reduced productivity. For example, if the energy lost in generating methane could contribute to weight gain, it would be cost effective to the producer. Past studies have shown that methane production is dependent on the quality and quantity of the diet (Beauchemin et al. 2008; Beauchemin et al. 2009). In general, highly digestible feeds yield lower methane emissions when compared to poorer quality diets.

As ranchers endeavour to develop their brands based on a healthier, environmentally friendly platform, it is important for them to understand the environmental impact of their product, and the environmental consequences of their management practices. Although the impact of GHG emissions from agriculture has been increasingly recognized as an extremely important anthropogenic source of emissions, very limited work to date has focussed on the impact of cattle ranching on these emissions in the grasslands of British Columbia. The primary focus of this study was to investigate the carbon footprint of cattle grazing in British Columbia. Examining, measuring, and modelling the grazing activity that is currently occurring within the Lac du Bois grasslands of British Columbia accomplished this task. Particular emphasis was placed on identifying point sources and removals of GHG emissions, and their potential future relevance for the ranching community in the province.

The specific objectives of this study were to: (1) empirically measure GHG emissions related to enteric fermentation from cattle grazing on native grasslands in the central interior of British Columbia, and assess the nutrient quality of the grasslands; and (2) using the information gathered, validate a whole system modelling approach, or life cycle assessment, to determine the carbon impact of different management practices used by the cattle ranching industry on the grasslands of British Columbia.

Methods

Study area

The Lac du Bois Grasslands Protected Area (herein referred to as the "Lac du Bois grasslands") served as the study location for this research. The Lac du Bois grasslands is a large multi-use area located on the outskirts of Kamloops, B.C. This area has served as an important grazing reserve for many years. Cattle use is managed in the park under five separate grazing licences administered by the Thompson Rivers Forest District, licensed under the *Range Act* with planning and practices guided by the *Forest and Range Practices Act*. The Lac du Bois Grasslands Protected Area is in three Range Units: Dewdrop, Watching Creek, and Lac du Bois, with each unit divided into several fenced pastures (Figure 1). Established in 1976, the pasture rotation system serves to move cattle around, based on elevation, season of the year, availability of water, and actual conditions. The grasslands cover 15 712 ha situated within the Ponderosa Pine, Bunchgrass, and Interior Douglas-fir



Figure 1. Mid-elevation grasslands of the Lac du Bois Grasslands Protected Area

biogeoclimatic zones (BC Parks 2000, 2015). During the average growing season (May–October inclusive), precipitation is 159 mm, with a potential annual evapotranspiration of 679 mm.

Empirical enteric methane measurement

To empirically measure methane on pasture for use in later modelling efforts, eight yoke and harness systems were prepared to sample 24-hour enteric methane production using the sulphur hexafluoride (SF_6) calibrated tracer technique (Figure 2). This technique, pioneered at Washington State University by Johnson et al. (1994), was used to collect methane from six young Hereford cows. Various improvements to this technique have taken place over the years; the version used in this study is a modification developed by the Department of Animal Science, University of Manitoba (McGinn 2006) and the Ag Research Limited, N.Z. (Pinares-Patino 2007). Briefly, the SF_6 technique is used to determine the volume of methane that animals produce by trapping all ambient gasses in a yoke placed around the animal's head. This gas mixture contains methane produced during ruminant digestion, as well as SF_6 from a slowly leaking bolus placed into the reticulum of the animals. As the bolus is purging SF_6 at a prescribed rate, the volume of methane observed in the yoke and the total methane produced during ruminant digestion can be extrapolated over the sampling period. Six of the eight yokes were placed on the cattle, one was used as a spare, and one was positioned adjacent to the grazing area to collect ambient methane levels. The sampling program consisted of four, 5-day sampling periods during the grazing season:

1. May 17–21, 2010, samples were collected in the mid-elevation area of the very dry warm Nicola variant of the Bunchgrass biogeoclimatic zone (BGxw1), formerly termed the “middle grasslands”;

2. May 31–June 4, 2010, samples were collected in the upper-elevation area of the very dry hot variant of the Interior Douglas-fir biogeoclimatic zone (IDFxh), formerly termed “upper grasslands”;
3. September 26 –30, 2010, in the upper-elevation area; and
4. October 24–28, 2010, in the mid-elevation area.



Figure 2. Yoke and harness system used to sample 24-hour enteric methane production

The experimental animal handling procedures were pre-approved by Thompson Rivers University’s Animal Care Committee in accordance with the Canadian Council on Animal Care guidelines for farm animals (Canadian Council on Animal Care 2009) and the Canadian beef cattle code of practice guidelines (Agriculture Canada 1991).

Forage analysis

In representative pasture areas, forage was collected utilizing a 1 x 1 m frame. On June 11 and 15, 2010, the quadrat samples were collected in triplicate at the two elevation zones grazed by our six study animals from three distinct forage communities: the bluebunch wheatgrass (*Pseudoroegneria spicata*), Kentucky bluegrass (*Poa pratensis*), and rough fescue (*Festuca scabrella*). All of the plant biomass within the frame was clipped and placed in paper sampling bags. Dry matter composition was determined by placing the samples in a drying oven at 60°C for 48 hours, and then grinding through a 1 mm screen. The ground samples were stored under ambient laboratory conditions. All samples were compared using a FOSS InfraXact near infrared spectrophotometer (Foss, Hillerod, Denmark). The ground samples were placed in sample cups and analyzed for the relevant parameters using the spectrophotometer according to manufacturer’s instructions.

Statistical analysis of the methane and forage data

Statistical analyses on the SF₆ data were conducted with JMP Software, Version 8 (SAS, Carey, NC) using a *t*-test (significance level $P < 0.05$, $n = 24$). Because the spectroscopic forage analysis was descriptive in nature for use in subsequent modelling efforts, no statistical analysis between means was conducted.

Description of livestock used for modelling

The livestock mix in the park is traditionally made up of 80% Hereford cows, 90% with calf, and 2% bulls, as well as 18% yearlings. The average annual stocking rate over the 5-year rotation is 3891 animal unit months (AUM) or 0.41 AUM/ha (R. Newman, Ministry of Forests, Lands and Natural Resource Operations, June 2014, personal communication). The pasture quality is considered good, and the average daily gain is typically 1 kg. The grazing period was considered to be 8 months. The actual stocking rates per pastured used in our modelling efforts were extrapolated to reflect the best historical usage pattern.

Use of HOLOS to estimate greenhouse gas emissions

To explore the potential impacts of different management options on the GHG emissions associated with the cattle industry, a life cycle assessment was conducted using HOLOS, a whole-farm modelling tool developed by Agriculture and Agri-Food Canada (Beauchemin et al. 2010). This empirical model is based primarily on an Intergovernmental Panel on Climate Change methodology (2006) that is modified for Canadian conditions and farm scale. Using a yearly time step, HOLOS considers all significant emissions and removals on a farm, and where applicable, emissions from the manufacture of inputs (fertilizer, herbicides) and off-farm emissions of nitrous oxide (N₂O) derived from nitrogen applied on a farm. The objective of this assessment was to capture a seasonal snapshot of the GHG emissions associated with the cattle grazing activities on the Lac du Bois grasslands for one season, which served as the “farm gate” or system boundary. HOLOS was then used to estimate the impact on GHG emissions through possible sequestration removals and reductions created as a result of pasture improvements, and reductions associated with stocking density management.

Pasture management/improvement scenarios

Several different pasture management/improvement scenarios were explored with HOLOS, including

Group 1: Stocking density

- Scenario 0 – Baseline
- Scenario 1a – animal stocking density reduction of 10% on Lac du Bois grasslands
- Scenario 1b – animal stocking density reduction of 25% on Lac du Bois grasslands
- Scenario 1c – animal stocking density reduction of 50% on Lac du Bois grasslands

Group 2: Reseeding

- Scenario 0 – Baseline
- Scenario 2a – reseed 10% of Lac du Bois grasslands
- Scenario 2b – reseed 25% of Lac du Bois grasslands
- Scenario 2c – reseed 50% of Lac du Bois grasslands

Group 3: Reseeding with addition of synthetic fertilizer

- Scenario 0 – Baseline
- Scenario 3a – reseed 10% of Lac du Bois grasslands, plus addition of synthetic fertilizer at rate of 22.7 kg nitrogen and 9.1 kg phosphorus per hectare on reseed
- Scenario 3b – reseed 25% of Lac du Bois grasslands, plus addition of synthetic fertilizer at rate of 22.7 kg nitrogen and 9.1 kg phosphorus per hectare on reseed

- Scenario 3c – reseed 50% of Lac du Bois grasslands, plus addition of synthetic fertilizer at rate of 22.7 kg nitrogen and 9.1 kg phosphorus per hectare on reseed

Note: reseed considered 6–10 years old.

Results

No statistically significant differences were found in cattle methane levels for either of the study sites, between the two seasons, or between the first and second week. Results indicate that cattle grazing the Lac du Bois grasslands produced an average of approximately 370 L per day of methane during the course of the study. The results produced by near-infrared reflectance spectroscopy indicate that no major visible difference was evident between the samples from the grassland communities in either the middle (mid) or the upper-elevation sampling areas, which could potentially introduce variability into the methane production results (Table 1). Table 2 provides an overview of the baseline GHG emissions from cattle production on Lac du Bois grasslands, and provides a placement for the 1071.6 Mg CO₂ eq (megagrams CO₂ equivalent) produced by ranching on the grasslands. Table 3 reflects the impact on the emissions as a direct result of improving the grassland by reseeding 10% (757 ha), 25% (1892 ha), and 50% (3783 ha) of the land area. The emissions associated

Quality component ^a	Grassland type								
	Bluebunch wheatgrass			Kentucky bluegrass			Rough fescue		
	Mid-	Upper	Average	Mid-	Upper	Average	Mid-	Upper	Average
ADF	30.55	34.34	32.45	29.16	37.73	33.45	35.08	33.07	34.08
NDF	64.41	68.65	66.53	57.68	67.6	62.64	62.07	60.97	61.52
Lignin	5.67	5.43	5.55	5.62	5.95	5.79	5.28	7	6.14
Protein	10.34	8.36	9.35	10.11	8.18	9.15	8.38	9.14	8.76
Simple Sugars	8.04	8.81	8.43	12.03	9.54	10.79	10.99	7.46	9.23
Ash	9.23	7.14	8.19	9.37	7.72	8.55	8.34	8.7	8.52
Sol. Carbo.'s	11.8	10.44	11.12	14.05	7.91	10.98	11.68	8.62	10.15
Starch	-0.49	-2.86	-1.68	3.37	1.91	2.64	0.61	1.99	1.3
TDN	68.31	64.09	66.2	69.85	60.31	65.08	63.27	65.5	64.39

with the livestock remain the same as the baseline scenario, as livestock populations did not change.

Table 1. Forage quality components of three grasses in two plant communities in the Lac du Bois grasslands

^a The quality components are defined, as follows. ADF = Acid Detergent Fibre; used to estimate the energy content (TDN, Net Energy) of forages. NDF = Neutral Detergent Fibre; used to predict ruminant feed intake of forages. Lignin is a complex polymer bound to cellulose that is indigestible to animals. Protein refers to complex combinations of amino acids essential for animal growth, production, and reproduction. Simple sugars refers to small carbohydrates that are a source of readily available energy. Ash refers to mineral elements contained in plants. Soluble Carbohydrates (Sol. Carbo.'s) are structural or non-structural CHOs readily digestible by rumen microorganisms. Starch refers to a polymer of glucose, which is the most common energy store for plants. TDN = Total Digestible Nutrients; estimates the energy value of feeds, calculated using ADF.

Table 2. HOLOS baseline scenario (Megagrams CO₂ equivalent) for Lac du Bois grasslands

Category	Enteric CH ₄	Manure CH ₄	Direct N ₂ O	Indirect N ₂ O	Soils CO ₂	Subtotals
Livestock	668.3	14.2	347.7	41.4		1071.6
Soils						
Total emissions						1071.6

Table 3. Group 2 pasture management/improvement scenarios for Lac du Bois grasslands (Megagrams CO₂ equivalent)

Category	Enteric CH ₄	Manure CH ₄	Direct N ₂ O	Indirect N ₂ O	Soils CO ₂	Energy CO ₂	Subtotals
<i>Scenario 3a – Reseed 10%, plus 22.7 kg nitrogen and 9.1 kg phosphorus per hectare on reseed</i>							
Livestock	651.6	13.8	338.9	40.5			1044.8
Soils			61.4	25.6	-1683.7		-1596.7
Cropping						151.6	151.6
Total Emissions							-400.3
<i>Scenario 3b – Reseed 25%, plus 22.7 kg nitrogen and 9.1 kg phosphorus per hectare on reseed</i>							
Livestock	645.2	13.7	335.6	40.0			1034.5
Soils			149.2	62.1	-4090.5		-3879.2
Cropping						368.2	368.2
Total Emissions							-2476.5
<i>Scenario 3c – Reseed 50%, plus 22.7 kg nitrogen and 9.1 kg phosphorus per hectare on reseed</i>							
Livestock	639.8	13.5	332.8	39.7			1025.8
Soils			295.5	123.1	-8102.6		-7684.0
Cropping						729.4	729.4
Total Emissions							-5928.8

HOLOS accounts for the adoption of management practices (e.g., grassland renovation) because these renovated lands improve overall emission reductions by removing more carbon from the atmosphere, serving as a carbon sink. The negative soil CO₂ values indicate sequestration of atmospheric C. The model, which actually reflects an increase in soil CO₂, also follows a linear reduction consistent with the management change associated with the reseeded scenarios investigated. HOLOS reports a consistent reduction of 2.12 Mg CO₂ equivalent per hectare across the Group 2 scenarios. For example, reseeded 10% (757 ha) of the area created a soil CO₂ sequestration increase of -1605.2 Mg CO₂ equivalent, resulting in an overall reduction of -533.6.

Some assumptions were made during the modelling to account for the limitations inherent in HOLOS when investigating the effects of improving the Lac du Bois grasslands. It was assumed that the reseeded activities were undertaken with a non-invasive, no-till

operation, which would minimize soil disturbance, eliminating or reducing soil carbon loss. The species interseeded into the grasslands were alfalfa (*Medicago sativa*) and crested wheatgrass (*Agropyron cristatum*). Although the introduction of these legumes and grasses is no longer commonly practised because of expense, ecological concerns, and resulting problems with invasive species, it was an historically popular improvement activity. HOLOS did not account for any primary CO₂ emissions resulting from the reseeding activities (i.e., fossil fuel combustion), as it was outside the system boundary inherent in the model used.

HOLOS calculates the various carbon factors associated with each scenario using the CENTURY model. Originally developed by the U.S National Science Foundation, CENTURY was designed to model plant–soil nutrient cycling, which provides information on carbon and nutrient dynamics in different ecosystems.

Table 4 reflects the impact on emissions when another variable is introduced to the land improvement scenarios—the addition of synthetic fertilizers. This model investigates the impact of including nutrient amendments to the reseeding scenarios as described in Group 2. Further, this model only contemplates a reseeding–fertilizer interaction together; as it is unlikely synthetic fertilizer applications would occur on the grasslands independent of a reseeding improvement.

The Group 3 scenarios now report direct and indirect soils N₂O emissions created as a result of the synthetic nitrogen fertilizer applications. The direct N₂O emissions are related to the processes of nitrification and de-nitrification, with the amount of N₂O produced roughly proportional to the amount of nitrogen added to the soil. The direct N₂O emissions are 80 kg CO₂ equivalent per hectare, which is again a linear relationship to the volume of fertilizer and area treated across all three scenarios. The indirect N₂O emissions are off-farm N₂O released from N lost from the farm (in this case a park) via run-off, leaching, and volatilization. These emissions were estimated from the assumed fractions of N lost from manure, residues, and fertilizer, as adjusted for local climatic conditions in the central interior of British Columbia and an emission factor (Intergovernmental Panel on Climate Change 2006). The indirect N₂O emissions are reported to be 30 kg CO₂ equivalent per hectare, again a linear relationship to the volume of fertilizer and area treated across all three scenarios. The presence of the fertilizer related to direct and indirect N₂O emissions reduced the net sequestration effect by approximately 5% in all scenarios.

Discussion

The enteric methane levels measured from the cattle on the Lac du Bois grasslands are comparable to the amount of methane observed by other research groups for similar beef-type animals, using the same measurement technique, where observations range from approximately 300–400 L per day (Boadi & Wittenberg 2002; McCaughey et al. 1997). The relatively small sampling size in this study was a result of the difficult and tremendous logistical hurdles and expense associated with studying cattle on range. The vast majority of previous studies using the SF₆ calibrated tracer technique with cattle were almost always on tame or cultivated pasture, not on native range. The low number of animals in this study did have the effect of reducing the strength of our statistical analysis, as shown by the lack of statistically significant results in the GHG emissions from cattle grazing between two biogeoclimatic zones; however, since we were primarily using the values for inventory purposes to validate our modelling efforts, as opposed to hypothesis testing of treatment differences, the resulting value was considered to be very reasonable.

Most estimates of methane emissions from cattle in Canada, using the Intergovernmental Panel on Climate Change's Tier 2 methodology, utilize digestible energy to calculate enteric methane emissions (Ominski et al. 2007). Digestible energy values are calculated for each diet type and represent the percent of gross energy intake of the feed that is digestible to the animal. Gross energy is defined as "the measure of the total combustible energy in a feed" (Wright & Lackey 2012). Where regional digestible energy values are not available for a particular animal's diet, a very similar measure, total digestible nutrients as a percent of dry matter is used. Total digestible nutrients is described as "the energy value of feedstuffs, comparable to digestible energy in accuracy" (Wright & Lackey 2012). The average total digestible nutrient values that we obtained through the spectroscopy analysis from the three different grassland communities in the Lac du Bois study area averaged 65.22%. This empirical, field-measured value is identical to the values used (diet digestible energy %) to estimate enteric methane emissions by other Canadian researchers using similar Tier 2 methodologies (Basarab et al. 2012; Ominski et al. 2007). The vast majority of the variation in GHG emissions in beef cattle is largely related to yearly differences in diet total digestible nutrients, crude protein, dry matter intake, and time on each diet (Basarab et al. 2012). Both sets of empirical measurements obtained in this study (enteric methane from cattle on range and the total digestible nutrients of the study site) validates the appropriateness of the use of the HOLOS model (which depends on the Tier 2 methodology) with native grasslands.

Changes in soil carbon on native grasslands can occur in response to a wide range of management and environmental factors and conditions, as demonstrated by the HOLOS model. Although the magnitude of these changes may be small compared with those reported for croplands and improved pastures, increases in terrestrial carbon resulting from grazing management, or the application of inputs, can account for a significant amount of carbon sequestration and a large reduction in overall atmospheric CO₂ emissions because of the sheer size of this land resource.

As we have demonstrated in our study, which has been corroborated by several other grazing studies (Derner et al. 2006; Reeder & Schuman 2002; Gao et al. 2008), high-quality pastures, and grazing best management practices can contribute to reducing GHG emissions from cattle ranching. Other studies have examined the potential of grassland pastures to counteract the increase in atmospheric CO₂ through carbon sequestration in soils, hence removing GHG from the atmosphere (Mortenson et al. 2004). Conant et al. (2001) conducted an analysis of 115 pastures and grazing-land studies worldwide and found that soil carbon levels increase with improved management (i.e., fertilization, grazing management, and conversion from cultivation to native vegetation) and that the greatest carbon sequestration occurs during the first 40 years of implementation of the management practice. Further, except for a single irrigated study, they found that the conversion of cultivated land to grazing land resulted in an average annual increase in soil organic carbon of 3–5%. Research shows that returning cultivated land back to grasslands can result in some of the highest rates of carbon sequestration because of the heavily degraded lands and associated low levels of soil organic matter following cultivation. Our life cycle analysis is consistent with these previous research findings, demonstrating that the reseeded of native grassland pastures resulted in significant carbon sequestration. Grasslands have high inherent soil organic matter content that supplies plant nutrients, increases soil aggregation, limits soil erosion, and also increases cation exchange and water-holding capacity (Miller & Donahue 1990). As our modelling work has demon-

strated, maintenance of soil organic matter is a key factor in the sustainability of grassland ecosystems and the ability to sequester carbon.

In this study, synthetic nitrogen fertilizer applications appeared to be very counter-productive in reducing total atmospheric GHG, related to the high global warming potential of NO_2 . Nitrous oxide is approximately 298 times more powerful than CO_2 in its global warming potential. Clearly, if maximizing total GHG emission reductions is the goal as a component of ecosystem services from grasslands, our work shows that the use of synthetic nitrogen fertilizer is contraindicated and is not recommended. In addition, historically intensive cultivation has resulted in large reductions of soil organic matter to the atmosphere in the form of CO_2 , including much of what was lost from native grasslands when they were tilled (Vergé et al. 2012). Losses of soil organic matter related to conversion of native grasslands to cultivation are well documented, and losses related to poor pasture management have also been observed (Conant et al. 2001). Through sound grassland management, it may be possible to reverse losses of soil organic matter, and consequently sequester greater volumes of atmospheric carbon.

As climate change issues pervade our societies, the environmental impacts that rising GHG levels have on the planet continue to raise the collective awareness of the potential consequences of inaction. Agriculture's relative importance to this issue cannot be understated. Agricultural lands occupy about 40–50% of the Earth's land surface; and animal production is estimated to use about one-fourth of all ice-free land for pasture, and about one-third of all cultivated land for forage production (Foley et al. 2011; Vergé et al. 2012).

Implications

Ultimately, the acceptance of strategies for removing and reducing GHG emissions by managers of grasslands will be a significant future factor in determining the rate of soil sequestration and the total level of GHG reductions achieved. The global willingness to accomplish GHG reductions to the atmosphere in general will depend on the costs of implementation and the real and perceived economic benefits, which include abatement potentials from grasslands (Vermont & De Cara 2010). Using life cycle analysis modelling approaches, such as we have done in this study with HOLOS, can provide insight into practices that are likely to be both operationally sound and financially cost effective in a grassland environment, which can then later be empirically tested. If agricultural soil sequestration is to play a role in future efforts to reduce GHG emissions from grasslands, it is important to determine that the soil carbon sequestration and emission reduction practices applied are meaningful and competitive as a low-cost means of addressing rising GHG emissions, and to design programs or incentives that make the implementation of these practices attractive for land use managers.

Acknowledgements

Future Forest Ecosystem Scientific Council of British Columbia, Ardcorp Agriculture Environment and Wildlife Fund, and the Horned Cattle Trust provided funding for this project. The authors would like to extend their appreciation to the staff at the Kamloops Range Research Unit, Agriculture and Agri-Food Canada, for their help in conducting this project. We further wish to thank Wade Archambault and Dave Pouw at Thompson Rivers University for their assistance with methane measurements, and cattle rancher Mr. Terry Inskip for allowing us the use of his cattle for empirical enteric methane measurements.

References

- Agriculture Canada. 1991. Recommended code of practice for the care and handling of farm animals: Beef Cattle. Communications Branch, Ottawa, Ont. Agriculture Canada Publication 1870/E.
- Basarab, J., V. Baron, O. López-Campos, J. Aalhus, K. Haugen-Kozyra, & E. Okine. 2012. Greenhouse gas emissions from calf- and yearling-fed beef production systems, with and without the use of growth promotants. *Animals* 2:195–220.
- BC Parks. 2000. Lac du Bois Grasslands Park Management Plan Background Document. Ministry of Environment, Lands and Parks, Victoria, B.C. p. 18.
- _____. 2015. Lac du Bois Grasslands Protected Area. http://www.env.gov.bc.ca/bcparks/explore/parkpgs/lacdubois_grass/ (Accessed March 2015).
- Beauchemin, K.A., H.H. Jansen, S.M. Little, T.A. McAllister, & S.M. McGinn. 2010. Life cycle assessment of greenhouse gas emissions from beef production in western Canada: A case study. *Agricultural Systems* 103(6):371–379.
- Beauchemin, K.A., H.H. Janzen, S.M. Little, T.A. McAllister, & S.M. McGinn. 2011. Mitigation of greenhouse gas emissions from beef production in western Canada – Evaluation using farm-based life cycle assessment. *Animal Feed Science and Technology* 166–167(0): 663–677.
- Beauchemin, K.A., M. Kreuzer, F. O’Mara, & T.A. McAllister. 2008. Nutritional management for enteric methane abatement: a review. *Australian Journal of Experimental Agriculture* 48(2):21–27.
- Beauchemin, K.A., T.A. McAllister, & S.M. McGinn. 2009. Dietary mitigation of enteric methane from cattle. *CAB Reviews: Perspectives in Agriculture, Veterinary Science, Nutrition and Natural Resources* 4(35):1–18.
- Beauchemin, K. & E. Mc Geough. 2012. Life cycle assessment: a holistic approach to assessing greenhouse gas emissions from beef and dairy production. *Revista Argentina de Producción Animal* 32(1):69–76.
- Boadi, D.A., & K.M. Wittenberg. 2002. Methane production from dairy and beef heifers fed forages differing in nutrient density using the sulphur hexafluoride (SF₆) tracer gas technique. *Canadian Journal of Animal Science* 82(2):201–206.
- Canadian Council on Animal Care. 2009. The care and use of farm animals in research. Ottawa, ON.
- Conant, R.T., K. Paustian, & T.E. Elliott. 2001. Grassland management and conversion into grassland: effects on soil carbon. *Ecological Applications* 11(2):343–355.
- Derner, J.D., T.W. Boutton, & D.D. Briske. 2006. Grazing and ecosystem carbon storage in the North American Great Plains. *Plant and Soil* 280(1–2):77–90.
- Foley, J.A., N. Ramankutty, K.A. Brauman, E.S. Cassidy, J.S. Gerber, M. Johnston, N.D. Mueller, C. O’Connell, D.K. Ray, P.C. West, C. Balzer, E.M. Bennett, S.R. Carpenter, J. Hill, C. Monfreda, S. Polasky, J. Rockström, J. Sheehan, S. Siebert, D. Tilman, & D.P.M. Zaks. 2011. Solutions for a cultivated planet. *Nature* 478(7369):337–342.
- Gao, Y.H., P. Luo, N. Wu, H. Chen, & G.X. Wang. 2008. Impacts of grazing intensity on nitrogen pools and nitrogen cycle in an alpine meadow on the eastern Tibetan Plateau. *Applied Ecology and Environmental* 6(3):69–79.
- Intergovernmental Panel on Climate Change. 2006. Guidelines for national greenhouse gas inventories, Chapter 10: Emissions from livestock and manure management. http://www.ipcc-nggip.iges.or.jp/public/2006gl/pdf/4_Volume4/V4_10_Ch10_Livestock.pdf (Accessed March 2015).
- Johnson, K., M. Huyler, H. Westberg, B. Lamb, & P. Zimmerman. 1994. Measurement of methane emissions from ruminant livestock using a sulfur hexafluoride tracer technique. *Environmental Science & Technology* 28(2):359–362.
- McCaughy, W.P., K. Wittenberg, & D. Corrigan. 1997. Methane production by steers on pasture. *Canadian Journal of Animal Science* 77(3):519–524.
- McGinn, S.B. 2006. Assessment of the sulphur hexafluoride (SF₆) tracer technique for measuring enteric methane emissions from cattle. *Journal of Environmental Quality* 135:1689–1691.
- McGinn, S.M., K.A. Beauchemin, T. Coates, & D. Colombatto. 2004. Methane emissions from beef cattle: Effects of monensin, sunflower oil, enzymes, yeast, and fumaric acid. *Journal of Animal Science* 82(11):3346–3356.
- Mortenson, M.C., G.E. Schuman, & L.J. Ingram. 2004. Carbon sequestration in rangelands interseeded with yellow-flowering alfalfa (*Medicago sativa ssp. falcata*). *Environmental Management* 33(1):S475–S481.
- O’Mara, F.P. 2011. The significance of livestock as a contributor to global greenhouse gas emissions today and in the near future. *Animal Feed Science and Technology* 166–168:7–15.

- Ominski, K.H., D.A. Boadi, K.M. Wittenberg, D.L. Fulwaka, & J.A. Basarab. 2007. Estimates of enteric methane emissions from cattle in Canada using the IPCC Tier-2 methodology. *Canadian Journal of Animal Science* 87(3):459–467.
- Pinares-Patiño, C.M., A. Machmuller, G. Molano, A. Smith, J.B. Vlaming, & H. Clark. 2007. The SF₆ tracer technique for measurements of methane emission from cattle: effect of tracer permeation rate. *Canadian Journal of Animal Science* 88:309–320.
- Reeder, J.D., & G.E. Schuman. 2002. Influence of livestock grazing on C sequestration in semi-arid mixed-grass and short-grass rangelands. *Environmental Pollution* 116(3):457–463.
- Steinfeld, H., & T. Wassenaar. 2007. The role of livestock production in carbon and nitrogen cycles. *Annual Review of Environment and Resources* 32:271–294.
- Vergé, X.P.C., D.E. Worth, R.L. Desjardins, B.G. McConkey, & J.A. Dyer. 2012. LCA of animal production. In: *Green technologies in food production and processing*. J.I. Boye & Y. Arcand (eds.). Springer-Verlag New York, N.Y. pp. 83–113.
- Vermont, B., & S. DeCara. 2010. How costly is mitigation of non-CO₂ greenhouse gas emissions from agriculture?: a meta-analysis. *Ecological Economics* 69(7):1373–1386.
- Wright, T., & R. Lackey. 2012. Definitions of feed manufacturing and livestock nutrition terms. Ontario Ministry of Agriculture and Food. <http://www.omafra.gov.on.ca/english/livestock/dairy/facts/08-039.htm> (Accessed March 2015).
- Yusuf, R.O., Z.Z. Noor, A.H. Abba, M.A.A. Hassan, M. Fadhil, & M. Din. 2013. Methane emission by sectors: a comprehensive review of emission sources and mitigation methods. *Renewable and Sustainable Energy Reviews* 16(7):5059–5070.

Author information

John S. Church – Associate Professor, Department of Natural Resource Science, Thompson Rivers University, 900 McGill Road, Kamloops, BC V2C 0C8. E-mail: jchurch@tru.ca. [Corresponding author]

Allan F. Raymond, Department of Natural Resource Science, Thompson Rivers University, 900 McGill Road, Kamloops, BC V2C 0C8.

Paul E. Moote, Department of Biological Sciences, Thompson Rivers University, 900 McGill Road, Kamloops, BC V2C 0C8.

Jonathan D. Van Hamme – Associate Professor, Department of Biological Sciences, Thompson Rivers University, 900 McGill Road, Kamloops, BC V2C 0C8.

Donald J. Thompson – Research Scientist, Range Plant Ecologist, Agriculture and Agri-Food Canada, 5403–1 Avenue South, PO Box 3000, Lethbridge, AB T1J 4B1.

CARBON FOOTPRINT
OF CATTLE ON
GRASSLANDS

Church,
Raymond,
Moote, Van
Hamme,
& Thompson

Article Received: August 31, 2013 • Article Accepted: March 11, 2015

© 2015, Copyright in this article is the property of the
Journal of Ecosystems and Management.

ISSN 1488-4674. Articles or contributions in this publication may be reproduced in electronic or print form for use free of charge to the recipient in educational, training, and not-for-profit activities provided that their source and authorship are fully acknowledged. However, reproduction, adaptation, translation, application to other forms or media, or any other use of these works, in whole or in part, for commercial use, resale, or redistribution, requires the written consent of the Journal of Ecosystems and Management. This publication and the articles and contributions herein may not be made accessible to the public over the Internet without the written consent of JEM. For consents, contact: Managing Editor, Journal of Ecosystems and Management, c/o CISP Press, Simon Fraser University, 515 West Hastings Street, Vancouver, BC.

The information and opinions expressed in this publication are those of the respective authors and JEM does not warrant their accuracy or reliability, and expressly disclaims any liability in relation thereto.

Test Your Knowledge

How well can you recall the main messages in the preceding article?
Test your knowledge by answering the following questions.

Church,
Raymond,
Moote, Van
Hamme,
& Thompson

Investigating the Carbon Footprint of Cattle Grazing the Lac du Bois Grasslands of British Columbia

1. The enteric methane levels measured from cattle on the Lac du Bois grasslands are comparable to which of the following?
 - a. The methane observed for similar beef-type animals on tame pasture
 - b. The methane produced by wild ungulates while grazing on grasslands
 - c. The methane produced by beef cattle in confined feeding operations
2. When digestible energy values are not available to estimate an animal's diet, as is the case in this paper, what similar measure is used to estimate methane emissions as a percentage of dry matter?
 - a. ME – Metabolizable Energy
 - b. ADF – Acid Detergent Fibre
 - c. TDN – Total Digestible Nutrients
3. Which land management practice results in some of the highest rates of carbon sequestration observed?
 - a. Improved grazing management
 - b. Returning cultivated land back to grasslands
 - c. Use of synthetic nitrogen fertilizer