# INVESTIGATING THE CARBON FOOTPRINT OF CATTLE GRAZING THE LAC DU BOIS GRASSLANDS:

## The effects changes in management may have on reducing and removing GHG emissions, and opportunities for BC ranchers to explore carbon offset opportunities.

A Dissertation Presented

by

Allan F. Raymond

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## ABSTRACT

Greenhouse gas emissions from agriculture, which includes cattle grazing, have been increasingly recognized as an extremely important anthropogenic source. The primary focus of this body of work was to investigate the impact of cattle ranching on these emissions in British Columbia in order to determine the overall carbon footprint. To accomplish this task, the grazing activity that is currently occurring within the Lac Du Bois grasslands of British Columbia was examined. Particular emphasis was placed 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, and it was found that the cattle emitted on average 370.01 L $CH_4$/day; these measurements done on native grasslands, are comparable to similar work done by others on tame pastures. The total digestible nutrients (TDN) from the pastures in the study area were determined to be 65.22% of dry matter; which is the default value used by the International Panel on Climate Change (IPCC) in their methodology for determining overall emissions. Utilizing this information, a whole system life cycle analysis (LCA) was conducted on cattle grazing in Lac Du Bois. Equipped with a validated model based on our empirical measurements, the following grassland improvement strategies were evaluated: reducing stocking density; and reseeding/interseeding grass and legumes with and without synthetic fertilizer additions. Of the scenarios modelled, 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 $CO_2$ eq/ha. Finally, the potential opportunities for BC livestock ranchers to participate in carbon markets were reviewed. While opportunities exist, cattle ranchers will have to adapt or develop applicable protocols in order to participate in carbon markets. Diet manipulation and pasture rejuvenation initiatives may offer the best carbon offset potential. It is recommended that 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:** Cattle grazing, carbon footprint, methane emissions, carbon sequestration

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# CHAPTER 1
# INTRODUCTION AND RELEVANCE

Global climate change has been attributed to increased emissions of greenhouse gases (GHG) such as carbon dioxide ($CO_2$), methane ($CH_4$) and nitrous oxide ($N_2O$) due to anthropogenic (human) activities (IPCC 2006a). Atmospheric concentrations of these gases have increased by 31% for $CO_2$, 151% for $CH_4$ and 17% for $N_2O$ since 1750. The global warming potential (GWP) of these gases are not equal, with methane (normally considered to be) 23 times, and nitrous oxide being 310 times more efficient in trapping heat in the atmosphere than carbon dioxide (Smith et al., 2008). It has recently been suggested a more accurate estimation of the GWP of $CH_4$ is 25 times more than $CO_2$ (IPCC, 2007). Following the conversion of these gases into their respective GWP's, the magnitude of the emissions of these gases can be reported in terms of carbon dioxide equivalents ($CO_2$ eq), and are typically expressed over a 100 year time horizon (Desjardins et al., 2012).

Globally, agriculture accounts for 10 to 12% of total anthropogenic emissions of GHG's, but 84% of $N_2O$ and 52% of $CH_4$ anthropogenic emissions (Smith et al., 2008). Both agricultural expansion and intensification are major contributors to climate change (Canadell et al., 2007; Vergé, De Kimpe, & Desjardins, 2007). In agriculture, carbon dioxide is released largely from microbial decay or burning of plant litter and soil organic matter (H. Janzen, 2004). Methane is produced when organic materials decompose in oxygen-deprived conditions, notably from fermentative digestion by ruminant livestock, stored manures and rice grown under flooded conditions (Mosier et al., 1998). Nitrous oxide is generated by the microbial transformation of nitrogen in soils and manures, and is often enhanced where available N exceeds plant requirements, especially under wet conditions (Smith & Conen, 2004).

The linkage between GHG emissions and agriculture are well documented. Because of agriculture's global size and scope, this sector's relative contribution to climate change is extensive. According to the Food and Agriculture Organization of the United Nations (FAO, 2009), croplands cover 1.53 billion hectares (about 12% of Earth's ice-free land), while pastures cover another 3.38 billion hectares (about 26% of Earth's ice-free land) (Figure 1.1). Altogether, agriculture occupies about 38% of Earth's terrestrial surface – the largest land use on the planet (Ramankutty, Evan, Monfreda, & Foley, 2008).

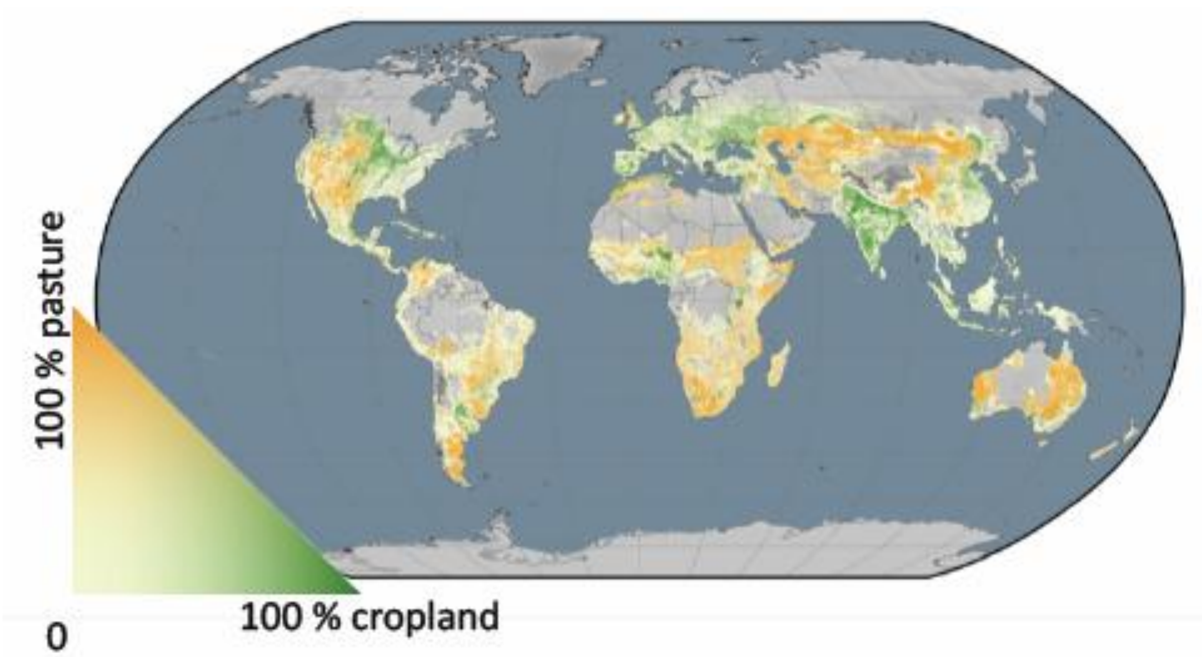


**Figure 1.1** Extent of Global Agricultural Lands (Foley et al., 2011). The global extent of croplands (green) and pastures (brown), as estimated from satellite, and census-based data by Ramankutty et al., (2008).

Increasing global population and consumption patterns are placing unprecedented demands on agriculture, and the lands that are necessary to produce the food to meet the demands of an ever-increasing population. It has been recently affirmed that we currently face one of the greatest challenges of the twenty-first century: meeting society's growing food needs while simultaneously reducing agriculture's environmental harm (Foley et al., 2011).

In 2005 agriculture accounted for 7.6% of Canada's total GHG emissions, of which 50% is attributed to emissions from soils primarily due to $N_2O$ from fertilizer applications, 32% from ruminants due to $CH_4$ emissions from enteric fermentation and 17% from $N_2O$ emissions due to manure management (Environment Canada, 2008). As a result of agriculture's dramatic contributions to GHG emissions, governments throughout the world are investigating strategies to reduce or mitigate GHG emissions. At the heart of these investigations is the realization that agriculture must undergo a transformation. To meet the projected demands of population growth and increasing consumption, humanity must roughly double food supplies in the next few decades (Davies et al., 2009). Concurrently, according to the International Panel on Climate Change (IPCC), the transformation of agriculture should also cut GHG emissions from land use and farming by at least 80% (IPCC, 2007) – this will be a daunting undertaking.

Until recently, most agricultural paradigms have focused on improving production, often to the detriment of the environment (DeFries, Foley, & Asner, 2004). At the same time, many environmental conservation strategies have not sought to improve food production. However, in order to achieve global food security and environmental sustainability, agricultural systems must be transformed to address both challenges simultaneously (Foley et al., 2005). Figure 1.2 qualitatively illustrates a subset of the goals agriculture must meet in the coming decades. At the top of the figure, four key food security goals are outlined:

- increasing total agricultural production;
- increasing the supply of food (recognizing that agricultural yields are not always equivalent to food);
- improving the distribution of and access to food;
- increasing the resilience of the whole food system.

At the bottom of the figure, four key environmental goals that agriculture must meet are illustrated:

- reducing GHG emissions from agriculture and land use;
- reducing biodiversity loss;
- phasing out unsustainable water withdrawals;
- curtailing air and water pollution from agriculture.

Panel “a” sketches out a qualitative assessment of how current agricultural systems may be measured against these criteria compared to goals for 2050. Panel “b” illustrates a hypothetical situation in which we meet all these goals by 2050 (Foley et al., 2011). The relative scope of the impact categories, as shown on the bottom of the illustration, is particularly noteworthy. This depicts which categories are the most problematic, and consequently where the focus needs to be in order to rectify these concerns. Greenhouse gas emissions are considered the largest threat to our environment, followed by biodiversity loss, and then impacts associated with water degradation and unsustainable water use patterns. To move from the current situation “a”, to the hypothetical situation “b”, would require substantial reductions in all four categories, but the most extensive reduction would have to come from GHG emissions. Practices associated with agricultural production, particularly ruminant livestock production, directly affect all these environmental impact categories.

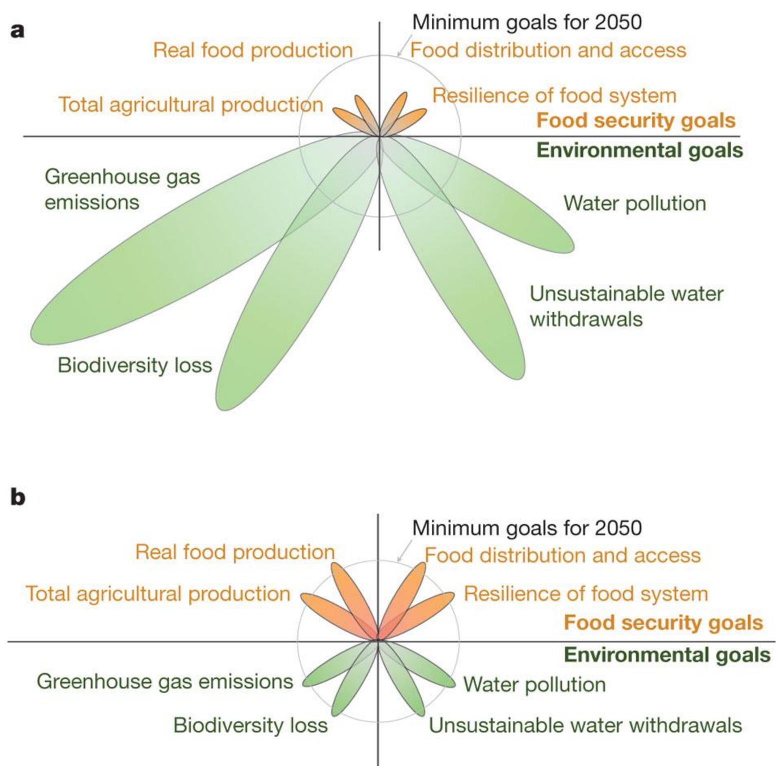


**Figure 1.2**. Meeting goals for food security and environmental sustainability by 2050 (Foley et al., 2011).

Canadian beef is perceived both domestically and globally as a premier product in the world marketplace. Canadian beef marketing is closely linked with the quality of the environment and the stewardship of resources. It is a critical advantage to the beef industry to have a solid environmental reputation, and it is increasingly important that industry promote their ecological goods and services to gain any competitive advantage that may be available in the global and domestic marketplace.

The ranching industry and beef production has a long and storied history both in Canada and specifically in British Columbia. In much of rural B.C. ranching is a mainstay of local economies. Most beef ranches are cow/calf, or cow/yearling operations. There were 4,086 cattle ranches in B.C. as reported in the 2006 agricultural census. Revenue from cattle sales in 2008 was $250 million. According to Statistics Canada, there were approximately 192,000 cows in 2011, down from approximately 212,000 cows reported in 2009. Alberta is the largest producer of beef in Canada, with 45% of the national herd, while B.C. represents 4.5% of Canada's herd (British Columbia Ranching Task Force, 2009).

Presently only a small portion of the calves produced in Canada are fed to slaughter weights by the original owner of the ranch where they were born. This trend is changing, as some producers are implementing alternative production systems and strategies in B.C.; producers are increasingly marketing provincially raised beef products that are branded as being local, natural (hormone or antibiotic free), organic, and/or grass-fed or grass-finished, either alone or in some combination. The serious financial difficulties endured by the beef industry over last several years has encouraged producers to explore alternative production systems and branding to add value to their products. Producers are hoping to capitalize on the consumer's growing awareness of the environment and the perception that products such as grass-fed beef are healthier. Grass-fed systems, for example, are more socially appealing, but due to their lower productivity, there is significant disagreement on whether this system is more environmentally friendly. Traditional grazing requires more time to finish an animal, and it often creates more methane because forages are often less digestible (Rance, 2010). While confinement systems produce less $CH_4$ emissions per animal, if all sources of greenhouse gas emissions are considered, an early study found that feedlots can produce more than double the GHG emissions than the pastoralist system (Subak, 1999).

Cattle herd structure and management can also have a significant impact on the carbon footprint of the beef cattle sector. In most beef producing regions, the beef industry usually consists of the following sectors: cow/calf; stocker/grasser; feedlot; and dairy, with an exchange of stock occurring between each of these systems (Figure 1.3). Feeding regimes can also have a substantial impact on the carbon footprint of the beef cattle sector (Desjardins et al., 2012). For example grain-fed feedlot cattle vs. grass-fed cattle generally have a significantly different carbon footprint, due in part because of the time to reach a desired slaughter weight. In grazing/grass-fed cattle, the quality of the pasture and the stocking density can also affect productivity and the carbon footprint.

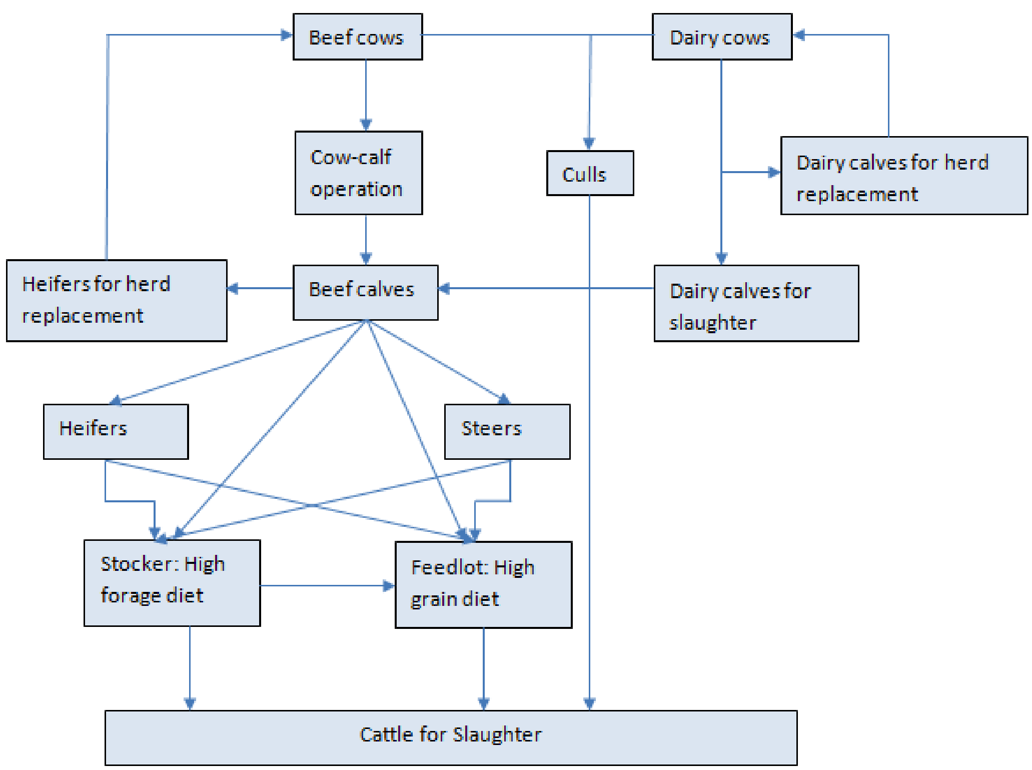


**Figure 1.3.** Flow Diagram of the typical North American beef production cycle.

Ranchers in British Columbia typically augment their private holdings with large tenures of both private and Crown land, increasing their capacity to raise beef beyond the limitations of the feed that can be produced on their own cultivated lands. B.C. ranches occupy over 2 million hectares of private land, and have tenure on a further 8.7 million hectares of Crown rangelands. The majority of these public grazing lands are not suited to cultivation, and are often in areas that lack sufficient moisture for growing higher value crops. By managing the grasslands sustainably, ranchers provide prime habitat for wildlife and many of the threatened species associated with grasslands. The maintenance of deep rooted healthy grasslands and the increase in soil organic matter produced by well-managed ranges are an effective means of carbon sequestration and carbon storage (British Columbia Ranching Task Force, 2009).

Not unlike other sectors during these recessionary times, the cattle sector has experienced financial distress. At the same time, the cattle industry remains optimistic that world demand for beef is increasing. Forecasters are predicting that North American demand for beef will level off, and growth will be focussed upon export markets. A portion of the sector may also turn its attention to local markets and finish more cattle to take advantage of opportunities for value-added beef products. As producers explore opportunities such as "grass-fed" branding to diversify and create additional value for their product, the grasslands and grazing areas become an ever increasingly important component of the production system. In Canada, cultivated forages for pasture, feed and seed production represent 13.7 million hectares, or 39% of the arable land base. The second largest crop in Canada is wheat, which accounts for 8.6 million hectares, or 23% of the arable land. In addition, there are over 14.6 million hectares of native or unimproved pastures in Canada (Government of Canada, 2011). The economic value of the forage and grassland industry is estimated to be $5.09 billion, trailing only wheat and canola in terms of economic contribution. In addition, the forage industry is the backbone of the beef and dairy sectors, and these two sectors contribute $11 billion in direct value to Canadian farmers, and over $50 billion in economic activity. Provincial studies have estimated the value of the indirect benefits from the forage industry, such as environmental services, could be worth as much again as the direct benefits (Yungblut, 2012).

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. While the impact of greenhouse gas emissions from agriculture has been increasingly recognized as an extremely important anthropogenic source of emissions, very limited work to date has focused on the impact of cattle ranching on these emissions in British Columbia. The primary focus of this body of work 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 greenhouse gas emissions, and their potential future relevance for the ranching community in the province.

The specific objectives of this study was to: 1) empirically measure greenhouse gas emissions from 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 (LCA), to determine the carbon footprint of the cattle ranching industry of British Columbia; as well as 3) explore GHG emission reduction and removal strategies; and 4) investigate possible opportunities for the ranching industry to participate in carbon market revenue.

# CHAPTER 2
# INVESTIGATING METHANE EMISSIONS FROM CATTLE GRAZING THE LAC DU BOIS GRASSLANDS UTILIZING THE $SF_6$ TRACER TECHNIQUE

## 2.1 Introduction

Methane ($CH_4$) is a greenhouse gas (GHG) whose atmospheric concentrations have increased dramatically over the last century. The rising concentration of $CH_4$ is strongly correlated with increasing populations, and currently about 70% of its production arises from anthropogenic sources (IPCC, 2006a). 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 = $10^{12}$ g = 1 million metric ton) of methane annually, accounting for about 33% percent of the global anthropogenic $CH_4$ emissions (Beauchemin, Kreuzer, O'Mara, & McAllister, 2008). Methane is considered by many to be one of the largest potential contributors to climate change(Sejian, Lal, Lakritz, & Ezeji, 2010). 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 (LCA) of beef production in Western Canada, Beauchemin, Janzen, Little, McAllister, & McGinn (2011) determined that enteric $CH_4$ was the largest contributing source of GHG from the beef industry, contributing 63% to total emissions. They further determined that the cow/calf sector accounted for approximately 80% of total industry emissions, with 84% of enteric $CH_4$ coming from mature cows.

Many governments have implemented strategies and policies to reduce greenhouse gas emissions from agriculture, and significant efforts are being directed towards developing animal husbandry methods that lower enteric methane emissions (Beauchemin, Janzen, Little, McAllister, & McGinn, 2010). In addition to GHG issues, methane emissions from cattle represent a carbon loss pathway that results in reduced productivity. If the energy that is lost in generating methane could contribute to weight gain for example, 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, McAllister, & McGinn, 2009). Generally highly digestible feeds yield lower methane emissions when compared to poorer quality diets. Dietary manipulation may provide a mechanism for reducing methane emissions from domestic livestock.

A measurement technique that makes use of an inert tracer gas, sulfur hexafluoride ($SF_6$), has been developed that allows methane production from individual grazing ruminants to be measured by placing a calibrated source of $SF_6$ (a permeation tube) in the rumen and determining the ratio of methane to $SF_6$ in the animals breath (Ulyatt, McCrabb, Baker, & Lassey, 1999). This technique can provide estimates of methane production that are comparable with those determined by respiration calorimetry in actual grazing conditions, avoiding the limitations of other controlled measurement techniques.

The tracer techniques has been widely adopted in many countries because it is the only viable technique for determining enteric methane emissions from individual grazing animals (Lassey, 2007). The technique's accuracy compared with alternative measurement protocols, including the use of chambers, has been well documented and validated (Boadi, Wittenberg, & Kennedy, 2002; K. Johnson, Huyler, Westberg, Lamb, & Zimmerman, 1994; Ulyatt et al., 1999). At the same time, there exist some uncertainties in the $SF_6$ tracer technique, arising from: extrapolation of permeation tube performance (Lassey, Walker, McMillan, & Ulyatt, 2001); variations in breath collection efficiency throughout the collection period; concerns that the imposition of sampling equipment may affect feeding behavior; and the fact emissions produced from flatulence are not measured. Most hindgut methane is absorbed into the bloodstream and respired, so the $SF_6$ technique will capture most of it, but to account for values where hindgut emissions of methane are not measured directly, an increase of 2-3% of the enteric emission value is considered a reliable adjustment (Lassey, 2007). Another limitation is that emissions are only measured from individual animals, and $CH_4$ emissions can vary between animals. Emissions from larger numbers of free moving livestock can be measured with techniques such as integrated horizontal flux (<6 animals), and open-path laser spectrometry (10-25 animals). These non-interference techniques tend to be more accurate and provide more realistic values associated with livestock activity and grazing/feeding patterns, but may still require the $SF_6$ method for verification (Derner et al., 2005; Kebreab, Johnson, Archibeque, Pape, & Wirth, 2008)

There have been many previous studies investigating methane emissions from livestock, particularly as methane production relates to diet and feeding regimes. The vast majority of these studies have been conducted on restrained and/or penned animals. The $SF_6$ tracer technique for measuring enteric fermentation has proven to be a reliable and useful tool for researchers endeavoring to investigate $CH_4$ emissions from free moving animals (Lassey et al., 2001). This technique allows direct rumen $CH_4$ measurements without restricting animals from their natural environment and feeding behavior (Johnson et al., 1994). As a result, studies can be undertaken to investigate issues such as dietary strategies as they relate to $CH_4$ production from grazing animals. For example, a group of Canadian researchers used the $SF_6$ tracer gas technique to measure the impact of grazing management on $CH_4$ production by steers and lactating beef cows (McCaughey, Wittenberg, & Corrigan, 1997, 1999). Boadi, Wittenberg, & McCaughey (2002) used the $SF_6$ tracer gas technique to measure the effects of grain supplementation on $CH_4$ production of grazing steers. Few studies have investigated the enteric methane production from beef cattle on native range in Canada, and to our knowledge none have been conducted on the unique grassland communities of the central interior of British Columbia, represented by the Lac Du Bois study site. The levels of methane produced by beef cattle in BC should be verified and compared to levels recorded in other regions in Canada and globally to accurately predict the carbon footprint of B.C. cattle and to determine the applicability of appropriate modelling tools.

Finally, in order to assess the digestibility of the forage/diet in the test areas, samples of the prevalent grassland communities were gathered and measured by Near Infrared Reflectance Spectrometry (NIRS). Significant differences in key nutritional constituents relating to digestibility within the two different sampling areas utilized in this study would suggest variability or unreliability in methane emissions. In addition, collection of this information would help determine the validity of implementing different modelling approaches used later in the thesis that require accurate knowledge of the digestibility of the nutrients in the diet.

### 2.2 Materials and Methods – Methane Measurement

The $SF_6$ calibrated tracer technique in ruminants was pioneered at Washington State University by Johnson et al. (1994). Various improvements have subsequently taken place, and the current version used in this study is a modification developed by the Dept. of Animal Science, University of Manitoba (McGinn, Beauchemin, Iwaasa, & McAllister, 2006) and from Ag Research Limited, N.Z (Pinares-Patiño et al., 2008).

Following the guidelines supplied by Agriculture and Agri-Food Canada on implementing the sulphur hexafluoride ($SF_6$) tracer technique method, a small, calibrated permeation tube containing $SF_6$ gas was inserted by bolus gun into the rumen of six beef cows one week prior to the start of the study. Once the study began, a halter fitted with a capillary tube was placed on the animals head and was connected to an evacuated sampling canister (PVC yoke). As the vacuum in the sampling canister slowly dissipated, a sample of the air around the mouth and nostril of the animal was collected into the PVC yoke at a constant rate. After collecting a sample, the yoke was removed, pressurized with nitrogen, and then the methane and $SF_6$ concentrations were sampled and subsequently determined by gas chromatography at Thompson Rivers University. The methane emission rate was calculated as the product of the permeation tube emission rate and the ratio of $CH_4$ to $SF_6$ concentration in the sample.

#### 2.2.1 Permeation Tube

The permeation tube body was constructed from a brass rod, drilled out in the centre to provide a cavity for the $SF_6$ (Figure 2.1). The open end was threaded to allow the attachment of a Swaglock nut. A thin Teflon window and a stainless steel frit was placed between two Teflon washers and assembled between the brass body and nut. The thickness and type of Teflon window dictated the permeation rate. TFE Teflon of 12mm thickness and a 2 micron frit normally provide $SF_6$ permeation rates in the range of 1,000-2,000 ng/min at 39$^{o}$ C. The purpose of the frit is to stabilize and protect the Teflon membrane. The weight of the assembled tube was taken and an identification number was stamped onto the tube.


**Figure 2.1.** Permeation tube and components.

To charge the tube with pure $SF_6$, the tube body was immersed into liquid nitrogen. After the tube reached the cryogen temperature, it was removed and any liquid was poured out of the cavity. The cavity was then filled with pure $SF_6$. This was accomplished by injecting the gas into the permeation tube body with a syringe. Once completed, the cap assembly was quickly installed, and the entire device was weighed. This procedure provided six tubes containing about 600 mg of $SF_6$. The tubes were placed in a glass receptacle in a 39$^o$ C water bath. A small flow of clean $N_2$ gas was maintained to purge the glass receptacle of any $SF_6$ emissions. Weights of the tubes were taken weekly to determine the release rate of the $SF_6$.

### 2.2.2 Halter Construction

The sampling apparatus consists of the collection canister (PVC yoke) and a modified halter (Figure 2.2). A snug, proper fitting halter is critical, as the position of the inlet over the nostril must be maintained to ensure sampling success. Halters with an adjustable chin strap are preferred, and additional holes were installed to ensure a snug fit to the noseband. A leather flap was riveted onto the halter noseband to provide support for the capillary tube inlet and filter.

**Figure 2.2.** Halter and yoke assembly.

### 2.2.3 Capillary Tubing

The length of the capillary tubing regulates the sampling rate. Stainless steel tubing with an inside diameter of 0.127 mm and an outside diameter of 1.59 mm served as the flow restrictor and transfer line. The capillary system is designed to deliver about half the volume contained in the yoke during a normal 24 hour collection period. Filling to ½ atm ensured that the fill rate was constant. A 50 micron filter system was installed on the upstream (nose) end of the capillary tube to protect it from filling with foreign material. The filter assembly was then attached to the leather noseband so that the filter and inlet tubing were located above the nostril of the animal. The stainless steel calibration tubing is located within a PVC tube for protection purposes (Figure 2.3). On the downstream end of the protective tube, the capillary tubing was connected to a length of 3.17 mm PTFE tubing, and a male quick-connect was installed on the end for connection to the yoke.

**Figure 2.3.** Stainless Steel capillary tubing housed in PVC tube for protection.

### 2.2.4 PVC Yoke

The sampling apparatus consisted of a PVC yoke that is designed to fit around a cow's neck, and then attached to the modified halter with 40 cm long electrical tie straps (Figure 2.4).

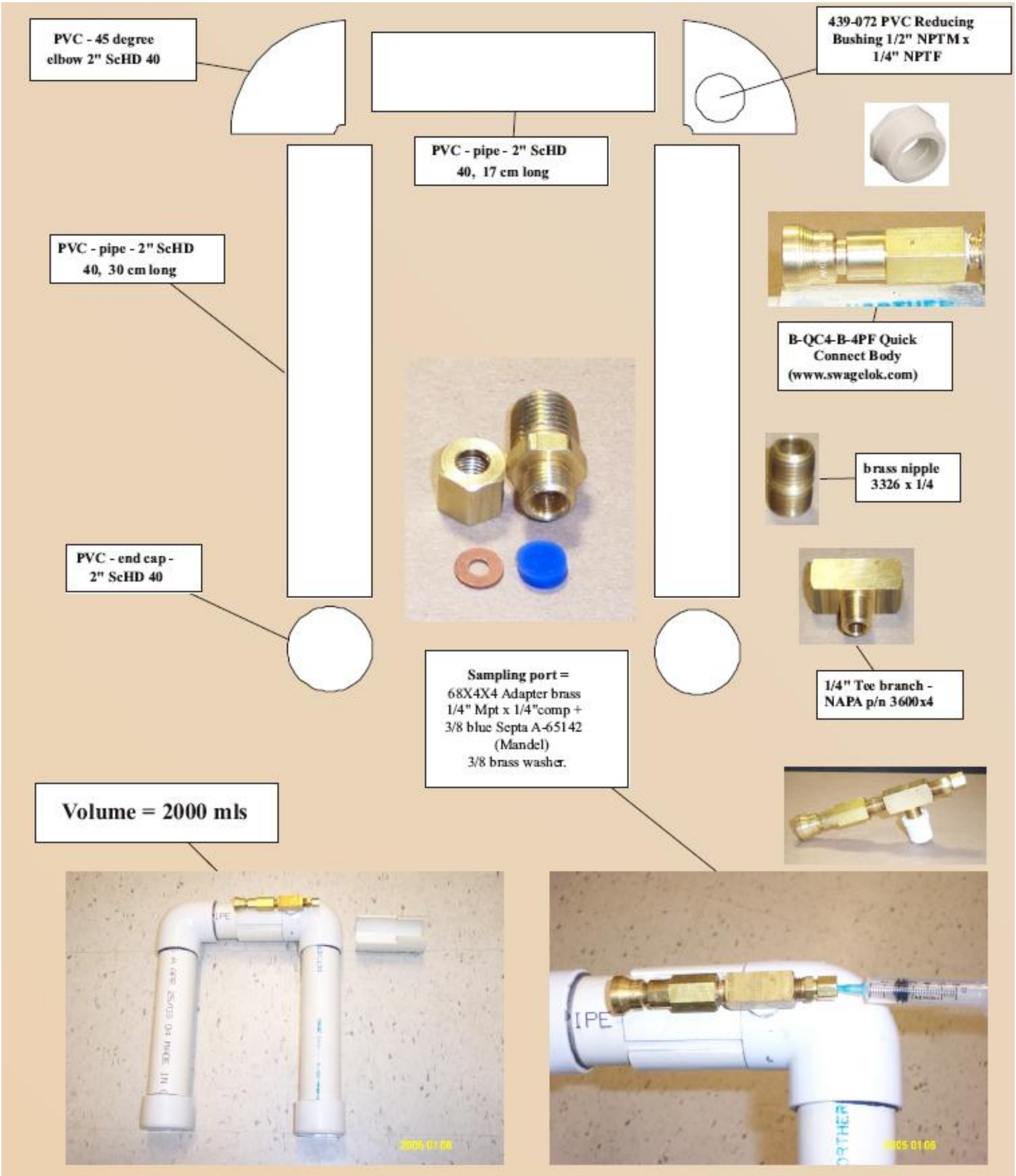


**Figure 2.4.** Schematic – SPARC PVC Methane collection apparatus (yoke) (Iwaasa et al, 2005).

### 2.2.5 Dilution System and Vacuum Pump

A vacuum pump was required to evacuate the yokes, and a pressure gauge was utilized to measure the pressure when filling the yoke with a gas sample. A dilution system was used to pressurize the sample with nitrogen gas. All components were fitted with the quick-connect system to facilitate use.

Prior to sampling, a collection yoke was evacuated, and the pressure recorded. After the sampling period, the pressure was again recorded to validate that the sampling was satisfactory. The yoke was then connected to the dilution system, and nitrogen was slowly added until the pressure in the canister was increased to about 1.5 atm. The exact pressure was recorded to calculate the dilution factor. A sample was then drawn out of the yoke with a syringe (Figure 2.5). Subsequently, gas chromatography was used to reveal the methane concentration in the sampling yoke (Figure 2.6).

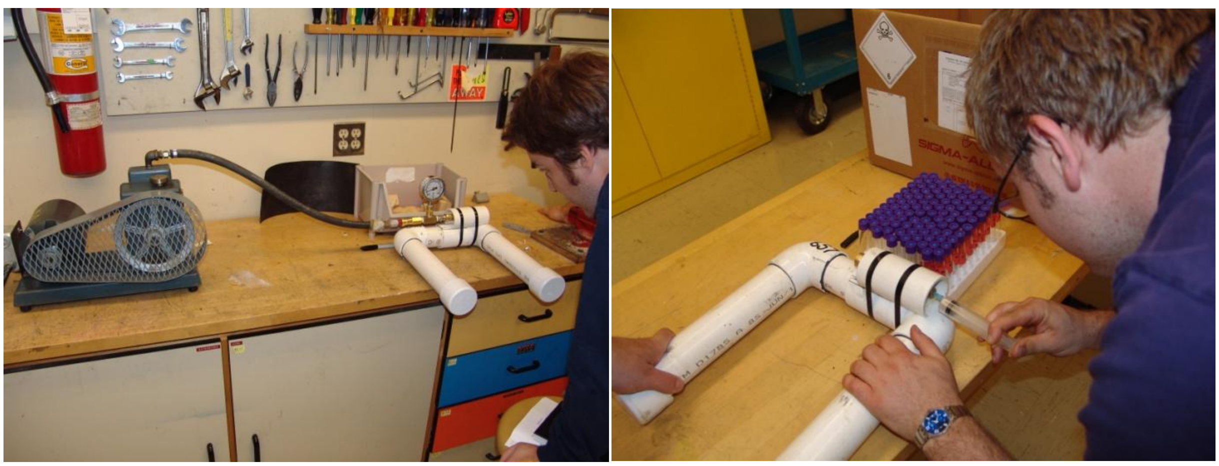

**Figure 2.5.** Each yoke is over-pressured with pure nitrogen to about 1.5 atm. After 1 hour a sub sample is taken (30 ml) to be analyzed by gas chromatography.

### 2.2.6 Gas Analysis

The tracer method utilized $SF_6$ to account for dilution as gasses exiting the cow's mouth mixed with ambient air. It is assumed that the $SF_6$ emission exactly simulates the $CH_4$ emission; thus the dilution rates for $SF_6$ and $CH_4$ are considered to be identical.

Determining the $SF_6$ and $CH_4$ mixing ratio (µmol $mol^{-1}$) in the yoke canisters ($C_{sf6}$ and $C_{ch4}$, respectively) was required, and the pre-determined $SF_6$ release rate ($Q_{sf6}$ in g $d^{-1}$) was used to determine the $CH_4$ emission ($Q_{ch4}$ in g $d^{-1}$) (refer to Equation 2.1). Background $SF_6$ and $CH_4$ mixing ratios ($CB_{sf6}$ and $CB_{ch4}$, respectively) were measured in the vicinity of the sampling or collection area using separate yoke canisters, hidden in surrounding vegetation, and these were subtracted from $C_{sf6}$ and $C_{ch4}$, respectively. The ratio of molecular weights (MW) was used to account for the difference in density between the gases.

$$\mathbf{Q_{ch4} \quad = \quad \frac{C_{ch4} - CB_{ch4}}{C_{sf6} - CB_{sf6}} \qquad Q_{sf6} \qquad \frac{MW_{ch4}}{MW_{sf6}}}$$

**Equation 2.1.** McGinn et al. (2006). J. Environ. Qual. 35 :1686-1691.


**Figure 2.6.** Measuring methane samples using gas chromatography.

**2.3 Sampling Site**

The La du Bois Provincial Park grasslands served as the study location for this research. The La du Bois grassland area 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 licenses administered by the Kamloops Forest District, in accordance with the Range Act and the Forest Practices Code Act. The Lac du Bois Grasslands

Park is in three Range Units: Dewdrop, Watching Creek and Lac du Bois, with each unit divided into a number of fenced pastures (Figure 2.7). 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. In general, cattle move from the lowest pastures in the spring up to higher elevation forests outside the park in the summer, then back to the grassland pastures again in the fall before being gathered for return to home ranches. The lowest elevation pastures have an 18-month rest period with no grazing in a three year cycle (Ministry of Environment, Lands and Parks, 2000).

**Figure 2.7.** Mid-elevation pasture, Lac Du Bois. Cattle belong to study co-operator Terry Inskip.

### 2.4.1 Sampling Methodology – Methane Collection

In preparation for the study, the experimental animal handling procedures were approved by Thompson Rivers University's Animal Care Committee. The study was undertaken in accordance with the Canadian Council on Animal Care (CCAC) guidelines at all times.

The sample size consisted of six cows. The cows had calibrated permeation tubes "installed" by a bolus gun; placing the tube in the rumen in advance (seven days) of the animals (with calves) being placed into the mid-elevation grazing area in the spring.

The sampling program consisted of four, five day sampling periods during the grazing season, as follows:

- The first spring sampling period took place from May 17 – 21, 2010 in the mid-elevation area.
- The second spring sampling took place from May 31 – June 4, 2010 in the upper elevation areas.
- The first fall sampling period took place from September 26 – 30, 2010 in the upper elevation area.
- The second fall sampling took place from October 24 – 28, 2010 in the mid-elevation area.

In preparation for the commencement of the sampling, eight yoke and harness systems were prepared. Six of those were placed on the cattle, with one as a spare, and one was positioned in an area adjacent to the grazing area to serve as a backgrounding apparatus to collect ambient methane.

The sampling procedure during each of the sampling periods consisted of the following activities:

- **Preparation:**
    1. arranged with cattle owner/co-operator to participate in the study.
    2. prepared and organized the yoke and harness assemblies.
    3. arranged for the hired wranglers to assist with herding animals to sampling corrals on each day of sampling period (Figure 2.8).
    4. arranged for livestock "squeeze" to be installed at sampling corrals.

- **Day 1:**
    1. wranglers herd cattle to sampling corrals.
    2. one by one animals were positioned into cattle "squeeze". Ear tag numbers were recorded, and suitable harness and yoke assemblies were

placed on each animal, with time recorded following connection of yoke to capillary system.

iii. animal weights were recorded, and an additional ear tag for experimental identification purposes was installed.

iv. procedure repeated for each animal.

v. harness and canister assembly were placed in a safe location adjacent to grazing area to monitor background $CH_4$.

vi. filled yokes were returned to lab for sample processing.

- **Day 2-4:**

  i. wranglers herd cattle to sampling corrals (Figure 2.9).

  ii. after 24 hrs. ($\pm$ 20 min.) filled yokes were exchanged on each animal.

  iii. filled background yoke exchanged.

  iv. filled yokes were returned to lab for sample processing.

- **Day 5:**

  i. wranglers herd cattle to sampling corrals.

  ii. after 24 hrs. ($\pm$ 20 min.) yokes and halters were removed (Figure 2.10).

  iii. animals were weighed.

  iv. filled background yoke and halter assemblies were collected.

  v. filled yokes were returned to lab for sample processing.

**Figure 2.8.** Cattle being gathered for sampling, Lac Du Bois pasture.

**Figure 2.9.** Cattle in pens waiting for yokes to be exchanged, Lac Du Bois.

**Figure 2.10.** Cattle in “squeeze”, removing yoke and halter, Lac Du Bois.

### 2.4.2 Sampling Methodology – Forage Analysis

In representative pasture areas, forage was collected utilizing a 1m x 1m square frame. The quadrate samples were collected in triplicate at the two elevation zones from three distinct forage communities (Bluebunch Wheatgrass (*Pseudoroegneria spicata*), Kentucky Bluegrass (*Poa pratensis)* and Rough Fescue (*Festuca scabrella*)) on June 11 and 15, 2010. All of the plant biomass within the 1 metre square frame was clipped and placed in paper sampling bags. Dry matter (DM) composition was determined by placing the samples in a drying oven at 60$^{o}$C for 48 hours, and then ground through a 1 mm screen. The ground samples were stored in ambient laboratory conditions. All samples were compared using a FOSS InfraXact Near Infrared Spectrophotometer (NIRS) (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.

### 2.5 Statistical Analysis

Statistical analyses on the $SF_6$ data was conducted with JMP Software V8 (SAS, Carey, NC) using a t-Test with a significance level of 0.05, n = 24. No statistically significant differences were found in methane levels for either of the study sites, between the two seasons, or between the first and second week. The forage analysis by NIRS, was descriptive in nature, and therefore no statistical analysis between means was conducted. Error bars in Figure 2.11 equal standard deviation.

### 2.6 Results

#### 2.6.1 Methane Measurements

Results indicate that cattle grazing the Lac Du Bois grasslands produced an average of approximately 370 L/day of methane during the course of the study. These results are comparable to the amount of methane observed by other research groups for beef type animals, using the same measurement technique, where observations range from approximately 300 – 400 L/day (Boadi & Wittenberg, 2002; McCaughey et al., 1997).

The relatively small sampling size was a result of the difficult and tremendous logistical hurdles and expense associated with studying cattle on range. The low number of animals in the study had the effect of reducing the strength of our statistical analysis.

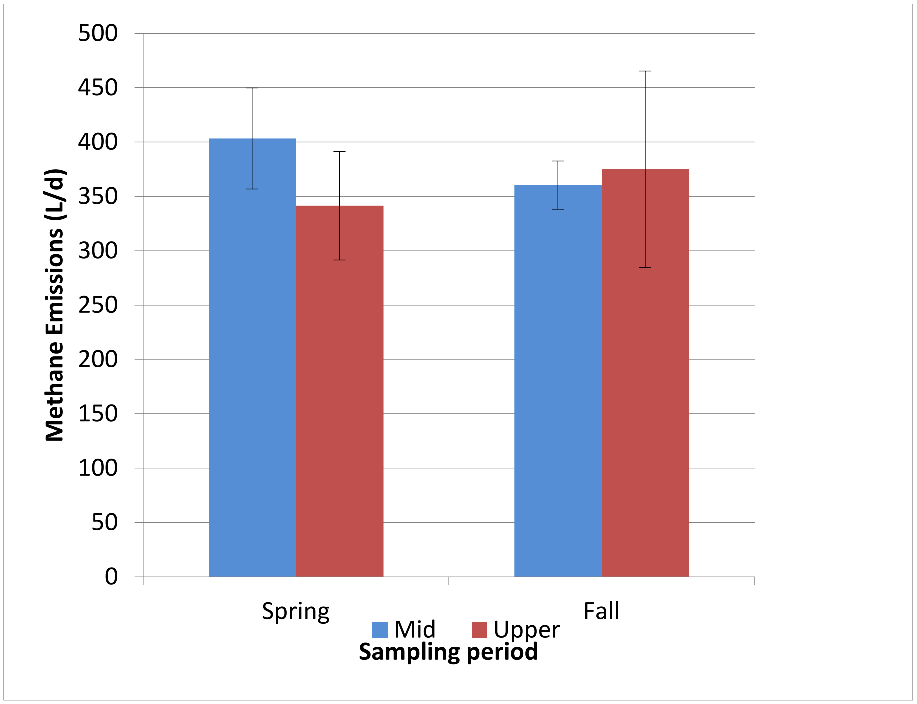


**Figure 2.11.** Cow Methane Output (L/day) from samples collected during the spring and fall of 2010 at the Lac Du Bois test site. Error bars indicate standard deviation (SD).

| | Spring 2010 | | Fall 2010 | |
|---|---|---|---|---|
| | $CH_4$ | SD | $CH_4$ | SD |
| First Week | 403.26 | 46.47 | 375.01 | 22.18 |
| Second Week | 341.37 | 49.90 | 360.38 | 90.33 |
| Average | 372.32 | | 367.70 | |

### 2.6.2 Pasture Analysis

The pasture analysis was conducted in order to evaluate the key forage nutrients, which in turn provide a basis for evaluating the digestibility of the main grassland communities between the two sampling areas. Representative samples were obtained and keyed by Dr. Don Thompson from Agriculture and Agri-Food Canada, Kamloops. The key area of relevance for us in this study was whether there was a significant difference in the dietary constituents between the two sampling areas (Table 2.1) which could impact methane production. The results produced by NIRS appear to indicate that there was no visible difference between the samples from the lower and upper elevation sampling areas, which could potentially introduce variability into the methane production results. The NIRS data collected was descriptive in nature, based on one sample. More samples would be required in the future to determine if true statistically significant differences exist between the three grassland communities within the Lac Du Bois study area.

**Table 2.1.** Comparison of select key nutrients between varieties in the grassland community of Lac Du Bois test site. Quadrat samples collected on June 11 & 15, 2010, and analyzed by Near Infrared Spectrometry.

| | **Blue Bunch Wheatgrass** | | | **Kentucky Bluegrass** | | | **Rough Fescue** | | |
|---|---|---|---|---|---|---|---|---|---|
| | ***Mid*** | ***Upper*** | ***Avg.*** | ***Mid*** | ***Upper*** | ***Avg.*** | ***Mid*** | ***Upper*** | ***Avg.*** |
| **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 | 1.30 |
| **TDN** | 68.31 | 64.09 | 66.20 | 69.85 | 60.31 | 65.08 | 63.27 | 65.5 | 64.39 |

Notes to Table 2.1 – Definitions (T. Wright & Lackey, 2008):

-**Acid detergent fibre (ADF)** – value used to predict the energy content (TDN, NE) of forages.

**-Neutral detergent fibre (NDF)** – value used to predict ruminant feed intake.

**-Lignin** – a complex polymer bound to cellulose that strengthens plant cell walls but is indigestible to animals.

**-Protein** – complex combinations of amino acids which are essential for animal growth, production and reproduction.

**-Ash** – inorganic mineral elements of animals and plants.

-**Soluble Carbohydrates (Sol. Carbo’s**) – structural or non-structural energy providing substrate, which includes starches, sugars, cellulose and hemicellulose. All carbohydrates contain carbon, hydrogen and oxygen.

**-Starch** – a carbohydrate that is a polymer of glucose; represents a store of energy for plants.

**-Total digestible nutrients (TDN**) – the energy value of feedstuffs, comparable to digestible energy (DE) in accuracy. TDN over-estimates the energy value of roughages in comparison to grains.

## 2.7 Discussion

Native grassland and improved pastures are important resources for beef production. As forages mature during a grazing season, there is decreased digestibility, related to decreased nitrogen and increased fibre and lignin contents of the forage (Beauchemin et al., 2008). Reduced forage digestibility is accompanied by decreased forage intake, and an increased acetate:propionate ratio, which favours increased $CH_4$ production per unit of forage consumed (McAllister, Cheng, Okine, & Mathison, 1996). Methane production from cattle constitutes 2-12% of gross energy lost, and is also a major contributor to atmospheric GHG emissions (Johnson & Johnson, 1995).

No statistically significant differences were observed in the methane produced by the six young cows in the spring vs. the fall grazing period in this study. It was anticipated that more methane would be produced in the fall as the digestibility of the forage begins to decline. However, it is possible that the higher average levels of methane observed in the spring could be attributable to the metabolic stress of lactation, which often necessitates a dramatic increase in feed consumption (Kebreab et al., 2008). This increased metabolic demand may have negated any potential difference between the spring and the fall. During our study, the cows had calves at foot, and were likely at peak lactation during the spring; whereas the metabolic demand from the nursing calves would have decreased in the fall, which was just prior to the normal weaning period. To address any seasonal differences in methane production that could be associated with lactation, studies using steers vs. cows could be conducted.

Again, though not statistically significant, it was further observed that there was a consistent reduction in methane collected from the first to the second week in each season. The cows were noticeably harder to handle during the second sampling week. Due to their relative unpleasant experience during the first week, during the second week they had to be chased more when gathering them each day, they were much more unruly in the pens, and it was much more difficult to move them into the squeeze. We speculate that this additional stress during the second week may have impacted their feeding behavior - less feed = less methane.

Other research scientists have noted that the $SF_6$ tracer technique is problematic in determining treatment differences, but the data are still very relevant if using it for inventory purposes (Karen Beachemin and Alan Iwaasa, personal communication).

As part of their work, The Intergovernmental Panel on Climate Change (IPCC) has provided a protocol for countries to estimate the magnitude of GHG emissions and carbon footprints associated with an activity. The IPCC (IPCC, 2006b) methodology is the basis for carbon footprint estimates; it relies on a tiered system which is based on the availability of emission factors associated with activity data. The Tier 1 level relies on default empirical emission factors as published by IPCC, and is the simplest approach available. Tier 2 is still empirical in nature, as the emission factors are usually derived from experimental data specific to a country (Rochette et al., 2008). Tier 3 is the most complex method and relies on process based models (Smith, Grant, Desjardins, Lemke, & Li, 2004). Moving to a higher Tier of estimation is generally considered a good practice, if the data is available to support it. The Tier 1 estimates use default values to predict $CH_4$ emissions from national inventory numbers for each class of animal. The Tier 2 methodology is more rigorous and detailed – it requires a very detailed characterization of the cattle population. Though it has its limitations, it offers improvements by including more animal classes and calculations based on methane emissions as a proportion of gross energy intake (GEI) (Vergé, Dyer, Desjardins, & Worth, 2008). Table 2.2 provides the Tier 2, enteric $CH_4$ emission guidelines as categorized by class of animal.

**Table 2.2.** IPCC Tier 2 enteric fermentation emission factors. Environment Canada, 2005.

| Livestock Class | $CH_4$ emission, kg/animal/year (IPCC Tier 2) |
|---|---|
| Bulls | 94 |
| Cows | 90 |
| Beef heifers | 75 |
| Heifers for slaughter | 63 |
| Steers | 56 |
| Calves | 40 |

In an effort to validate the emission values, in 2005, the Beef Technical Working Group (BTWG) reviewed several relevant research projects that have been undertaken to determine the actual emissions from beef cattle. Three of the research projects reviewed by the BTWG were conducted in Canada testing different pasture types, stocking rates and grazing practices. The studies all utilized the $SF_6$ method. The actual emissions from these studies were compared against the Tier 1 and Tier 2 estimates from IPCC. Table 2.3 provides an adapted summary of the studies reviewed, and compares the actual results with the Tier 1 and 2 values in g/head/day, and the respective % of actual emissions. The results show the IPCC Tier 1 estimates were considerably lower than the actual emissions in all cases. The Tier 2 estimates tended to underestimate the emissions in most situations. Part of the differences can be accounted for due to the fact the IPCC estimates were based on a combination of feedlot cattle and grazing cattle, while the studies included just grazing cattle. IPCC estimates that grazing animals emit more methane on an animal, and per-animal weight basis than feedlot animals (IPCC, 2006a).

**Table 2.3.** Actual vs. predicted enteric emission of methane (g/head/day) by beef cattle fed pasture (adapted from BTWG, (2005)).

| Study | Actual emissions | IPCC, Tier 1 (% of actual emissions) | IPCC, Tier 2 (% of actual emissions) |
|---|---|---|---|
| **Boadi et al., 2002** | | | |
| Pasture only | 230.2 | 128.8 (56%) | 217.0 (94.3%) |
| Pasture + Barley | 245.6 | 128.8 (52.4%) | 252.2 (102.7%) |
| Early | 190.0 | 128.8 (67.8%) | 258.3 (136%) |
| Mid | 269.9 | 128.8 (47.7%) | 198.3 (73.5%) |
| Late | 253.9 | 128.8 (50.7%) | 246.9 (97.2%) |
| **McCaughey et al., 1997** | | | |
| Rot. Graze – Hi SR | 195.6 | 128.8 (65.8%) | 285.6 (146%) |
| Rot. Graze – Lo SR | 207.8 | 128.8 (62%) | 255.8 (123.1%) |
| Cont. Graze – Hi SR | 179.6 | 128.8 (71.7%) | 255.3 (142.1%) |
| Cont. Graze – Lo SR | 227.4 | 128.8 (56.6%) | 253.8 (111.6%) |
| **McCaughey et al., 1999** | | | |
| Alfalfa/grass | 277.2 | 197.3 (71.2%) | 225.1 (81.2%) |
| Grass only | 304.8 | 197.3 (64.7%) | 192.5 (63.2%) |

Notes to Table 2.3:

**Boadi et al., 2002.** Angus beef steers (334.6 kg) grazed a legume/grass pasture and were either unsupplemented or supplemented with barley (2 or 4 kg/hd/day) during the grazing season. Intakes and methane emissions, using the $SF_6$ method, were sampled on the steers three times during the grazing season (Boadi, Wittenberg, & McCaughey, 2002).

**McCaughey et al., 1997.** Crossbred yearling steers (356 kg) grazed 60% alfalfa, 40% grass pastures and managed by rotational or continuous grazing stocking at each of high and low stocking rates (2 x 2 factorial design). Methane emissions measured using the $SF_6$ method (McCaughey et al., 1997).

**McCaughey et al., 1999.** Hereford x Simmental lactating heifers (511.2 kg) grazed alfalfa/meadow brome or meadow brome only pastures. Methane emissions measured using the $SF_6$ method (McCaughey et al., 1999).

Our study results on methane capture are consistent with previous work done in comparable backdrops. The average of our spring and fall results are 370.01 L/head/day, this converts to 233.37 g/head/day, nearly identical to Boadi, Wittenberg, & Kennedy (2002), and within 95% of the IPCC Tier 2 estimates.

Most estimates of methane emissions from cattle in Canada using IPCC Tier 2 methodology utilize digestible energy (DE) to calculate enteric methane emissions (Ominski, Boadi, Wittenberg, Fulawka, & Basarab, 2007). Digestible energy (DE) values are calculated for each diet type and represent the percent of GE intake of the feed that is digestible to the animal. GE is defined as “the measure of the total combustible energy in a feed” (T. Wright & Lackey, 2008). Where regional DE values are not available for a particular animals diet, a very similar measure, total digestible nutrients (TDN) as a percent of dry matter is used (Mangino, Peterson, & Jacobs, 2002). TDN has been described as “the energy value of feedstuffs, comparable to digestible energy in accuracy” (T. Wright & Lackey, 2008). The average TDN values that were obtained in this study through NIRS analysis from the three different grassland communities in the Lac Du Bois study area was 65.22%. This empirical value that we measured in the field is identical to the values used (Diet DE %) to estimate enteric methane emissions by other Canadian researchers using IPCC (2006) Tier 2 methodology (Basarab et al., 2012; Ominski et al., 2007). The vast majority of the variation in GHG emissions in beef cattle has been shown to be largely due to yearly differences in diet TDN, crude protein (CP) and dry matter intake (DMI), and time on each diet (Basarab et al., 2012).

## 2.8 Conclusion

Capturing reliable emissions data from grazing livestock could be considered integral in developing more reliable information when it comes to quantifying methane emissions over a full range of spatial scales, from individual animals to national and global scales. Grazing livestock form the foundation of the data, which can then be extrapolated to help comprehend and further validate the impact that the livestock sector, specifically the cattle ranching industry, has on global warming. Grazing animals account for the majority of the world's farmed livestock, yet are the least amenable logistically to investigation of their emissions and their emission determinants (Lassey, 2007).

Gaining insight into emission determinants, or factors that influence methane production, requires that feed properties be determined, enabling methane to be expressed as per unit of feed intake. This later concept is known as the "methane conversion factor", or "$Y_m$", and is an entity that enables small-scale methane emission estimates to be extrapolated to national and global enteric methane inventories (Ominski et al., 2007).

Determining feed intake by grazing animals is particularly difficult compared to confined animals under controlled feeding conditions. The intake estimates of grazing animals will usually be the biggest source of uncertainty when using $SF_6$-based estimates of $Y_m$ for individual animals. Enteric methane emissions can be calculated using the methane conversion factors ($Y_m$) for each diet, as established by the IPCC (2006) Tier 2 guidelines.

The $SF_6$ technique not only measures a per animal methane emission rate, with co-determined feed consumption rate (a corresponding $Y_m$ value), but also facilitates the study of those factors that influence methane emissions. An important objective when investigating methane determinants is the development of methane abatement strategies. Many such strategies target a reduced methane emission per unit through greater feed utilization efficiency (Mosier et al., 1998). The $SF_6$ technique has proven itself to be a valuable tool in methane mitigation research (Lassey, 2007).

The enteric $CH_4$ emission results of our study are consistent with the results observed by other researchers using the same measurement approach on similar pasture scenarios. Our emission results are 17.5% lower than our baseline scenario in our Holos LCA model, as described in Chapter 3. This level of variation is also within acceptable limits as demonstrated by other researchers, and could be primarily due to factors such as diet and feed intake variability. The empirical $CH_4$ measurements collected in the field, and the concurrent pasture analysis results served to validate the Holos LCA modelling efforts in Chapter 3, and the results described therein.

# CHAPTER 3
# LIFE CYCLE ASSESSMENT OF GREENHOUSE GAS EMISSIONS AND MITIGATION OPPORTUNITIES ASSOCIATED WITH CATTLE GRAZING THE LAC DU BOIS GRASSLANDS USING HOLOS

## 3.1 Introduction

Global atmospheric concentrations of greenhouse gases have increased in recent decades as a result of anthropogenic (human) activities. The increase in these GHG's is seen to be a primary driver of climate change by some groups (Lassey 2007). While $CO_2$ emissions are primarily due to fossil fuel use, $CH_4$ and $N_2O$ arise mainly from agriculture (Smith et al., 2007). Enteric $CH_4$ from ruminant livestock accounts for 17-37% of anthropogenic $CH_4$ emissions (Basarab et al., 2012; Lassey, 2008). Many governments have implemented policies to reduce GHG emissions from agriculture and significant efforts are now being directed towards developing techniques that may lower, or remove emissions. Alterations in diet composition and animal husbandry practices have been proposed as a means of reducing $CH_4$ and $N_2O$ emissions from cattle (Beauchemin et al., 2010; Eckard, Grainger, & de Klein, 2010). Improving forage quality, either through feeding forage with lower fibre and higher soluble carbohydrates, changing from C4 to C3 grasses, or even grazing less mature pastures can reduce $CH_4$ production (Beauchemin et al., 2008; Ulyatt, Lassey, Shelton, & Walker, 2002).

Grasslands have the potential to have a significant impact on global warming because they are the most extensive major natural vegetation formation in the world. This global formation is comprised of steppes in Russia, velds in South Africa, pampas in South America, puszta in Hungary and prairies in North America. Though gradually being reduced in size, the historical area of grasslands was 3.2 billion ha, or 24% of the global land area (Shantz, 1954). Grasslands once occupied 50 million ha in Canada, but has now declined to approximately 15 million ha contained in the four western provinces, with British Columbia representing 1.7 million ha (Samson, Knopf, & Ostlie, 2004). Despite the reduction in natural grasslands, they are considered to contain 10 - 30% of the global soil organic carbon (SOC) (Eswaran, Van Den Berg,

& Reich, 1993). Follett (2001) suggested that even small increases of carbon sequestered in the soil would have a significant global impact because of the extensiveness of the grasslands.

Canada has over 4.8 million hectares of tame or seeded pasture and over 15.3 million hectares of natural pasture, with a large portion used by beef cattle (Alemu, Ominski, & Kebreab, 2011). Through various soil and crop management techniques, crop lands, pastures and grasslands have the potential to sequester carbon dioxide from the atmosphere and trap the carbon in plant material and the soil. Canada's pastures are considered a large terrestrial carbon sink (Basarab et al. 2012). Older long term, or native pastures tend to sequester carbon dioxide at relatively low rates, however certain management approaches, including pasture improvements, may contribute to increasing these rates.

The North American beef production cycle is complex, typically including a cow-calf sucking/grazing period and a growing phase with cattle fattened on high grain diets in confined feedlots. GHG emissions from individual aspects of the production cycle have been investigated, as well as attempts to assess the entire sequence (Beauchemin et al., 2010). Few LCA studies have investigated the emissions associated with the grazing period on native grasslands.

Cattle and other ruminant animals have a unique ability to digest plant materials, such as grass and straw that have high contents of cellulose (Ominski, Boadi, & Wittenberg, 2006). This plant material is digested by microorganisms such as bacteria, archaea, protozoa and fungi that are found in the rumen. Anaerobic digestion by the microorganisms, also known as enteric fermentation, results in the production of $CH_{4,}$ which the animal "belches" into the atmosphere. Feeds high in fibre, such as straw, result in the production of more methane than forages of low fibre content, such as fresh green grass and alfalfa. The addition of grains (i.e. corn, barley, wheat) to the diet will reduce $CH_4$ emissions further. An imbalance in the nutrient content of the feed eaten, such as a shortfall in the amount of protein or mineral, will also increase the amount of $CH_4$ produced. Consequently, cattle fed in a feedlot usually emit less $CH_4$ than grazing cattle because they consume a substantial amount of grain and the ration is formulated to meet the animals' requirements for nutrients (Pelletier, Pirog, & Rasmussen, 2010).

Carbon sequestration is a result of plants taking $CO_2$ from the atmosphere and using it for plant growth. The carbon sequestration potential of soils comes from increasing soil organic matter (SOM). The below ground organic carbon storage is usually more than twice the above-ground storage potential (Swift, 2001). Grasslands accumulate large quantities of soil organic matter, mostly in the form of roots, and much of this organic matter can remain in the soil for long periods of time. Estimating potential carbon sequestration is more difficult for native grassland pastures than for cultivated croplands. Pastures tend to have a wide diversity in plant communities, soils and landscapes. Pasture ecosystem responses are complex, because management practices may induce shifts in plant communities that may, over time, exert secondary effects on the rate of carbon sequestration and the overall carbon storage ability (Liebig et al., 2005).

Two methods of grassland pasture management practices that have shown to be effective in improving carbon sequestration potential are: Improved Pasture Management (IPM), and, Reduced Grazing Intensity (RGI) (Paustian, Antle, Sheehan, & Paul, 2006). Paustian et al described IPM as a technological package including the use of high-residue crop rotations, reductions or elimination of fallow periods between crops, efficient use of manures, nitrogen fertilizers and irrigation, the use of low, or no-till practices, and/or improved grazing land and hay land. Other studies suggest that management options including fertilization, irrigation, inter-sowing of grasses and legumes, intensification of grazing, conservation tillage and crop rotation can enhance soil C pools (Conant, Paustian, Del Grosso, & Parton, 2005; Hutchinson, Campbell, & Desjardins, 2007). Carbon stocks in temperate grasslands may increase significantly under management with single or multiple improvements. Ogle, Conant, & Paustian (2004) estimated an increase in soil organic carbon (SOC) of temperate grasslands by 14% under management with a single improvement (either fertilization or introduction of legume or irrigation) using linear mixed effect modeling. Further, pasture management offers the potential to reduce GHG emissions by providing cattle with better quality forage, as well as the ability to sequester carbon from the atmosphere. Ominski, Boadi, Wittenberg, Fulawka, & Basarab (2007) concluded that pasture quality plays a major role in the extent to which methane production can be reduced in grazing animals. Their study compared methane emissions based on pasture quality in early season pasture vs. mid-season and late season conditions. Methane production declined with grazing on high quality forages; steers on the early pastures had 44% and 29% lower energy loss as methane than animals on mid and late pastures, respectively. There was also a 54% lower $CH_4$ emission when animals entered new paddocks relative to those exiting the paddocks.

Life cycle assessment (LCA) conducted according to International Organization for Standardization standard 14040 (IPCC, 2006) can be a useful tool for evaluating potential reductions and removals of GHG arising from a change in management practices, including pasture improvement. The objective of this study was to use a farm based LCA to explore the impacts of grazing intensity and select pasture improvement practices on total GHG production from cattle ranching associated with the Lac Du Bois grasslands.

It is hypothesized that increased pasture management/improvement and reduction in stocking density in the Lac Du Bois grasslands should result in the removal of atmospheric $CO_2$ through carbon sequestration, and reduction of livestock related GHG emissions, ultimately resulting in an overall reduction in total GHG emissions.

It is important to not only investigate possible *removals* of GHG emissions through increased carbon sequestration, but to investigate strategies that may assist in *reducing* GHG emissions like enteric methane emissions in the Lac Du Bois grasslands, as both contribute to overall GHG emissions.

## 3.2 Experimental Section - Materials and Methods

### 3.2.1 Use of Holos to estimate GHG emissions

In order to explore the potential impacts of different management options on the greenhouse gas emissions associated with the cattle industry utilizing the Lac Du Bois grasslands, a life cycle assessment was conducted using Holos. Holos is a whole-farm GHG modeling tool developed by Agriculture and Agri-Food Canada (Little et al. 2008). Holos is an empirical model, with a yearly time step, based primarily on IPCC (2006) methodology, modified for Canadian conditions and farm scale. 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 $N_2O$ derived from N applied on a farm. Estimates of GHG intensity often vary widely, reflecting differences in modeling approach and the farming systems studied.

The objective of this LCA was to capture a seasonal snap shot 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. This information could then be extrapolated to account for an estimate of the emissions over a longer period of time. The emissions associated with the existing stocking rates and pasture/rotational management practices currently employed within this single season snapshot would serve as the baseline. A comparative analysis is then conducted in order to reveal the potential impact on GHG emissions associated with changing stocking density rates and implementing pasture improvement strategies.

All gases were expressed as $CO_2$ eq to account for the global warming potential of the respective gases: $CH_4$ kg x 23 + $N_2O$ kg x 298 + $CO_2$ kg. Depending on the scenario being investigated, Holos can report on: on farm $CH_4$ emissions from cattle and manure; on farm $N_2O$ emissions from manure, soils, and growing crops; off farm $N_2O$ emissions from N leaching, runoff and volatilization; $CO_2$ emissions and removals derived from management induced soil C change; and energy based $CO_2$ emissions from on and off farm sources.

Holos estimates enteric $CH_4$ emissions for each class of cattle using a modified IPCC (2006) Tier 2 approach. Daily net energy (NE) requirements for cattle in each stage of production are estimated from NE expenditures for maintenance, activity, growth, pregnancy and lactation as appropriate. The gross energy (GE) intake required to meet NE requirements is then estimated, taking into account the digestibility of the diet. Enteric $CH_4$ emissions are calculated from GE intake using diet specific $CH_4$ conversion factors (i.e. Ym; defined as enteric $CH_4$ expressed as a proportion of GE intake). The TDN values reported in our Pasture Analysis in Chapter 2 (section 2.6.2) correlate almost identically with GE values used in IPCC (2006) emission prediction equations, thus confirming the validity of this approach.  Holos calculates $CH_4$ emissions from manure based on volatile solids production according to IPCC (2006) methodology, which factor in the gross energy (GE) intake of the animal as well as diet digestibility.

Direct $N_2O$ emissions from soils are based on N inputs, modified by soil texture, climate, tillage and topography. Total N inputs include those from synthetic N fertilizer, land applied manure, crop residue decomposition (above and below ground), and net mineralization estimated from net change in soil C. Soil derived $N_2O$ emissions are calculated from total N inputs using Canada specific algorithms for estimating national GHG inventories. Indirect $N_2O$ emissions (N lost from the farm via leaching, runoff and volatilization) are considered from assumed fractions of N lost from manure, residues, and fertilizer and IPCC (2006) factor.

Holos uses a methodology derived from that developed for the Canadian National Inventory report to estimate soil C gains and losses. The approach assumes that land which has been consistently managed for decades (e.g. long term native) has approached steady state C storage so that net exchange of $CO_2$ is negligible. Changes in land use or management can induce loss or gain of soil C. Changes that lead to removal of atmospheric $CO_2$ (sequestration) include reducing tillage intensity, eliminating summer fallow, planting perennial forages in rotation, or establishing permanent grass on cropland. Conversely, management shifts in the other direction results in soil C losses and increased atmospheric $CO_2$ emissions. The annual rate of soil C change diminishes with time from adoption of a management or land use change. Holos can also consider $CO_2$ emissions arising from the burning of fossil fuels from on and off farm sources using general coefficients.

### 3.2.2 System Boundary and Scope

The baseline scenario described reflects the current seasonal use of the Lac Du Bois grasslands for cattle grazing.

### 3.2.3 Description of the Pasture Complex

The Lac Du Bois grasslands park is comprised of three Range Units: Dewdrop, Watching Creek and Lac Du Bois, with each unit divided into a number of fenced pastures (Figure 3.1). Established in 1976, the pasture rotation system is predicated on the need to protect the grassland resources and ensure there is sufficient forage production, while protecting conservation values. The rotation system works in a variety of ways to move cattle around, based on elevation, season of year, availability of water, and actual conditions on the ground. Grazing is managed on a rest-rotation cycle that has been modified over the years as range conditions have improved, and as managers better understand the factors at play. In general, cattle move from the lowest pastures in the spring up to higher elevation forests outside the park in the summer, then back to the grassland pastures again in the fall before being gathered for return to home ranches. The lowest elevation pastures have an 18-month rest period with no grazing in a three-year cycle. All licensees are required to comply with Range Use Plans as administered under the Forest Practices Code Act (2004), which covers pastures both in the park and outside.

Our study area was associated with the Lac Du Bois grassland range units, which feed into the Watching Creek forest range units. The lowest grassland pastures – Batchelor, Halston, and Westsyde are used in April for two weeks and late fall for four weeks; the higher, largely grassland pastures, Deep Lake, Dairy and Griffin are used for four weeks in May; and the upper grassland pasture Long Lake, is used for two weeks in mid-fall. The cattle are moved from the grassland pastures up into the forests outside the park, in the Watching Creek range Unit, for June through August. Cattle are then moved to the upper grassland pasture, Long Lake for a two week period in September, then on to the Lac Du Bois pastures, before finishing the grazing season in the lower grassland pastures.

### 3.2.4 Description of Climate and Location

The Lac du Bois grasslands fall within Ecodistrict 1005 (an ecodistrict is a subdivision in the National Ecological Framework of Canada and is defined as a geographical area characterized by distinctive assemblages of relief, landforms, geology, soil, vegetation, water bodies and fauna). The study area is comprised of 7,566 ha of native grassland. The soil type is a brown Chernozem of medium soil texture. The average growing season (May – October inclusive) precipitation is 159 mm, with a potential evapotranspiration of 679 mm.

### 3.2.5 Description of Livestock System

The livestock mix on the pasture was made up of 232 cows, 90% with calf, and 6 bulls, as well as 39 stockers/grassers. The pasture quality was considered good, and average daily gain was 1 kg/day. The grazing period was considered to be 8 months. The actual stocking rates per pasture were extrapolated to reflect the historically likely usage pattern.

### 3.2.6 Mitigation Strategy

In this study, an LCA investigation, utilizing a Holos model, was chosen 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 in particular was very relevant, as there are currently reseeding activities underway in certain sectors of the Lac Du Bois grasslands.

This research investigated two methods of grassland pasture management practices that have shown to be effective in improving carbon sequestration potential: Improved Pasture Management (IPM), and, Reduced Grazing Intensity (RGI) (Paustian 2006). This LCA dealt with components of both. Opportunities to mitigate GHG emissions that were tested by the Holos model which are particularly relevant to the Lac Du Bois grasslands include: improved grazing/pasture management (stocking density); improved pasture quality through reseeding; and improvements in soil fertility through fertilization.

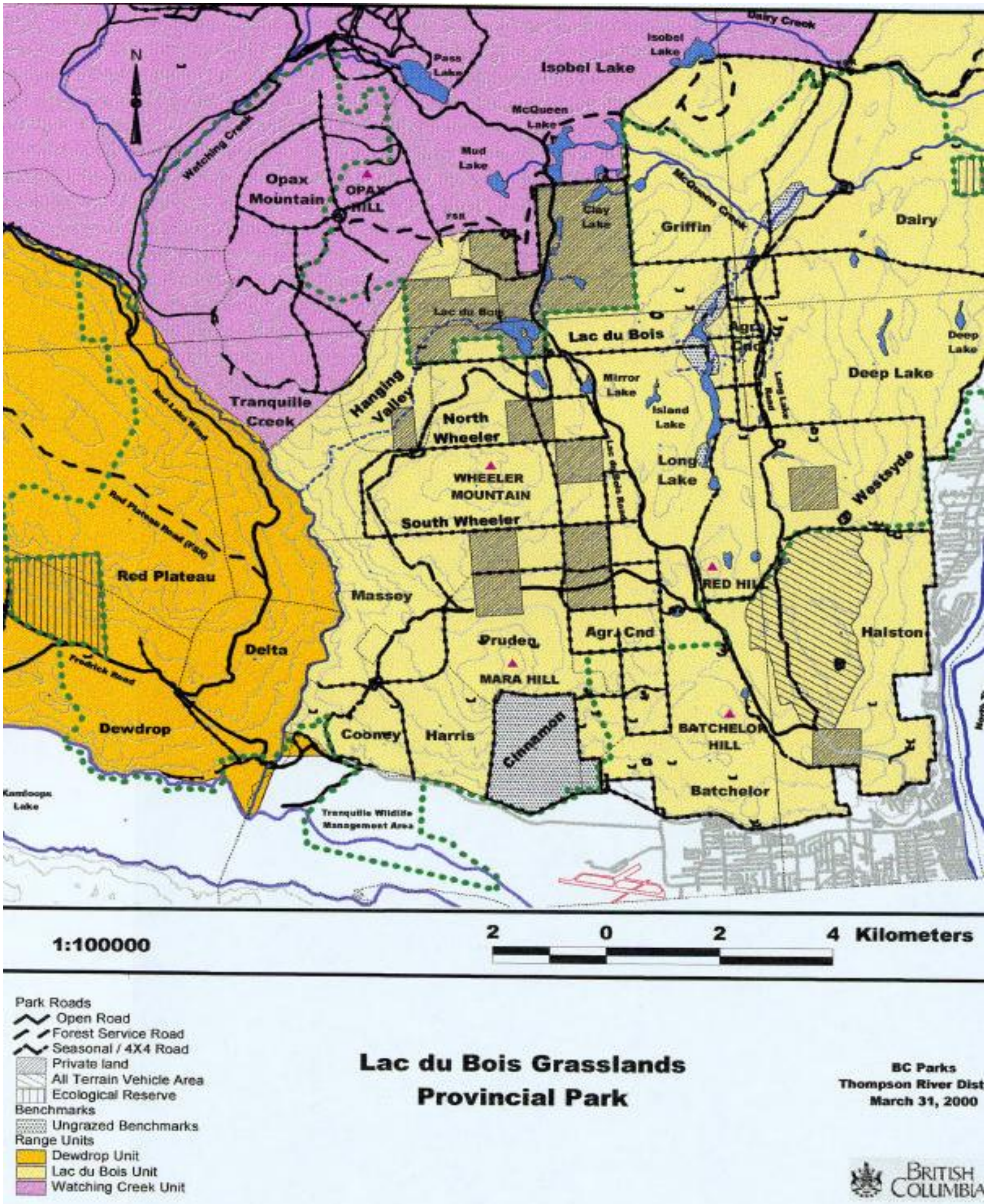


**Figure 3.1.** Grazing Pastures and Fences

### 3.2.7 – Pasture Management/Improvement Scenarios

Different scenarios associated with the pasture management/improvement approaches that were explored with Holos included:

**<u>Group 1:</u>**

i. Scenario 0 – Baseline
ii. Scenario 1a – animal stocking density reduction of 10% on Lac Du Bois grasslands.
iii. Scenario 1b – animal stocking density reduction of 25% on Lac Du Bois grasslands.
iv. Scenario 1c – animal stocking density reduction of 50% on Lac Du Bois grasslands.

**<u>Group 2:</u>**

i. Scenario 0 – Baseline
ii. Scenario 2a – reseed 10% of Lac Du Bois grasslands.
iii. Scenario 2b– reseeding 25% of Lac Du Bois grasslands.
iv. Scenario 2c – reseeding 50% of Lac Du Bois grasslands.

Note: reseed considered 6-10 years old.

**<u>Group 3:</u>**

i. Scenario 0 – Baseline
ii. Scenario 3a – reseeding 10% of Lac Du Bois grasslands, plus addition of synthetic fertilizer at rate of 50lbs N and 20lbs P/ha on reseed.
iii. Scenario 3b – reseeding 25% of Lac Du Bois grasslands, plus addition of synthetic fertilizer at rate of 50lbs N and 20lbs P/ha on reseed.
iv. Scenario 3c – reseeding 50% of Lac Du Bois grasslands, plus addition of synthetic fertilizer at rate of 50lbs N and 20lbs P/ha on reseed.

Note: reseed considered 6-10 years old.

### 3.3 Results:

#### 3.3.1 Baseline Results

The emissions from the 232 cow/calf pairs, 6 bulls and 39 stockers/grassers that occurred in the baseline scenario are shown in Table 3.1. The emissions associated with enteric fermentation are produced as a by-product of digestion in the rumen of the animals, as carbohydrates are broken down for energy and escape the animal through exhalation, eructation and/or flatulation. The emissions were calculated for each class of cattle according to the IPCC (2006) Tier 2 methodology. Daily net energy requirements were estimated from energy expenditures for maintenance, activity, growth, pregnancy, and lactation as appropriate. The gross energy intake required to meet energy requirements was then estimated taking into account the energy density of the diet, and enteric $CH_4$ was calculated from gross energy intake using $CH_4$ conversion factors (Ym) for each diet. The direct $N_2O$ emissions emanate from the livestock manure. Methane emissions attributed to manure are based on volatile solids production, according to IPCC (2006), taking into account the gross energy intake of the animals, and the digestibility of the diet. Manure N was estimated from dry matter intake (DMI) and the crude protein content of the diet, and the N retention of the animals based on IPCC (2006) and NRC (2000). Manure N content was multiplied by an emission factor to reflect the manure being deposited on the pasture to calculate the direct $N_2O$ emissions IPCC (2006). The indirect $N_2O$ emissions are attributed to nitrogen loss associated with volatilization and ground and surface water leaching and run-off, after loss from the grasslands. These emissions were estimated from the assumed fractions of N lost from manure and plant biomass residues, as adjusted for climatic conditions and the IPCC (2006) emission factor.

**Table 3.1.** Baseline Scenario (Mg $CO_2$ eq)

| Category | Enteric $CH_4$ | Manure $CH_4$ | Direct $N_2O$ | Indirect $N_2O$ | Soils $CO_2$ | Subtotals |
|---|---|---|---|---|---|---|
| **Livestock** | 668.3 | 14.2 | 347.7 | 41.4 | | 1,071.6 |
| **Soils** | | | | | | |
| **Total Emissions** | | | | | | 1,071.6 |

### 3.3.2 Group 1 Results – Stocking Density (SD) Reduction

Table 3.2 and Figure 3.2 reflect the impact on the emissions created as a direct result of reducing the cattle stocking density from the baseline scenario (277 animals) by 10% (250 animals), 25% (208 animals) and 50% (139 animals) respectively. The relationships between the values as reported by Holos follow a clear linear reduction in emissions. In the baseline scenario the percentages of the total emissions from enteric and manure $CH_4$ were 62.4% and 0.3%, respectively, and the direct and indirect $N_2O$ emissions were 32.4% and 3.9%, respectively. The corresponding shares of the total emissions in each stocking density scenario remained constant. The $CH_4$ emissions from enteric fermentation were observed to be the most prevalent (62.4%); the direct $N_2O$ emissions from manure were the second most important (32.4%); the indirect $N_2O$ associated with off-farm emissions (volatilization, leaching, run-off) were the third most important (3.9%); and the manure $CH_4$ emissions were the least (1.3%). Holos did not report any $CO_2$ emissions associated with the soils; no change in these emissions is consistent with Holos assuming that unimproved, native grasslands are in a “steady state”, hence no net carbon reduction or accumulation.

The reduction in emissions from each source also followed a consistent pattern. The overall reduction in emissions from each source was approximately 50.7% from baseline scenario to scenario 3c, mimicking the SD reduction of 50%. The reduction from baseline to scenario 1a (SD -10%) was 10%. The reduction from scenario 1a to 1b (SD -15%) was 16.4% for all sources except manure $CH_4$, where the reduction was 17.2%. The reduction from scenario 1b to 1c (SD -25%) was 34.4%.

**Table 3.2.** Group 1 Results – Stocking Density Reduction (Mg $CO_2$ eq)

| Scenario # | Category | Enteric $CH_4$ | Manure $CH_4$ | Direct $N_2O$ | Indirect $N_2O$ | Soils $CO_2$ | Subtotals |
|---|---|---|---|---|---|---|---|
| 0 | Baseline | 668.3 | 14.2 | 347.7 | 41.4 | | 1,071.6 |
| 1a | SD -10% | 601.3 | 12.8 | 312.8 | 37.3 | | 964.2 |
| 1b | SD -25% | 502.4 | 10.6 | 261.4 | 31.2 | | 805.6 |
| 1c | SD –50% | 329.7 | 7.0 | 171.6 | 20.4 | | 528.7 |

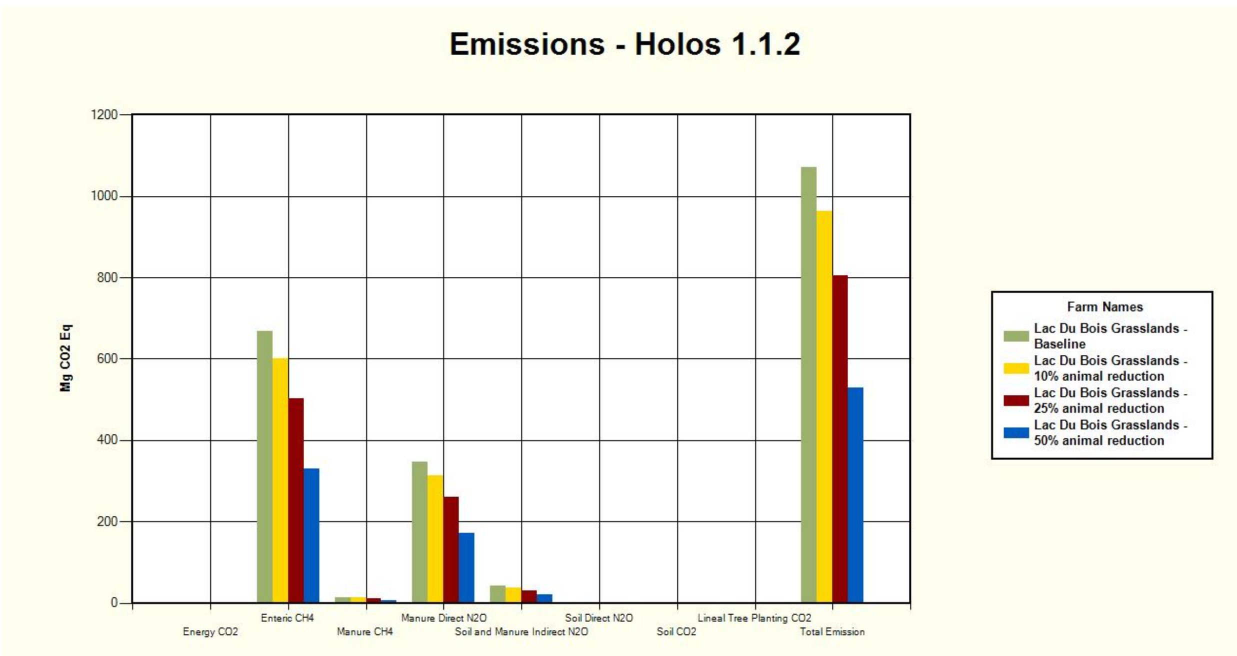


**Figure 3.2.** Group 1 Results – Stocking Density Reduction

### 3.3.3 Group 2 Results – Reseeding

Tables 3.3, 3.4 and 3.5, and Figure 3.3 reflect the impact on the emissions as a direct result of improving the grassland by reseeding 10% (757 ha), 25% (1,892 ha) and 50% (3,783 ha) of the land area respectively. The emissions associated with the livestock remain the same as the baseline scenario, as there is no change in livestock population.

Holos recognizes that through adoption of management practices, such as grassland renovation, these lands can contribute to overall emission reductions by removing carbon from the atmosphere, thus serving as a carbon sink. The negative soils $CO_2$ values suggest sequestration of atmospheric C. The model, which reports the reduction in soil $CO_2$, also follows a linear reduction consistent with the management change associated with the scenarios investigated. Holos reports a consistent reduction of 2.12 Mg $CO_2$ eq/ha across each scenario. For example, reseeding 10% (757 ha) of the area created a soil $CO_2$ reduction of -1,605.2 Mg $CO_2$ eq, resulting in an overall reduction of -533.6 Mg $CO_2$ eq.

Some overall assumptions had to be introduced into the modeling exercise in order to account for the limitations inherent in Holos when investigating the effects of improving the Lac Du Bois grasslands. It is assumed the reseeding 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)*. The introduction of these legumes and grasses are consistent with the existing improvement activities on the grasslands. Holos also did not account for any primary $CO_2$ emissions resulting from the reseeding activities (i.e. fossil fuel combustion etc.).

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 3.3.** Scenario 2a – reseed 10% (757 ha) of Lac Du Bois grasslands (Mg $CO_2$ eq).

| **Category** | **Enteric $CH_4$** | **Manure $CH_4$** | **Direct $N_2O$** | **Indirect $N_2O$** | **Soils $CO_2$** | **Subtotals** |
|---|---|---|---|---|---|---|
| **Livestock** | 668.3 | 14.2 | 347.7 | 41.4 | | 1,071.6 |
| **Soils** | | | | | -1,605.2 | -1,605.2 |
| **Total Emissions** | | | | | | -533.6 |

**Table 3.4.** Scenario 2b – reseed 25% (1,892 ha) of Lac Du Bois grasslands (Mg $CO_2$ eq).

| **Category** | **Enteric $CH_4$** | **Manure $CH_4$** | **Direct $N_2O$** | **Indirect $N_2O$** | **Soils $CO_2$** | **Subtotals** |
|---|---|---|---|---|---|---|
| **Livestock** | 668.3 | 14.2 | 347.7 | 41.4 | | 1,071.6 |
| **Soils** | | | | | -4,012.1 | -4,012.1 |
| **Total Emissions** | | | | | | -2,940.5 |

**Table 3.5.** Scenario 2c – reseed 50% (3,783 ha) of Lac Du Bois grasslands (Mg $CO_2$ eq).

| Category | Enteric $CH_4$ | Manure $CH_4$ | Direct $N_2O$ | Indirect $N_2O$ | Soils $CO_2$ | Subtotals |
|---|---|---|---|---|---|---|
| Livestock | 668.3 | 14.2 | 347.7 | 41.4 | | 1,071.6 |
| Soils | | | | | -8,022.0 | -8,022.0 |
| Total Emissions | | | | | | -6,950.4 |

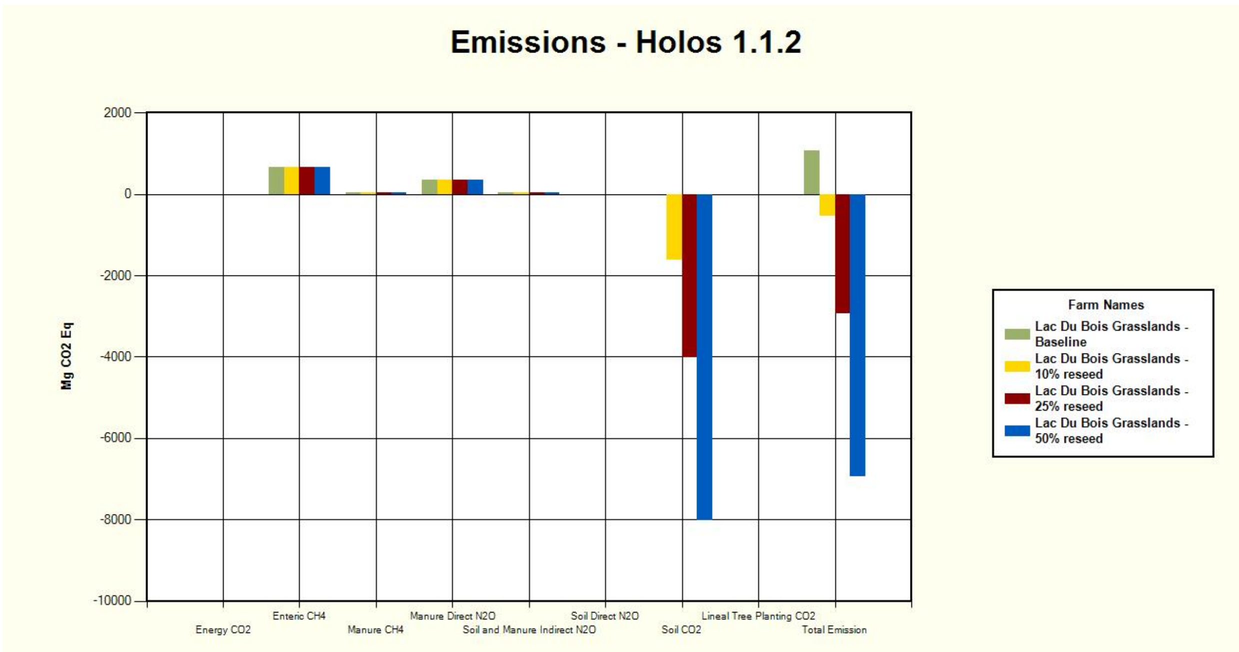


**Figure 3.3.** Group 2 Results - Reseeding

**3.3.4 Group 3 Results – Reseeding with Fertilizer:**

Tables 3.6, 3.7 and 3.8 reflect 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.

In Scenario 3a, as compared to Scenario 2a, the addition of the fertilizer improved the pasture quality, which resulted in a reduction in livestock related emissions of 26.8 Mg $CO_2$ eq or 2.5%, and a further removal of soil $CO_2$ of 78.5 Mg $CO_2$ eq or 4.8%.

In Scenario 3b, as compared to Scenario 2b, the fertilizer application resulted in a reduction in livestock related emissions of 37.1 Mg $CO_2$ eq or 3.5 %, and a further removal of soil $CO_2$ of 78.4 Mg $CO_2$ eq or 2.0%.

In Scenario 3c, as compared to Scenario 2c, fertilization resulted in a reduction in livestock related emissions of 45.8.0 Mg $CO_2$ eq or 4.3%, and a further removal of soil $CO_2$ of 80.6 Mg $CO_2$ eq or 1.0%.

The Group 3 scenarios now report direct and indirect soils $N_2O$ emissions created as a result of the synthetic nitrogen fertilizer applications. The direct $N_2O$ emissions are related to the processes of nitrification and denitrification, with the amount of $N_2O$ produced roughly proportional to the amount of nitrogen added to the soil. The direct $N_2O$ emissions are reported to be 80 kg $CO_2$ eq/ha on a linear relationship to the volume of fertilizer and area treated across all three scenarios. The indirect $N_2O$ emissions are off-farm $N_2O$ released from N lost from the farm 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 climatic conditions and the IPCC (2006) emission factor. The indirect $N_2O$ emissions are reported to be 30 kg $CO_2$ eq/ha, again a linear relationship to the volume of fertilizer and area treated across all three scenarios.

The presence of the fertilizer related direct and indirect $N_2O$ emissions reduced the net sequestration effect by approximately 5% in all scenarios. Holos reports the removal of 2.11, 2.05 and 2.03 Mg $CO_2$ eq/ha of emissions in scenarios 3a, 3b and 3c respectively, when fertilizer was used vs. the removal of 2.12 Mg $CO_2$ eq/ha of emissions when reseeding activities did not include the addition of fertilizers.

Holos has also reported energy $CO_2$ emissions of 0.19 Mg $CO_2$ eq/ha in each scenario. These secondary source emissions are directly associated with the manufacture of synthetic fertilizers. It is important to point out, however, that Holos did not account for any primary $CO_2$ emissions resulting from the reseeding activities (i.e. fossil fuel combustion etc.).

The most notable differences in the Group 3 results compared to the Group 2 results reside in the reductions in the livestock related emissions and the additional soil $CO_2$ removals. Livestock related $CH_4$ and $N_2O$ emissions were reduced an additional 3.4% on average across the three scenarios; soil related $CO_2$ levels were reduced by a further 2.6% on average across the three scenarios.

**Table 3.6.** Scenario 3a – reseeding 10% of Lac Du Bois grasslands, plus 50lbs N and 20lbs P/ha on reseed (Mg $CO_2$ eq).

| Category | Enteric $CH_4$ | Manure $CH_4$ | Direct $N_2O$ | Indirect $N_2O$ | Soils $CO_2$ | Energy $CO_2$ | Subtotals |
|---|---|---|---|---|---|---|---|
| **Livestock** | 651.6 | 13.8 | 338.9 | 40.5 | | | 1,044.8 |
| **Soils** | | | 61.4 | 25.6 | -1,683.7 | | -1,596.7 |
| **Cropping** | | | | | | 151.6 | 151.6 |
| **Total Emissions** | | | | | | | -400.3 |

**Table 3.7.** Scenario 3b – reseeding 25% of Lac Du Bois grasslands, plus 50lbs N and 20lbs P/ha on reseed (Mg $CO_2$ eq).

| Category | Enteric $CH_4$ | Manure $CH_4$ | Direct $N_2O$ | Indirect $N_2O$ | Soils $CO_2$ | Energy $CO_2$ | Subtotals |
|---|---|---|---|---|---|---|---|
| **Livestock** | 645.2 | 13.7 | 335.6 | 40.0 | | | 1,034.5 |
| **Soils** | | | 149.2 | 62.1 | -4,090.5 | | -3,879.2 |
| **Cropping** | | | | | | 368.2 | 368.2 |
| **Total Emissions** | | | | | | | -2,476.5 |

**Table 3.8.** Scenario 3c – reseeding 50% of Lac Du Bois grasslands, plus 50lbs N and 20lbs P/ha on reseed (Mg $CO_2$ eq).

| Category | Enteric $CH_4$ | Manure $CH_4$ | Direct $N_2O$ | Indirect $N_2O$ | Soils $CO_2$ | Energy $CO_2$ | Subtotals |
|---|---|---|---|---|---|---|---|
| **Livestock** | 639.8 | 13.5 | 332.8 | 39.7 | | | 1,025.8 |
| **Soils** | | | 295.5 | 123.1 | -8,102.6 | | -7,684.0 |
| **Cropping** | | | | | | 729.4 | 729.4 |
| **Total Emissions** | | | | | | | -5,928.8 |

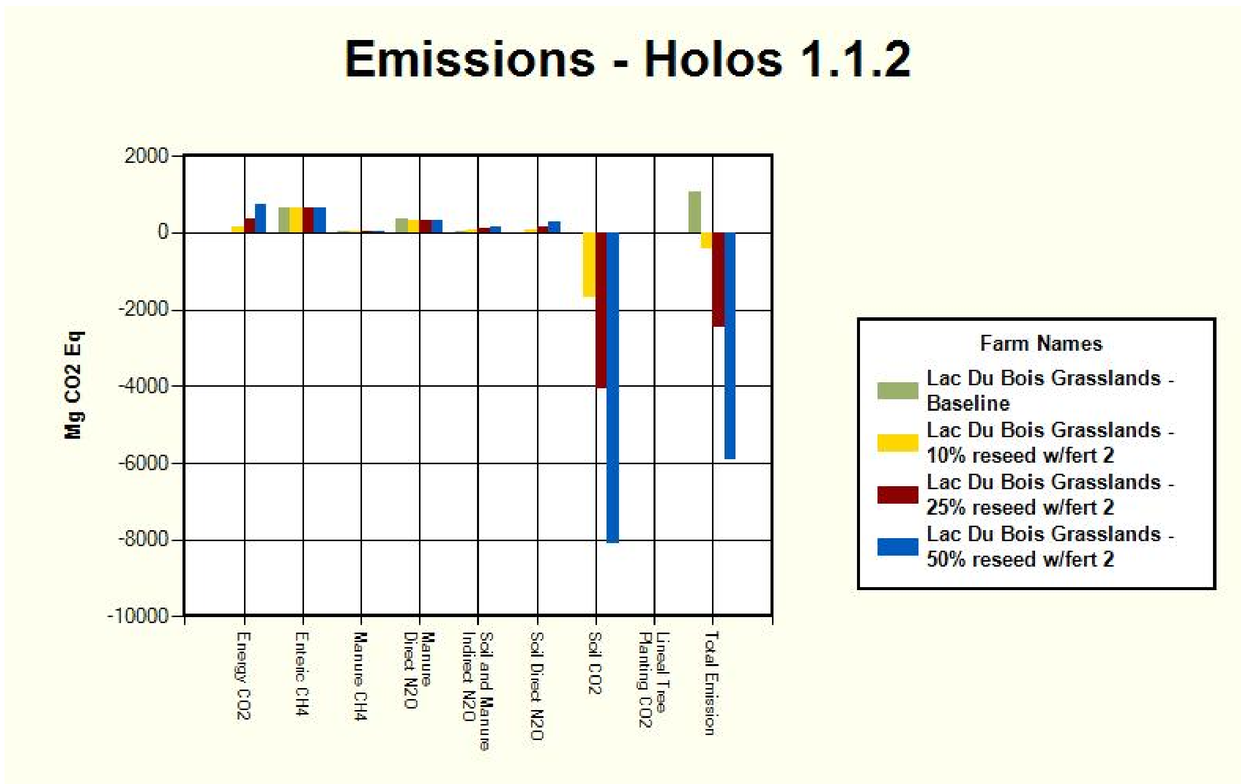


**Figure 3.4.** Group 3 Results – Reseeding with Fertilizer

**3.4 Discussion**

**3.4.1 Pasture Management – Grazing Intensity**

Our first LCA model (Group 1) investigated the impact on GHG emissions as a result of reducing the stocking density (SD) on the grasslands. Holos reported a direct linear relationship between SD and emissions of livestock related GHG's. A stocking density reduction of 10% resulted in a reduction in GHG $CO_2$ eq. levels of the same magnitude, and so on.

While Holos reported direct livestock related emissions, it did not report any changes in soil $CO_2$ levels, (sequestration removals) associated with stocking density and/or grazing intensity. Rangeland research over the past 15-20 years has focused on assessing the effects of management practices on soil C dynamics. Schuman, Janzen, & Herrick (2002) observed that soil organic C reserves in a given rangeland ecosystem will eventually approach a steady state, and a shift in management, environment or inputs would be required to increase the potential for additional soil C sequestration.

Changes in stocking density and grazing intensity on the grasslands are management techniques that can affect changes in soil $CO_2$. There have been a number of studies supporting the relationship between reductions in grazing intensity and net C removals through sequestration, which would suggest a limitation in the Holos model.

For example, (Reeder & Schuman, 2002) evaluated five rangeland grazing treatments: non-grazed enclosures; continuous season-long grazing at a light (22 steer-day/$ha^{-1}$) stocking rate; and, rotationally deferred, short-duration rotation, and continuous season-long grazing, all three at a heavy stocking rate (59 steer-day/$ha^{-1}$). They found that compared to the enclosures, all grazing treatments resulted in significantly higher levels of C (6-9,000 kg/$ha^{-1}$) in the surface 15 cm of the soil. They further surmised that the higher levels of soil C with grazing are likely the result of faster litter decomposition, recycling and redistribution of C within the 0-60 cm plant-soil system. Grazing at an appropriate stocking rate had beneficial effects on plant composition, forage production, and soil C sequestration. Without grazing, deterioration of the plant-soil system was observed (Reeder & Schuman, 2002). Holos did not report any change in soil C in the Group 1 stocking density reduction scenarios.

In addition, Derner, Briske, & Boutton (1997) found that grazing of the shortgrass steppe in Colorado at a moderate stocking rate resulted in increased soil organic C compared to ungrazed enclosures. They found 19.8 MT C/ha in the surface 15 cm of the soil under grazing and only 13.2 MT C/ha in the ungrazed enclosure, but found no differences in soil C in the 15-30 cm soil depth between grazed and ungrazed areas. They further estimated the rate of C sequestration attributable to moderate grazing would be 0.12 MT C/ha/yr. The grazing intensity in our baseline scenario on the Lac Du Bois grasslands would be classified as moderate to light (27 animals/ha). If we apply Derner et al.'s rate of C removal to our baseline scenario on the Lac Du Bois grasslands, we calculate the C sequestration to be 908 MT C/ha/yr. or approximately 3,300 Mg $CO_2$ eq – Holos reports none.

As another example, Schuman, Reeder, Manley, Hart, & Manley (1999) found that twelve years of light or heavy grazing in a northern mixed-grass prairie increased soil organic C in the surface 30 cm of the soil compared to non-grazed enclosures. They estimated the C sequestration rate to be about 0.30 MT C/ha/yr compared to the ungrazed enclosures. Extrapolating these findings to our baseline scenario again, this would translate into 8,330 Mg $CO_2$ eq – equivalent to the quantity of soil $CO_2$ removed as a result of reseeding 50% of the Lac Du Bois grasslands as reported in scenario 2c in our Holos model.

Bruce et al. (1999) has shown livestock grazing, as the predominant agricultural activity on grasslands, has the potential to alter the quantity and quality of carbon input to the system by affecting the species composition, structure and functioning of grassland ecosystems. Grazing facilitates the physical breakdown, soil incorporation and rate of decomposition of residual plant material. Grazing intensity and frequency are thought to cause the primary effects on C storage across rangelands, although these effects are often inconsistent and difficult to predict (Reeder & Schuman, 2002). For example, Gao, Luo, Wu, Chen, & Wang (2008) found that livestock grazing has the potential to substantially alter carbon storage in grassland ecosystems. They determined heavy grazing intensity leads to higher levels of soil organic C and total plant components C through changes in species composition. Heavy grazing markedly decreased vegetation cover and aboveground biomass, undesirable for livestock production and sustainable grassland development.  Which, without proper management, leads to deterioration of the plant-soil system, and possible declines in C sequestered in the soil. On the other hand, Schuman et al. (1999) also found that season long, moderate and heavy stocking rates in the northern mixed-grass prairie resulted in a shift in plant community composition. The proportion of cool-season ($C_3$) grasses were reduced, and replaced by a plant community dominated by the warm-season ($C_4$) species, blue grama (*Bouteloua gracilis*). They concluded reducing the $C_3$ grasses lowers the production potential of the rangelands, but because blue grama transfers more C to the below ground plant parts, and has a more fibrous root system with greater root to shoot ratio, increases in overall C were observed. Ogle, Breidt, & Paustian (2005) observed soil organic C tended to be higher in grazed vs. ungrazed treatments, and that C storage was dependent upon the moisture regime. Contradictory to our modeling results, McCaughey, Wittenberg, & Corrigan (1997) found $CH_4$ production was greatest for steers continuously grazed at low stocking rates (1.1 steer/ha$^{-1}$; 307 L/d$^{-1}$) and least for steers grazing continuously at high stocking rates (2.2 steer/ha$^{-1}$; 242 L/d$^{-1}$). A possible explanation for these observed results for the higher stocking rates may be due to lower forage availability and intake for the grazing animal (i.e. less feed). When pastures were rotationally grazed, stocking rates had no effect on $CH_4$ production. At low stocking rate, $CH_4$ production was 9% lower on rotational grazing than continuous grazing.

Clearly, addressing issues such as how the grassland species composition and environmental factors influences soil carbon dynamics as a result of cattle grazing is extremely difficult and complex, and currently outside of the realm of existing modeling approaches using tools such as Holos.

### 3.4.2 Pasture Management – Reseeding effects on Removal and Reduction of GHG Emissions

In our Group 2 scenarios, we investigated the impact on GHG emissions associated with improving the grasslands through a process of reseeding. Scenario's 2a, 2b and 2c modeled the GHG emissions impact as a result of reseeding areas equivalent to 10%, 25% and 50% of the 7,655 ha in our study area respectively. The overall premise of the model was that the areas were interseeded using a minimally invasive no-till operation to improve the forage through the introduction of new grasses and legumes. It was assumed in the model that the reseeding took place 6-10 years previous.

In the baseline scenario in our LCA, there is no change in soil $CO_2$ levels, suggesting that the native grasslands do not remove any atmospheric C, hence no sequestration. As previously mentioned, Holos assumes that native grasslands are in a steady-state, and are essentially carbon neutral. This perspective is consistent with the current widely held paradigm that the ecosystem will reach a “steady state” and a change in management and/or inputs would be required to sequester additional C (Conant, Paustian, & Elliott, 2001; Conant, Six, & Paustian, 2003; Post et al., 2004; Schuman et al., 2002; Swift, 2001).

Where improvements occur, Holos recognizes changes in net GHG emissions. In the case of Group 2, Scenario 2a for example, improving 10% of the land area resulted in a net removal of 533.6 Mg $CO_2$ eq, more than offsetting the 1,071.6 Mg $CO_2$ eq created as a result of the livestock activity on the native grasslands. In each scenario, the removal of soil $CO_2$ is calculated to be 2.12 Mg $CO_2$ eq/ha.

Holos also did not report any primary energy related $CO_2$ emissions resulting from the reseeding activity itself. This appears to be a limitation in Holos, and how well it can adapt to our unique grassland application. We clearly know the physical activity of reseeding is not carbon neutral, and there would be some emissions created through burning of fossil fuels.

Other studies have also displayed how management changes can impact soil/plant carbon levels. Mortenson, Schuman & Ingram (2004) demonstrated interseeding of yellow-flowered alfalfa (*Medicago sativa* ssp. *Falcata*) into northern mixed-grass prairie increased organic C storage by 4, 8, and 17% in a 1998, 1987, and 1965 interseeding, respectively. This resulted in C sequestration rates of 1.56, 0.65, and 0.33 MT C/ha/yr, for the 1998, 1987, and 1965 interseeding respectively. This data demonstrate that C sequestration rates will be greater immediately after initiation of a new management practice because of the lower inherent C levels. The above C sequestration rates convert into 5.73, 2.39 and 1.21 Mg $CO_2$ eq/ha/yr for 6, 17 and 39 yr old reseeding activities respectively. Our Holos model reported C sequestration rates of 2.12 Mg $CO_2$ eq/ha/yr for a reseeding improvement conducted 6 – 10 years ago. Holos would seem to have underestimated the rates compared to this empirical research, but it is at least still within reason.

Conant et al. (2001) conducted an analysis of 115 pasture and grazing-land studies worldwide and found that soil C levels increase with improved management (i.e. fertilization, grazing management, and conversion from cultivation or native vegetation) and that the greatest C sequestration occurs during the first 40 years of implementation of the management practice. Further, except for a single irrigated study, they found the conversion of cultivated land to grazing land resulted in an average annual increase in SOC of 3-5%. Research has shown that returning cultivated land back to grassland is where some of the highest rates of C sequestration may occur, because of heavily degraded lands and associated low SOM levels. This study reports annual rates of 3-5%; Holos reported annual rates of 0.58 Mg C/ha/yr for grassland renovation. We would expect grassland renovation rates to be lower than land conversion rates.

Conant et al. (2001) also found that within established pastures, soil C can be increased by reducing disturbances to the soil and by increasing primary production of forages. A variety of management practices have evolved to increase forage production for livestock (which also have the potential to increase SOM). It is felt that as forage production increases, an ancillary benefit may be increased sequestration of atmospheric carbon. Introduction of legumes into native grasslands of the Northern Great Plains has been the subject of research for years. It has been estimated that 70% of the native rangelands in North America were in fair to poor condition, and that 10Mha of Canadian rangelands could benefit from the introduction of a legume into the system (Kruger and Vigil 1979). Our Group 2 scenarios show 0.58 Mg/ha of soil C was accumulated as a result of our minimally invasive no-till seeding of additional grasses and legumes, enhancing the forage quality and quantity in the treated areas.

Soil carbon dynamics and sequestration involve complex interactions involving environmental factors, soils, plant communities and management. The scientific community admittedly has only a rudimentary knowledge of these interactions as controlling drivers influencing soil C sequestration (Schuman et al., 2002). There is evidence to support that the relative contribution of management practices can be lower compared to climatic drivers (Ingram et al., 2008). Each combination of land-use history, climate, edaphic factors, and vegetation type leads to a different response of soil carbon to changes in management. Modeling exercises such as this one help increase the understanding of this variation, and provides insight into the relationships among environmental factors and carbon sequestration (Post et al., 2004) A quantitative understanding of the relationships among environmental factors and SOM dynamics is most often formulated in SOM models such as CENTURY (Parton, Stewart, & Cole, 1988), ROTHC (Rothamsted carbon model) (Jenkinson, Andrew, Lynch, Goss, & Tinker, 1990), and EPIC (erosion productivity impact calculator) (Izaurralde, Williams, McGill, Rosenberg, & Jakas, 2006). Holos did endeavor to account for these climatic variables, and utilizes the CENTURY model to assist in calculating carbon dynamics.

### 3.4.3 Pasture Management – Effects of Fertilization

In our Group 3 scenarios, we took the Group 2 conditions, and endeavored to model the impacts on GHG emissions resulting from adding fertilizer inputs. This management practice improved the productivity of the grasslands and also had an effect on the overall GHG emissions on the grasslands.

Most notably in the group 3 scenarios, we observed marginal reductions in livestock related emissions, and additional soil $CO_2$ removals. The additional pasture improvement resulting from a nutrient amendment has translated into an improved and more vigorous forage spectrum. The addition of nutrient amendments, such as synthetic fertilizers can improve forage productivity, which can ultimately enhance sequestration, but there are also increased financial costs and GHG emissions associated with this practice. Holos also reported proportional increases in both direct and indirect soil $N_2O$ levels, corresponding to the application of the synthetic fertilizers. These emissions reduce the net soil $CO_2$ eq benefit by 0.53%, 3.3% and 4.2% in scenario's 3a, 3b, 3c respectively. The modeling reports the presence of secondary energy $CO_2$ emissions, directly associated with the manufacture of the fertilizers, which slightly reduce the overall net soil $CO_2$ eq benefit.

It has been shown that many rangelands are nutrient deficient, particularly nitrogen (N) deficient, and have shown to exhibit increased production and water use efficiency in response to nutrient amendments. Grassland fertilization has been used for centuries to increase forage production (Johnston, Poulton, & Coleman, 2009). Fertilization can result in increased below-ground production as well as above-ground production, which can lead to increased soil carbon.

Further, studies have supported that pasture and grazing management offers the potential to reduce GHG emissions through practices which ultimately provide cattle with improved forage quality. It is generally recognized that $CH_4$ production in ruminants generally increases with forage maturity and that $CH_4$ yield from the ruminal fermentation of legume and legume/grass forages is generally lower than the yield from grass forages. The explanation for the reduced $CH_4$ emissions can be attributed to the lower proportion of structural carbohydrates in legumes and faster rate of passage, which shift the fermentation pattern towards higher propionate production (Johnson & Johnson, 1995). In our model we included legumes in the reseed mix vs. a grass mix only to ensure we optimized our pasture improvement to realize the full emissions reduction benefit. Studies have shown pasture quality is the critical factor in reducing $CH_4$ emissions from grazing animals, however when endeavoring to develop best management practices (BMP), it is important to remember that the grazing animal's ability to select its diet will have a major effect on its performance and $CH_4$ production (Iwaasa, 2007).

Chaves et al. (2006) concluded that methane production by grazing beef heifers was significantly affected by pasture type, depending on site. Among their observations was that as forage stands matured, their feed value decreased and methane emissions increased; and pasture composition also impacts methane emissions and cattle performance. McCaughey, Wittenberg, & Corrigan (1999) found that when pastures are managed to ensure forage quality is high, methane production per unit basis of beef production can be reduced as much as 20% compared to poor quality forage. Boadi, Wittenberg, & McCaughey (2002) observed early grazing of alfalfa/grass pastures reduced $CH_4$ production 29 – 45% in steers compared to grazing at mid to late seasons. In our modeling, we assumed the feed quality was good on the grasslands at the outset. Pasture renovation through reseeding and the addition of fertilizer would contribute to additional improvements in feed quality. We were not starting with poor quality feed (consistent with our feed quality analysis as described in Chapter 2), so we would not expect the levels of $CH_4$ reduction as described in the aforementioned studies. At the same time, Holos did report some reductions, which were anticipated.

In addition, to determine the impacts of improving pastures, Kopp, McCaughey, & Wittenberg (2003) conducted a study on the effects of forage type and fertilization on yield and quality of dryland pastures on the Canadian prairies. The studied pastures contained either meadow bromegrass or a mix of alfalfa and meadow bromegrass that were either fertilized or unfertilized. Incorporating the alfalfa into grass pastures improved carrying capacity by 28% and met the nutritional requirements of lactating beef cows at no additional cost. The fertilization of meadow bromegrass pastures improved carrying capacity by 64% and met the nutritional requirements of lactating beef cows. Incorporating alfalfa with fertilization improved carrying capacity of pasture by 57% and met the nutritional requirements of lactating beef cows. They concluded that incorporating alfalfa and fertilizing or just fertilizing the meadow bromegrass pastures included significant financial risk as they were only cost-effective strategies when precipitation was not limiting. The only treatment that did not have financial risk and was always a cost effective treatment was the incorporation of the alfalfa into the meadow bromegrass. Our Holos model reported an emissions reduction response as a result of improving the pastures through: enhancing the forage with legumes; and increasing soil fertility/productivity through fertilization.

Further, soil C increases were generally greater with higher levels of fertilization, though this is not always the case (Hassink, 1994). The variability in the results reported in the literature can be significant. Our Holos Group 3 model reported 0.61, 0.59 and 0.58 MT C/ha removed in Scenarios 3a, 3b and 3c respectively. Turner, Blair, Schartz, & Neel (1997) found the addition of N fertilizer to the tallgrass prairie increased plant production and increased soil organic C by 1.6 MT C/ha after 10 years. Reeder, Schuman, & Bowman (1998) reported increases in soil organic C of 0.41 and 1.16 MT C/ha/yr in the surface 7.5 cm and 10 cm respectively, after 4 years of annual applications of 34 kg N/ha on two different CRP sites seeded to a mixture of native C3 grasses. Nyborg, Malhi, Solberg, & Izaurralde (1999) reported soil organic C increases of 5.4 to 9.3 MT C/ha occurred on a grassland in north-central Saskatchewan when both N and sulfur (S) were applied.

And finally, N fixation significantly increased the total soil N and aboveground production (Mortenson et al. 2004). Schuman, Ingram, & Parkin (2004) also found that the increased production created through N fixation accounts for the enhanced soil organic C storage and does not represent any "C costs" in the production of N, nor does it appear that the greater soil N increases $N_2O$ from soils that would offset the benefits to the atmosphere resulting from the increased C sequestration. Consequently, the benefits of increased soil C sequestration must be compared to the "C costs" associated with production of synthetic fertilizers, to assess whether there is any net beneficial effects on the atmosphere (Schlesinger, 1999). Our Holos model also reported direct and indirect $N_2O$ emissions corresponding to the application of nitrogen fertilizer, and these additional emissions did not offset the benefits of increased soil C sequestration. The inclusion of the legumes in a reseed mix will contribute to improved fertility through N fixation, while reducing the requirements for synthetic fertilizers through improved nitrogen fixation.

**3.5 Conclusion**

Changes in soil C 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 to those reported for croplands and improved pastures, increases in terrestrial C resulting from grazing management or the application of inputs account for a significant amount of carbon sequestration and a reduction in overall atmospheric carbon dioxide emissions because of the sheer size of this land resource.

As we have demonstrated in our study, which has been corroborated by a number of grazing studies in the literature, high quality pastures, and grazing best management practices (BMP) can contribute to reducing GHG emissions from cattle ranching. A number of other studies have examined the potential of grassland pastures to counteract the increase in atmospheric $CO_2$ through C sequestration in soils, hence removing GHG from the atmosphere. Our LCA is consistent with these previous research findings and demonstrated that the improvements applied to the native grassland pastures resulted in significant C sequestration.

Grasslands have high inherent soil organic matter (SOM) content that supplies plant nutrients, increases soil aggregation, limits soil erosion, and also increases cation exchange and water holding capacities (Miller & Donahue, 1990). As our modeling exercise has clearly demonstrated, maintenance of SOM is a key factor in the sustainability of grassland ecosystems and the ability to sequester carbon. Historically intensive cultivation has resulted in reductions of SOM to the atmosphere in the form of $CO_2$, including much of which was lost from native grasslands. SOM losses due to conversion of native grasslands to cultivation are well documented, and losses due to poor pasture management have also been observed (Conant et al., 2001). Through sound agricultural management it may be possible to reverse SOM losses, and consequently sequester greater volumes of atmospheric carbon.

We hypothesized that increased pasture management/improvement and reduction in stocking density in the Lac Du Bois grasslands should result in the removal of atmospheric $CO_2$ through carbon sequestration, and reduction of livestock related GHG emissions, ultimately resulting in an overall reduction in total GHG emissions. We observed both of these events in our modeling – our research using the Holos modeling tool supports our original hypothesis.

Like other models, Holos has many limitations and its outputs carry significant uncertainty. The unique parameters applied to Holos resulted in some obvious limitations being exposed. For example, we did not see livestock related emissions reductions in the Group 2 scenarios; only when fertilizer was added was this revealed. Further we did not see primary $CO_2$ emissions associated with equipment operation and field activities. In addition, Holos did not make it clear if the reseeding operation initially contributed to a loss of soil C as a result of some soil disturbance; how much (if any), and how long it took for the ecosystem to recover from this was not elucidated well. Notwithstanding, as illustrated in this study, modeling efforts such as this can provide conceptual guidance, and help to identify future research questions and directions. We felt overall Holos pointed us in right direction when endeavoring to determine what strategy might prove the most effective and have the greatest impact on reducing the overall environmental impact of livestock grazing activity on the Lac Du Bois grasslands. Our modeling exercise would suggest that manipulating the biomass through improving the forage quality of the grasslands provides the best “bang for the buck” when evaluating removing and reducing GHG emissions.

Ultimately, the acceptance of strategies for removing and reducing GHG emissions by land managers of grasslands will be a significant future factor in determining the rate of soil sequestration and level of total 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 unpriced environmental benefits. Using LCA modeling approaches such as we have done in this study with Holos can help provide insight into practices that are likely to be both operationally sound as well as 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 soil sequestration and emission reduction practices applied are 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.

# CHAPTER 4
# EXPLORING GREENHOUSE GAS EMISSION MITIGATION STRATEGIES IN AGRICULTURE, AND OPPORTUNITIES FOR BC RANCHERS TO MARKET CARBON OFFSETS.

## 4.1 Greenhouse gas mitigation in agriculture – the big picture

Global climate change has been attributed to increased emissions of greenhouse gases (GHG) such as carbon dioxide ($CO_2$), methane ($CH_4$) and nitrous oxide ($N_2O$) due to anthropogenic (human) activities (IPCC, 2006b). Atmospheric concentrations of these gases have increased by 31% for $CO_2$, 151% for $CH_4$ and 17% for $N_2O$ since 1750. The global warming potential of these gases are not equal, with methane being 23 times, and nitrous oxide being 310 times more efficient in trapping heat in the atmosphere than carbon dioxide (Smith et al., 2008).

Globally, agriculture accounts for 10 to 12% of total anthropogenic emissions of GHG's, but 84% of $N_2O$ and 52% of $CH_4$ anthropogenic emissions (Smith et al., 2008). In agriculture, carbon dioxide is released largely from microbial decay or burning of plant litter and soil organic matter (Janzen, 2004). Methane is produced when organic materials decompose in oxygen-deprived conditions, notably from fermentative digestion by ruminant livestock, stored manures and rice grown under flooded conditions (Mosier et al., 1998). Nitrous oxide is generated by the microbial transformation of nitrogen in soils and manures, and is often enhanced where available N exceeds plant requirements, especially under wet conditions (Smith & Conen, 2004).

In 2005, agriculture accounted for 7.6% of Canada's total GHG emissions, of which 50% is attributed to emissions from soils primarily due to $N_2O$ from fertilizer applications, 32% from ruminants due to $CH_4$ emissions from enteric fermentation and 17% from $N_2O$ emissions due to manure management (Environment Canada, 2008). In Australia, agriculture accounts for 16% of that country's total GHG emissions, with livestock accounting for two-thirds of agriculture emissions (Peters et al., 2010). In New Zealand agriculture represents 49% of all New Zealand's emissions and is dominated by $CH_4$ (66%) and $N_2O$ (34%) (Andrew & Forgie, 2008). As a result of agriculture's dramatic contributions to global GHG emissions, governments throughout the world are investigating strategies to reduce or mitigate GHG emissions.

Opportunities for mitigating GHGs in agriculture fall into three broad categories based on the following underlying mechanism:

1. **Reducing emissions**. The significant quantities of $CO_2$, $CH_4$ and $N_2O$ emissions released by agricultural activities can be reduced by managing more efficiently the flows of carbon and nitrogen in agricultural ecosystems (Cole et al., 1997). For example, practices that deliver added N more efficiently to crops often suppress the emissions of $N_2O$ (Bouwman, Boumans, & Batjes, 2002) and managing livestock to make the most efficient use of feeds often suppresses the amount of $CH_4$ produced (Beauchemin & McGinn, 2006). The approaches that best reduce emissions depend on local conditions, and specific management approaches will vary from region to region.

2. **Enhancing removals**. Agricultural ecosystems hold large reserves of C (Metz, Davidson, de Coninck, Loos, & Meyer, 2005), mostly in soil organic matter. Historically these systems have lost significant amounts of C, but some of this lost C can be recovered through improved management, thereby withdrawing atmospheric $CO_2$ (Lal, 2004). Any practice that increases the photosynthetic input of C or slows the return of stored C via respiration or fire etc. will increase stored C, thereby "sequestering" C or building C "sinks". Many studies have now shown that significant amounts of soil C can be stored in this way, through a range of practices suited to local conditions (Lal, 2004). Significant amounts of vegetative C can also be stored in agroforestry systems or other perennial plantings on agricultural lands. Agricultural lands also remove $CH_4$ from the atmosphere but this effect is small when compared with other GHG fluxes (Smith & Conen, 2004).

3. **Avoiding or displacing emissions.** Crops and residue from agricultural lands can be used as a source of fuel, either directly or after conversion to fuels such as ethanol or diesel (Melvin, 2003). These bioenergy feedstocks still release $CO_2$ upon combustion, but now the C is of recent atmospheric origin (via photosynthesis), rather than from fossil fuels.

The net benefit to these bioenergy feedstocks to the atmosphere is equal to the fossil-derived emissions displaced less any emissions from their production, transport and processing. Emissions of GHGs, notably $CO_2$, can also be avoided by agricultural management practices that reduce or eliminate the cultivation of new lands now under forest, grassland or other non-agricultural vegetation (Foley et al., 2005).

In agriculture, the many practices advocated to mitigate emissions through these mechanisms, are commonly known as beneficial management practices (BMP). BMP can promote good land stewardship and sustain or increase net economic return and they have been recommended to reduce global warming potential (Desjardins et al., 2001; Johnson, Franzluebbers, Weyers, & Reicosky, 2007). BMP are reported to improve C sequestration, reduce N losses to the environment (Jayasundara et al., 2007) and minimize aggregate stressors (i.e. nutrients, pesticides and sediments) to water bodies (Yates, Bailey, & Schwindt, 2007). The impacts of various important BMP or mitigation options are reviewed below:

1. **Cropland Management** – croplands, because they are often intensively managed, offer a number of opportunities to impose practices that reduce net emissions of GHGs. Mitigation practices in cropland management include the following categories:
    a. Agronomy – Improved agronomic practices that lead to increased yields and generate higher inputs of residue C can lead to increased C storage (Follett, Kimble, & Lal, 2001). Examples of such practices include: using improved crop varieties; extending crop rotations (especially those with perennial crops which allocate more C below ground); and avoiding or reducing use of bare fallow (Smith et al., 2008). Adding nutrients, when deficient, can encourage soil C gains, but the relative benefits from N fertilizer can be offset by higher emissions of $N_2O$ from soils and $CO_2$ from fertilizer manufacture (Gregorich, Rochette, VandenBygaart, & Angers, 2005). Emissions can also be reduced by adopting less intensive cropping systems which reduce usage of inputs. An important example is the use of rotations with legumes, which reduce requirements for direct N

applications, though legume derived N can also be a source of $N_2O$ (Ambrosi & Janzen, 2005).

A third group of agronomic practices that may reduce GHGs are those that provide temporary vegetative cover between agricultural crops. These “cover” crops add C to soils and may also extract plant available N unused by the preceding crop, consequently reducing $N_2O$ emissions (Freibauer, Rounsevell, Smith, & Verhagen, 2004).

b. Nutrient Management – In that nitrogen applied in fertilizers and manures is not always used efficiently by crops, improving this utilization can reduce emissions of $N_2O$ (generated by soil microbes) associated with the excess N. Further, it can directly reduce emissions of $CO_2$ from fertilizer manufacture (Schlesinger, 1999). Practices that improve N use efficiency include: adjusting application rates to conform to estimation of crop requirements; using slow release fertilizers; improving timing between N application and uptake; and placing N more precisely into the soil, which improves overall efficiency and excesses (Paustian, Six, Elliott, & Hunt, 2000).

c. Tillage/Residue Management – Developments in weed control techniques and improvements in farm machinery now allow many crops to be grown with “reduced tillage” or “no tillage” management systems. Since soil disturbance/cultivation tends to stimulate soil C losses through enhanced decomposition and erosion, reduced-till, or no-till agriculture normally (but not always) results in soil C gain (Gregorich et al., 2005). Adopting tillage reduction approaches may affect emissions of $N_2O$, which could be influenced by soil and climatic conditions. Management systems that endeavour to retain crop residues also tend to increase soil C because these residues are the precursors for soil organic matter, the main source of carbon in the soil.

d. Water Management – Approximately 20% of the world’s croplands now receive supplementary water through irrigation (Ahmed, 2002). Expanding this area or using more effective irrigation techniques can enhance C storage in soils through enhanced yields and residue returns (Lal, 2004). Some of these gains could be offset by $CO_2$ from energy used to deliver the water, or from $N_2O$ emissions from higher moisture and fertilizer N inputs (Liebig et al., 2005).

e. Rice production management – Cultivated wetland soils emit large quantities of $CH_4$ (Yan, Ohara, & Akimoto, 2003). Emissions during the growing season can be reduced. Draining the wetland rice once or more has been shown to reduce $CH_4$ emissions (Yan et al., 2003), though this benefit may be partly offset by higher $N_2O$ emissions, and this practice may be impractical if insufficient water supplies exist. Rice cultivars with low exudation rates could offer important methane mitigation options (Aulakh, Wassmann, & Rennenberg, 2001). Further, in the off-season, methane emissions can be reduced by improved water management, specifically, keeping the soil as dry as possible.

f. Agroforestry - Agroforestry is the production of livestock or food crops on land that also grows trees, either for timber, firewood or other tree products. These lands may include shelterbelts and riparian zones/buffer strips of woody species. The standing stock of carbon above ground is usually higher than the equivalent land use without trees, and planting trees may also increase the soil carbon sequestration, although the effects on $N_2O$ and $CH_4$ are not well known (Oelbermann, Voroney, & Gordon, 2004).

g. Land use change – One of the most effective methods of reducing emissions is to allow or encourage the reversion of cropland to another land cover, most notably one similar to the native vegetation. This type of conversion can encompass the entire land area, or well suited localized areas such as grassed waterways, field margins/perimeters or shelterbelts (Follett et al., 2001). Such land cover change often increases storage of C; for example, converting arable cropland to grassland typically results in the accrual of soil C owing to lower soils disturbance and reduced C removal in harvested products. Compared to cultivated lands, grasslands may also have reduced $N_2O$ emissions from lower N inputs and higher rates of $CH_4$ oxidation (Conant et al., 2001). Converting drained croplands back to wetlands can result in rapid accumulation of soil C (removal of atmospheric $CO_2$), although this conversion may stimulate $CH_4$ emissions because waterlogging creates anaerobic conditions. Since land cover/land use conversion comes at the expense of lost agricultural productivity, it is usually an option on surplus land, or on croplands with marginal productive capabilities. There have been government sponsored programs in both Canada and the US which have encouraged conversion of marginal lands back to their native condition, but these programs are costly and have met with limited success (Karlen et al., 1999).

2. **Grazing land/pasture management** – Grazing lands occupy much larger areas than croplands, but are usually managed less intensively. The following provides some examples of practices that could reduce GHG emissions and enhance removals.
   a. Grazing intensity – The intensity and timing of grazing can influence the growth, C allocation and flora of grasslands, thereby affecting the amount of C accrual in soils (Conant et al., 2001). Carbon accrual on optimally grazed lands is often greater than on ungrazed or overgrazed lands (Liebig et al., 2005). These effects have been shown to be inconsistent, owing to the many types of grazing practices employed and the diversity of plant species, soils and climates involved (Derner, Boutton, & Briske, 2006). The influence of grazing intensity on emission of non-$CO_2$ gases is not well established, apart from the indirect effects from adjustments in livestock numbers.
   b. Increased productivity – Carbon storage in grazing lands can be improved by a variety of measures that promote productivity. For example, remedying nutrient deficiencies by fertilizer or organic amendments increases plant litter returns and, as a result, increases C storage. Adding nitrogen, however, may stimulate $N_2O$ emissions thereby offsetting some of the benefits (Conant et al., 2005). Irrigating grasslands can promote soil C gains, though the net effect of this practice depends on the emissions from energy use and other related activities on the irrigated land. Introducing grass species with higher productivity or C

allocation to deeper roots has been shown to increase soil C. Introducing legumes into grazing lands can also promote C storage through enhanced productivity from the associated N inputs, and perhaps also reduce $N_2O$ emissions if the biological $N_2$ fixation displaces the need for fertilizer N (Soussana et al., 2004).

3. **Management of soils** – Organic soils contain high densities of C because decomposition is suppressed by the absence of oxygen under flooded conditions. To be used for agriculture these soils are drained, which aerates the soil, favouring decomposition and therefore high fluxes of $CO_2$ and $N_2O$. Methane emissions are usually suppressed after draining, but this effect is far outweighed by pronounced increases in $CO_2$ and $N_2O$ (Kasimir-Klemedtsson et al., 1997). There are several management practices that can reduce emissions on drained soils, but the most important mitigation practice is likely avoiding drainage of these soils in the first place, or re-establishing a high water table where GHG emissions are still high (Freibauer et al., 2004).

4. **Restoration of degraded lands** – A significant quantity of agricultural lands have been degraded by erosion, excessive disturbance/cultivation, organic matter loss, salinization, acidification or other processes that curtail productivity (Foley et al., 2005). Often C storage in these in these soils can at least be partially restored by practices that reclaim productivity, including: revegetation; improving fertility by adding nutrient amendments; applying organic substrates (manure etc.); reducing tillage and conserving water (Paustian et al., 2000).

5. **Livestock management** – Livestock, particularly ruminants such as cattle and sheep are important sources of $CH_4$, accounting for approximately 18% of global anthropogenic emissions of this gas (Koneswaran & Nierenberg, 2008). The methane is produced primarily by enteric fermentation and voided by eructation. Practices for reducing $CH_4$ emissions from this source fall into three general categories: improved feeding practices, use of dietary additives, and longer term management adjustments and animal breeding.

a. Improved feeding practices – Methane emissions can be reduced by feeding more concentrates, normally replacing forages (Beauchemin & McGinn, 2005). Although concentrates may increase daily methane emissions, emissions per kilogram feed intake and per kilogram product are generally reduced. The overall net benefit, however, depends on reduced animal numbers or younger age at slaughter for beef cattle and how the practice affects emissions when producing and transporting the concentrates (Lovett, Shalloo, Dillon, & O'Mara, 2006).

   Other practices that can reduce $CH_4$ emissions include: adding oils to the diet; improving pasture quality; and optimizing protein intake to reduce N excretion and $N_2O$ emissions (Clark, Pinares-Patiño, De Klein, & McGilloway, 2005).

b. Dietary additives – A wide range of dietary additives, or "specific agents" have been proposed as a means of suppressing methanogenisis to reduce $CH_4$ emissions. They include:
   - Ionophores – antibiotics that can reduce methane emissions (McGinn, Beauchemin, Coates, & Colombatto, 2004).
   - Halogenated compounds – inhibit methanogenic bacteria (Van Nevel & Demeyer, 1995).
   - Probiotics – e.g. yeast culture may reduce methane emissions (Beauchemin et al., 2008).
   - Propionate precursors – reduce methane formation, e.g. including edible oils in the diet (Newbold et al., 2005).
   - Vaccines – against methanogenic bacteria (Wright et al., 2004).
   - Bovine somatotrophin (bST) and hormonal growth implants – improve animal performance which results in reduced emissions per unit of animal product (Johnson, Ward, & Torrent, 1992).

c. Management changes and animal breeding – Increasing productivity through breeding and better management practices spreads the energy cost of maintenance across a greater feed intake, often reducing methane output per kilogram of animal product (Boadi, Benchaar, Chiquette, & Massé, 2004). Further, with improved efficiency, meat producing animals reach slaughter weight at a younger age which translates into reduced lifetime emissions (Alemu et al., 2011; Basarab et al., 2012).

6. **Manure management** - Animal manures can release significant quantities of $N_2O$ and $CH_4$ during storage and application, but the magnitude of these emissions varies significantly. Methane emissions from liquid manure stored in lagoons or tanks can be reduced by cooling or covering, or by capturing the $CH_4$ emitted (Monteny, Bannink, & Chadwick, 2006). The manures can also be digested anaerobically to maximize retrieval of $CH_4$ as an energy source (Clemens, Trimborn, Weiland, & Amon, 2006). Storing and handling the manures in solid rather than liquid form can suppress $CH_4$ emissions, but may increase $N_2O$ formation. Preliminary evidence suggests covering manure stockpiles can reduce $N_2O$ emissions. In reality there is limited opportunity for meaningful manure management worldwide, as the majority of the excretion happens in the field.

7. **Bioenergy** – Increasingly, agricultural crops and residues are seen as sources of feedstocks for energy to displace fossil fuels. A wide range of materials have been considered for use, including grain, crop residue, cellulosic crops (e.g. switchgrass, sugarcane) and various tree species. These products can be burned directly, but often are processed further to generate liquid fuels such as ethanol or diesel fuel (Richter, 2004). These fuels release $CO_2$ when burned, but this $CO_2$ is of recent atmospheric origin (via photosynthesis) and displaces $CO_2$ which otherwise would have come from fossil C. The net benefit to atmospheric $CO_2$, however, depends on energy used in growing and processing the bioenergy feedstocks (Spatari, Zhang, & MacLean, 2005). The interactions of an ever developing bioenergy sector with other land uses, and impacts on agro-ecosystem services such as food production, biodiversity, soil and nature conservation, and carbon sequestration are not well understood, but integrated assessment modeling offer opportunities to gain additional insights (Smeets, Faaij, Lewandowski, & Turkenburg, 2007).

Figure 4.1 summarizes the global biophysical mitigation potential categorized by each management practice, in order of magnitude of contribution. Of these total mitigation potentials, approximately 89% is from reduced soil emissions of $CO_2$, approximately 9% from mitigation of $CH_4$, and approximately 2% from mitigation of soil $N_2O$ emissions.

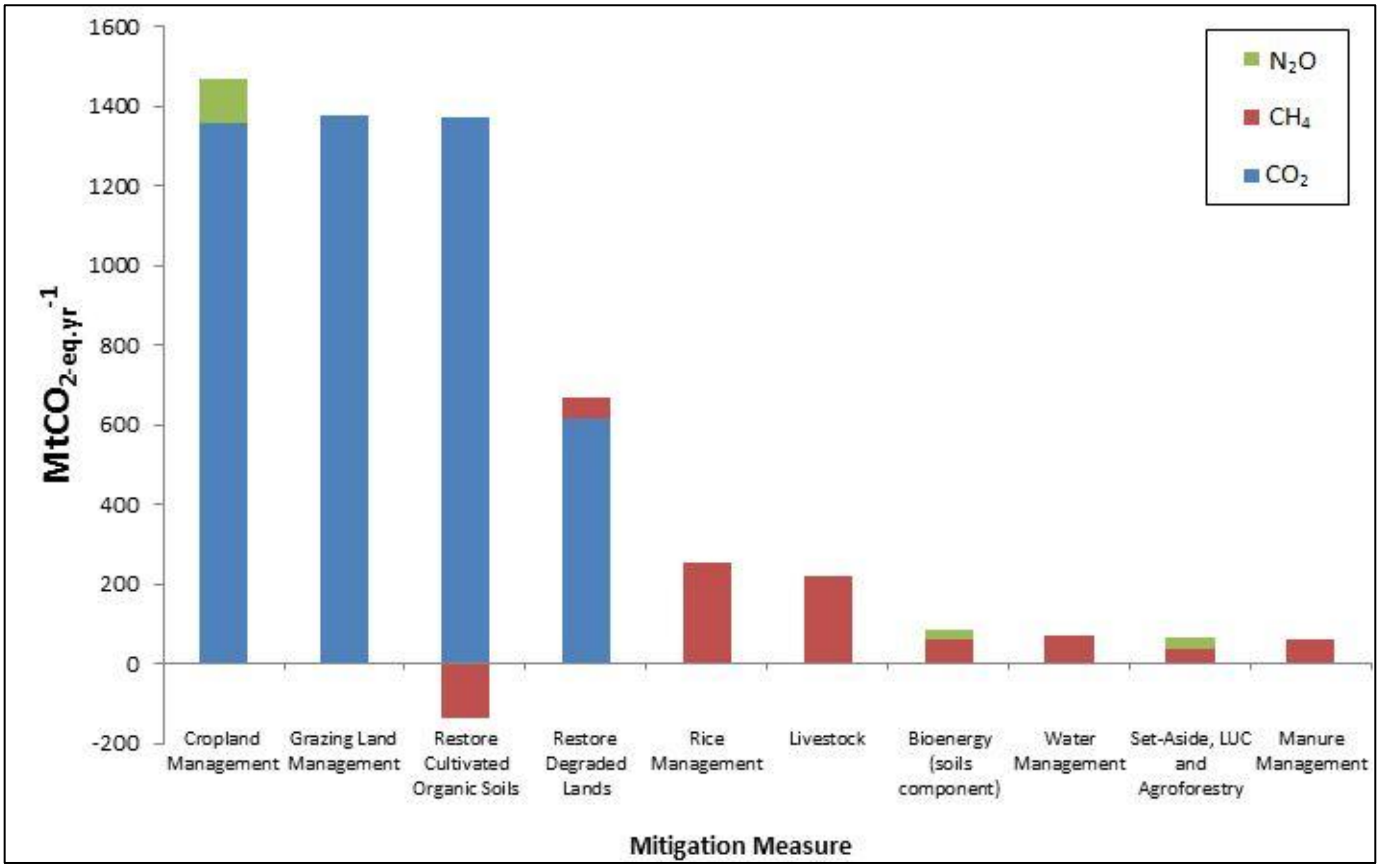


**Figure 4.1.** Global biophysical mitigation potential (Mt $CO_2$ eq. Yr) by 2030 of each agricultural management practice. (adapted from Smith (2008)).

**4.2 The Global Carbon Market**

Global Carbon Markets have been established in an effort to create monetary incentives to reduce or mitigate GHG emissions through the sale of carbon offsets. In agriculture there is a relationship between the benefit, or the amount paid for GHG's (i.e. the price of $CO_2$ equivalents) and the actual level of mitigation realized. At low prices, the dominant strategies are those consistent with existing production, such as change in tillage practice, fertilizer application, diet formulation and manure management. Higher prices elicit land use changes that displace current management practices, such as biofuels, afforestation, and allow the use of more costly animal feed-based mitigation options. Smith et al. (2008) found the global technical mitigation potential from agriculture by 2030, considering all gases, is estimated to be approximately 5,500 – 6,000 Mt $CO_2$ eq/yr, with cumulative economic potentials of 1,500-1,600, 2,500-2,700 and 4,000-4,300 Mt $CO_2$ eq/yr at carbon prices of up to $20, up to $50 and up to $100 USD per t $CO_2$ eq, respectively. To put this information into context, annual $CO_2$ emissions during the 1990s were approximately 29,000 Mt $CO_2$ eq/yr., so agriculture could offset, at full biophysical potential, about 20% of total annual $CO_2$ emissions, with reductions of approximately 5, 9 and 14% at $CO_2$ eq prices of up to 20, 50 and $100 USD per t $CO_2$ eq. The IPCC Second Assessment Report noted that GHG mitigation approaches will not be adopted by agricultural land managers unless they improve profitability, but some measures are adopted for reasons other than for climate mitigation. Options that both reduce GHG emissions and increase productivity are more likely to be adopted than those which only reduce emissions (IPCC, 2006b).

### 4.3 The Carbon Market – a North American perspective

The North American carbon market as a whole is a complex and diverse network of provincial, state and regional markets. Despite several attempts under recent Canadian governments, little policy direction regarding the development of a national carbon market has occurred. The current administration in the US had indicated a desire to increase the prominence and importance of climate change policy. However, the global economic downturn and difficulties passing legislation has significantly delayed the implementation of a US climate change bill. Canada, seeking to partner with the United States in a North American wide carbon market initiative, has also largely stalled the development of climate change policy, choosing instead to wait for US policy to develop (Rabe, 2007). In the absence of federal policy direction, numerous regional GHG markets have developed to service provincial, state and regional demands for carbon offsets, generated through local regulatory compliance measures largely imposed on heavy industry and fossil-based energy producers (Saidur, Islam, Rahim, & Solangi, 2010).

Currently, the only regulated, regional market in Canada is the Alberta carbon offset market. Saskatchewan and Ontario have also signalled their intention to develop domestic compliance based carbon markets, and British Columbia is currently soliciting for offsets projects through the voluntary Pacific Carbon Trust (PCT). The segregated nature of the Canadian market has resulted in the development of carbon offset trade barriers, as regulated jurisdictions seek to limit the flow of capital outside of their borders – as a result offsets must be created within the specific province. The Alberta Climate Change Emissions Management Act was amended in 2007 to require companies with annual emissions of more than 100,000 tonnes $CO_2$ eq to reduce their emissions by 12% from a 2003-2005 baseline. This created a strong demand for carbon offsets as the affected companies became obligated to reduce their emissions in house; purchase offsets from others; or purchase from a public technology fund in order to reach regulatory compliance. Non-compliant companies are faced with stiff penalties of up to $200 per tonne $CO_2$ eq and possibly an additional flat fee of $250,000. The financial implications of inaction have created a market for “Gold Standard” credits consistently valued at $12-15 per tonne $CO_2$ eq. This has created a significant opportunity for developing carbon offset projects in Alberta and the demand side of the marketplace has looked favourably towards the agricultural industry as a supplier of offset credits. As in other North American jurisdictions, the Alberta offset market rules state that regulatory compliance can only be met with offsets created within Alberta, effectively shutting out any potential non-Alberta offsets created in North America from flowing into the Alberta market (Alberta Environment, 2008).

The voluntary carbon markets, on the other hand, do not tend to place restrictions on where offsets projects are located, and are thus more accessible for projects located outside a regulated market region. The voluntary markets were initially designed to service the anticipated growing need for regulatory compliance offsets. However with the lack of federal regulations in North America, voluntary markets have instead evolved to service the growing market for offsets used in marketing and promotion and/or long term carbon liability risk management (Capoor & Ambrosi, 2007). Well known voluntary exchanges, such as the Chicago Climate Exchange, the Montreal Climate Exchange and the European Climate exchange have provided a means for corporations to purchase carbon offsets, validated and verified by certified third parties, providing a high level of assurance that the offsets that were purchased were real and bankable. The risk associated with regulatory non-compliance is well reflected in the market price of carbon in a regulated market, as is the case of the Alberta Offset System (\$12-15 per t $CO_2$ eq). Voluntary carbon markets tend to return a much lower price for carbon, (historically in the range of \$2-5 per t $CO_2$ eq), reflecting the lack of risk of non-compliance and possible fines.

Carbon aggregation is an important concept in the realm of marketing agricultural based carbon offsets. Due to the relatively small offset packages that can be developed on a per farm basis, it is usually necessary to aggregate numerous packages in order to engage the market, which typically requires at least 10,000 t $CO_2$ eq to consider a transaction. Further, the transaction costs for moving an offset package are typically 15-30% of the gross value of the offsets. A 10,000 t package marketed for \$15 per t $CO_2$ eq will gross \$150,000 and carry transaction fees of \$22,500-\$45,000. Transaction fees may include, but are not limited to, the costs of validation, verification, marketing, contract and financing negotiation, and legal due diligence. Aggregation allows these transaction costs to be spread over a large number of projects, making the costs more manageable for each project participant.

Another important function of aggregation is shared market risk. If the minimum offset package size is 10,000 t $CO_2$ eq, and each participating farm is able to contribute 200 t $CO_2$ eq, it is necessary to have 50 farms as part of the aggregation group to satisfy the volume requirements. It is highly likely that a number of farms will not meet the criteria of the project and have to be excluded. An aggregated project will allow the risk associated with non-delivery to be spread over the remaining participants, or if possible, the excluded operations can be replaced. This shared risk helps to ensure a project will not falter completely if a portion of the group is not able to meet their individual requirements.

### 4.4 BC's GHG mitigation and carbon offset opportunities

On a per capita basis, BC is one of the lowest GHG emitters in North America. Within Canada, BC ranks second lowest after Quebec in GHG emissions per person. According to the BC Ministry of Environment (2008), B.C. emitted 68.7 million tons ($CO_2$ eq) of GHG emissions, representing 8.9% of Canada's total. The two main reasons for the relatively low per capita emissions in B.C. are because of the predominance of hydroelectricity in the provincial energy grid, and that the agricultural sector is quite small relative to other parts of Canada. As shown in Figure 4.2, emissions from agriculture represent 5% of all emissions in the province in 2008. Within B.C.'s agricultural sector, livestock production accounts for 48% of agricultural emissions, emissions from agricultural soils account for 36% and, emissions from manure account for 15%. Given these statistics, it is clear that a focus on GHG reduction strategies in the provinces agricultural sector should be on livestock production and management.

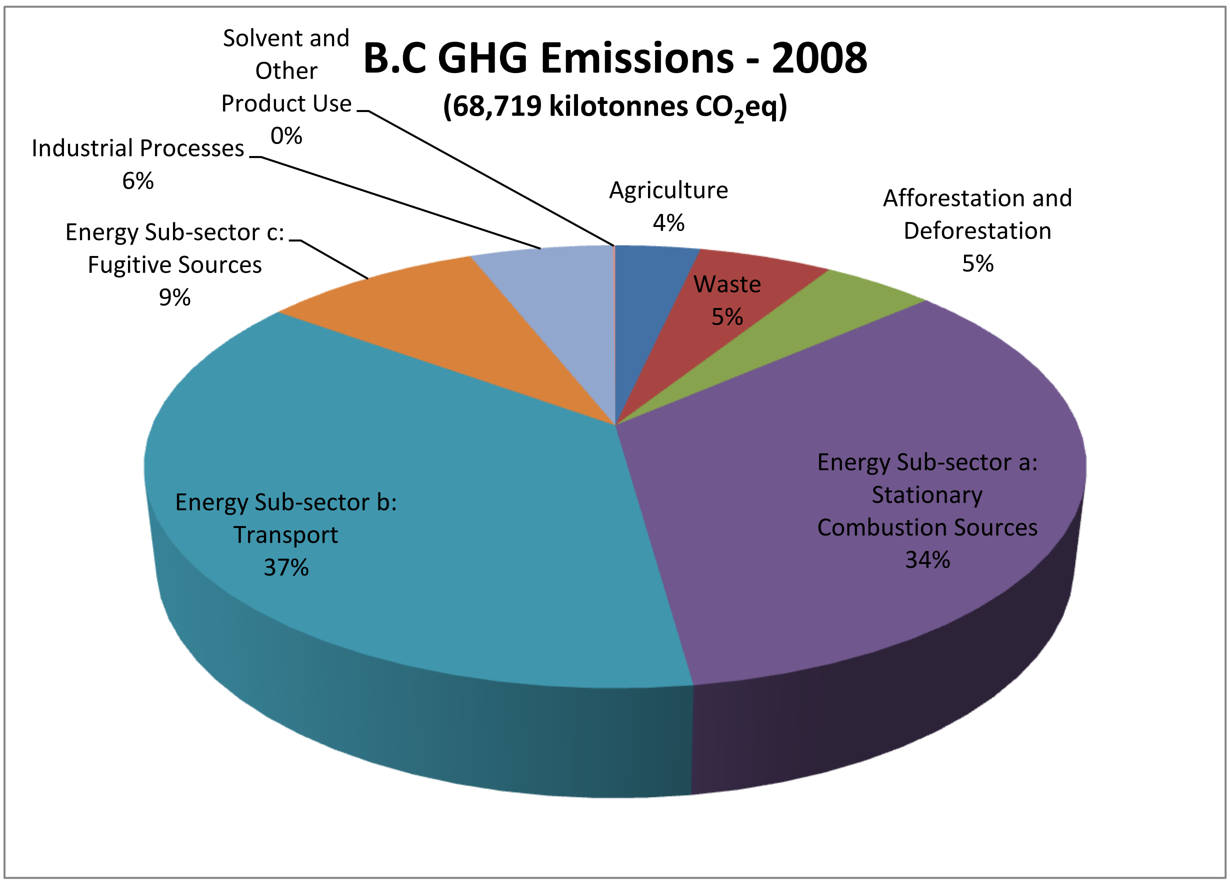


**Figure 4.2.** B.C. GHG Emissions - 2008. (adapted from BC Ministry of Environment (2010)).

In November 2007, the government of British Columbia introduced legislation aimed at reducing the province's GHG emissions. Under the Greenhouse Gas Reduction Targets Act (GGRTA) the provincial government set out the objectives to reduce the provincial carbon footprint by 33% of 2007 levels by 2020, and to make the public sector in B.C. carbon neutral by

2010. The government guidelines established two systems to facilitate the public sector organizations achieving zero net GHG emissions (carbon neutral):

1) Pursue actions to minimize its own GHG emissions (i.e. reduce travel, improve efficiency of buildings, use less paper etc.)
2) Use carbon offsets acquired by the Pacific Carbon Trust to cancel out remaining GHG emissions that it is unable to reduce to zero through its own actions.

The Pacific Carbon Trust (PCT) (www.pacificcarbontrust.com/) is a provincial crown corporation dedicated to acquiring carbon offsets so that public sector organizations and other clients can achieve their carbon neutral objectives. The PCT only purchase carbon offsets that are generated from projects or activities within B.C., and meet the provincially defined eligibility criteria for qualifying carbon offsets. B.C.'s agricultural sector may be able to sell eligible carbon offsets to the PCT from agriculturally based offset projects.

The GGRTA specifies a carbon offset is created when an entity voluntarily undertakes a project/action that reduces the amount of GHG emissions entering the atmosphere (reduction), prevents GHG emissions from entering the atmosphere (avoidance), or increases the amount of GHG emissions being taken out of the atmosphere (removal enhancement or sequestration). In the case of methane, for example, because methane has a $CO_2$ equivalency of 23, for every tonne $CH_4$ emissions reduced or avoided, 23 offsets will be generated. Carbon offsets are created through projects that reduce, avoid or remove GHG emissions (Figure 4.3).

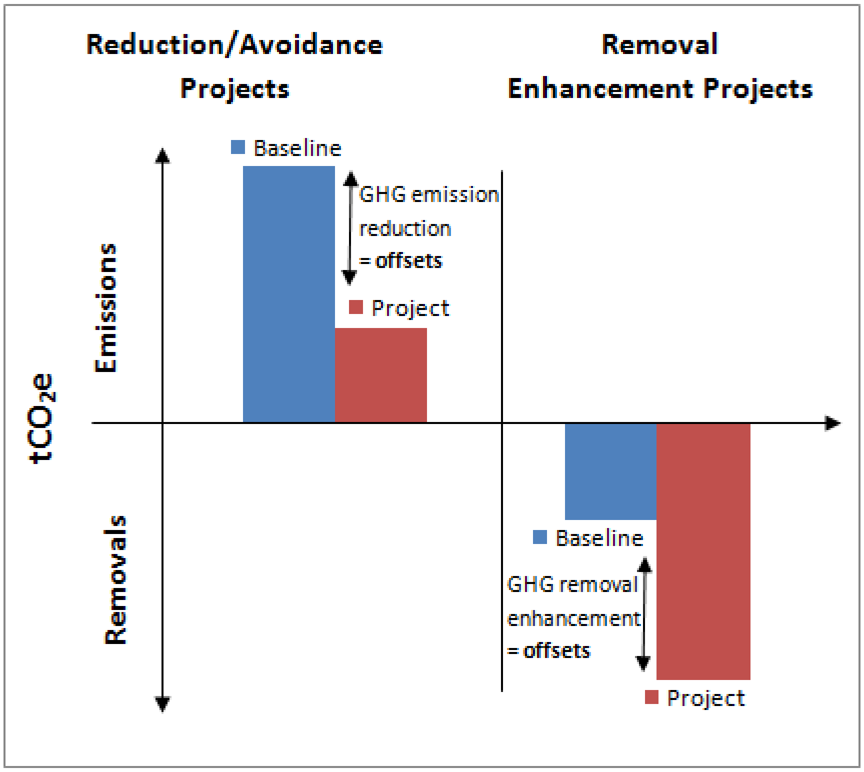


**Figure 4.3.** Carbon Offset Projects. (adapted from BC Ministry of Agriculture and Lands (2009)).

It is important to distinguish between the terms "carbon offsets" and "carbon credits". A carbon offset is generated when a voluntary action is undertaken that reduces, avoids or removes GHG emissions. Carbon credits, on the other hand, refer to either carbon offsets or carbon allowances. Carbon offsets can be found in both voluntary and mandated carbon markets, and they can be purchased by anyone trying to reduce their emissions for mandated or non-mandated purposes. A carbon allowance is found only in mandated carbon markets, and is an authorization to emit a certain amount of GHG emissions, i.e. each carbon credit in the allowance enables the owner to emit one tonne $CO_2$ eq. Carbon allowances are issued by a regulatory body to industries/sectors that have been mandated to limit their emissions. Carbon allowances can be traded between companies within the same mandated industries/sectors to help them meet their reduction obligations. These same industries/sectors can purchase carbon offsets from non-mandated industries/sectors (e.g. agricultural sector) to help them meet their emissions targets.

Project proponents must prepare a Project Plan, which provides details about the offset project, including what the project entails, how it will be conducted and how the GHG reductions, avoidance or removals will be calculated. The project plan must be prepared in accordance with the Emission Offset Regulation (www.env.gov.bc.ca/epd/codes/ggrta/pdf/offsets-reg.pdf). Projects will be eligible to sell offsets to the PCT only if their project plan meets all of the following seven criteria:

1) Within Scope – only projects that are carried out within B.C., and reduce carbon dioxide, methane, nitrous oxide, hydrofluorocarbons (HFCs), perfluorocarbons (PFCs) and sulphur hexafluoride ($SF_6$) gases are eligible.
2) Measurable – projects must specify a justifiable methodology to quantify the GHG emission reductions in an accurate and conservative manner.
3) Real – GHG reductions must be as a result of some specific identifiable action, and projects must result in absolute net reductions into the atmosphere. If the impact of a project results in increases or decreases of removals elsewhere, this "leakage" must be accounted for regardless of whether they are intentional or accidental. Leakage could partially or completely negate the reductions associated with the original project. "Reversals" must also be accounted for; if GHGs that were originally removed are released back into the atmosphere during the lifetime of a project, these allowances must be replaced. Risk mitigation and contingency plans must be developed to ensure reductions will endure for at least 100 years.
4) Additional – an offset project must demonstrate that it has reduced, removed or avoided emissions beyond what would have occurred if the project had not been undertaken – i.e. the project is not "business as usual". To determine additionality, the PCT will use the following tests:
    a. Regulatory test – a project must result in GHG reductions beyond existing or proposed regulatory requirements/standards.
    b. Timing test – the project must not have started before November 29, 2007.

c. Barrier analysis – a project must face a technological, financial or other barrier to implementation that will only be overcome, or partially overcome, as a result of receiving carbon offsets. For example:
    i. Financial barrier – a project faces a financial barrier if the ROI is too low, or the risk to high without the revenue derived from the sale of carbon offsets (Figure 4.4).
    ii. Technological barriers – a project faces a technical barrier when there is a lack of equipment of expertise to undertake the project and this deficiency can only be addressed with the revenue derived from the sale of carbon credits.
d. Verifiable – the PCT will only buy carbon credits from projects that have had their plan validated and verified by independent third parties with recognized accreditation (Table 4.1).
    i. Validation – the plan must be capable of delivering all of the offsets promised.
    ii. Verification – the project report and the validated project plan verify if the project has delivered all of the offsets promised.
e. Clear evidence of ownership – a project proponent must have established clear rights to claim legal or commercial benefits arising from the projects GHG reductions.
f. Counted once – reductions can only be counted once. The PCT will not buy offsets from projects that: have already sold reductions in other carbon markets; or, have allowed another entity to use the reductions when they calculate their own emissions.

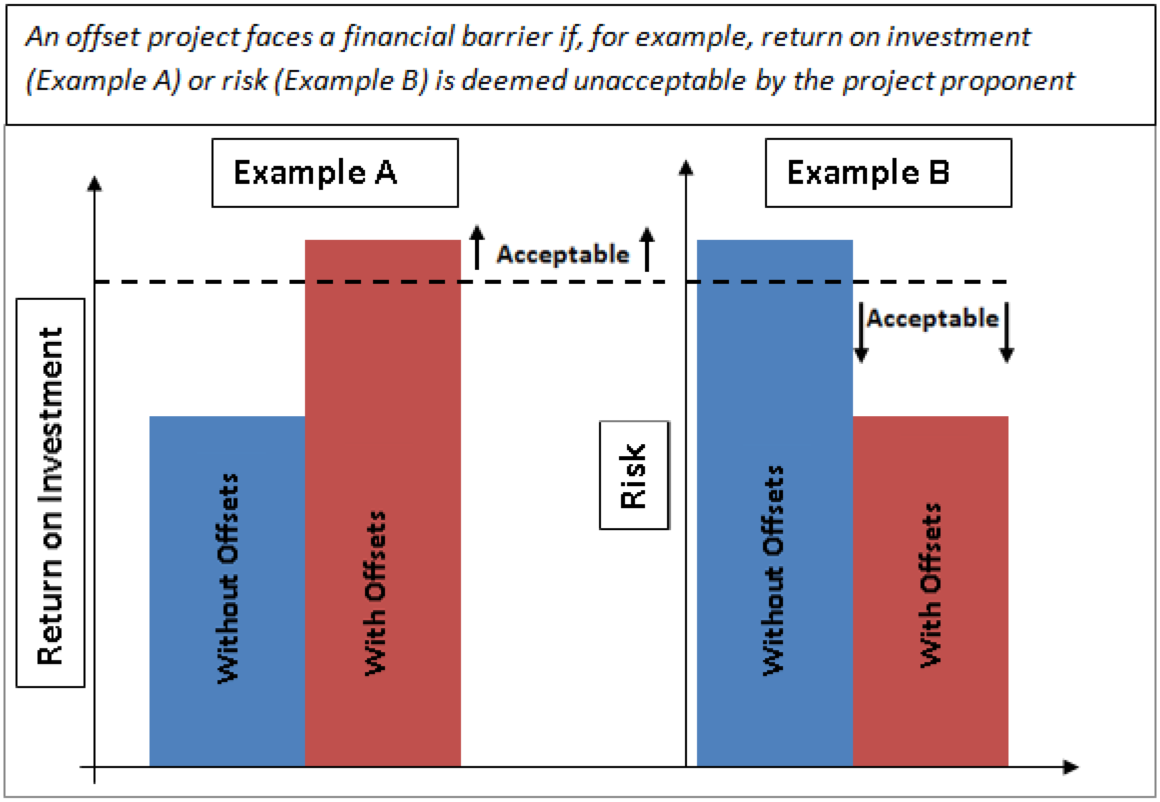


**Figure 4.4.** Carbon Offset Projects – ROI vs. Risk. (adapted from BC Ministry of Agriculture and Lands (2009)).

**Table 4.1.** Carbon Offset Projects – Validation and Verification. (adapted from BC Ministry of Agriculture and Lands (2009)).

| Differences | Validation | Verification |
|---|---|---|
| **Timing:** | Occurs before the project developer signs an agreement to supply carbon offsets. | Occurs after the emission reductions have occurred. |
| **Objective:** | Future oriented: Statement of intent and forecasts. | Past orientated: Statements of performance. |
| **Subject Matter:** | Baselines are accurate and offset project meets the eligibility criteria. | Offset project delivery and emissions data (in accordance with project plan). |
| **Focus:** | Justification, assumptions, quantification methodologies. | Offset project and data integrity (consistency with project plan). |
| **Frequency:** | Only once (before the offset project is accepted). | Periodic (each time carbon offsets are delivered). |

### 4.5 Investigating Offset Opportunities for BC Cattle Producers

As described previously, a project proponent, in this case a B.C. beef producer, must prepare a Project Plan, which provides details about the offset project, including what the project entails, how it will be conducted and how the GHG reductions, avoidance or removals will be calculated. In order to create high quality offsets, science based protocols must be developed to properly identify GHG emission reductions that result from the use of different management practices. Protocols are detailed instructions, or roadmaps, on how to conduct an offset project. They may include information on standard approaches, equipment, procedures and requirements for project development, operation monitoring, calculation, reporting and verification.

Protocol development is not a simple case of a couple of people deciding one day to start tracking emissions and creating an offset. Generally, protocols are developed according to an international "gold standard" using the ISO 14064-2 guidelines that requires a review of the scientific literature to form a "Science Discussion Document", peer review of the document, several rounds of stakeholder reviews, and then if a "go", development of the actual quantification protocol (Basarab, Baron, & Okine, 2009). The more rigor in producing offset quantification protocols should yield more of a blue chip protocol that produces a higher value offset. In BC, the PCT is continually developing protocols to help project proponents quantify their carbon offsets. On January 30, 2012, PCT announced that the BC protocol for the creation of forest carbon offsets had been submitted for formal recognition under the international Verified Carbon Standard (VCS). The VCS is a leading GHG accounting program used by projects around the world to verify and issue carbon credits in voluntary markets. The VCS was founded in 2005 by business and environmental leaders who identified a need for greater quality assurance in voluntary carbon markets. Information on the VCS methodology approval process is available at: www.v-c-s.org/sites/v-c-s.org/files/MethodologyApprovalProcess.pdf.

In the case of B.C.'s Pacific Carbon Trust, protocols have not been developed supporting projects associated with livestock production and associated livestock related GHG emissions. The PCT suggests that where a protocol has not been suggested and/or approved, proponents are encouraged to adopt an established protocol of recognized origin, adapted as necessary to B.C.

Alberta Agriculture and Rural Development has been instrumental in the development of four GHG-mitigating quantification protocols in the area of beef cattle production. These protocols address management improvements that include:

- supplementing backgrounding and feedlot diets with edible oils (2010);
- reducing age at harvest in youthful cattle (2011);
- reducing the number of days that cattle are on feed in the feedlot (2011);
- selecting for low residual feed intake in beef cattle (2012).

There is currently a conversion to perennials protocol pending (2013), and protocols on grazing management under investigation in Alberta that could be adapted to the B.C. production system.

It is estimated these changes have the potential to reduce GHG emissions from cattle by 0.025 to 1.1 t $CO_2$ eq per animal, with an estimated value of \$0.25 - \$11 per animal in the Alberta carbon market (Basarab et al., 2009).

1. **Adding edible oils to the diet** (2010) – it is well documented that adding 3-6% edible oils such as canola, soy, sunflower, corn and flaxseed oil to the diet of ruminants decreases methane emission by 15-25% (Beauchemin & McGinn, 2006; Jordan et al., 2006; McGinn et al., 2004). The addition of dietary lipids reduces methane emissions through a combination of: decreasing fibre digestibility; suppressing the metabolic activity of methanogenic bacteria; enhancing relative propionate production; and through the provision of an alternative means of electron disposal, especially when unsaturated fatty acids are fed to cattle (Johnson & Johnson, 1995; Jordan et al., 2006). In addition to edible oils, there has been interest in the effects that feeding corn based dried distillers grain and solubles (DDGs) has on methane emissions, manure production and nitrogen loss in cattle. Few studies have examined the net GHG balance of feeding corn DDGs to cattle, for that reason the quantification protocol does not include the

feeding of corn DDGs as a method of increasing the oils content of diets fed to cattle in Alberta (Basarab et al., 2009). The inclusion of edible oils in the diets of cattle as a GHG mitigating strategy is relatively straight forward since oils, oilseeds and animal fats are already in use in the Canadian cattle industry. Calculations of methane emissions requires knowledge of the animal category (i.e. beef cow on pasture lactating, backgrounding steer, yearling steer on a finishing diet), diet composition, dry matter or gross energy intake (GE), and methane conversion rate as expressed as percent of GE of each specific diet (IPCC, 2006a).

Basarab, Baron, & Darling (2007a) conducted a study in Alberta on feeding edible oils to 10,245 youthful cattle in three commercial feedlots. Using a value of $10 per t $CO_2$ eq for the carbon credits, the overall carbon credit benefit averaged $109.22 per 100 head. Their findings further revealed that the inclusion of 4% edible oil in the feedlot finishing diets increases feeding costs by $25-35/head, so feeding edible oils as GHG mitigating strategy would not be viable until oil costs dropped by approx. 50% to $4-500/t, or there was a premium paid for beef with an enhanced fatty acid profile (i.e. more omega-3 or conjugated linoleic acid).

2. **Reducing age at slaughter in youthful beef cattle** (2011) – there a numerous studies documenting the relationship between forage concentration ratio and methane emissions expressed as a percentage of gross energy intake (GE) (Beauchemin & McGinn, 2005; Johnson & Johnson, 1995; Ominski, Boadi, & Wittenberg, 2006). These studies support the notion that methane emissions from the cattle industry could be reduced by optimizing the gain during each feeding period, decreasing the length of the backgrounding period, increasing the proportion of grain in the backgrounding diets, and reducing the number of days cattle spend on unproductive and poor quality pastures, all resulting in reduced age at harvest in youthful beef cattle. The Canadian Cattle Identification Agency (CCIA) database reveals the average age at slaughter was 19.1 and 18.6 months of age as of May 1/08 and June 1/09 respectively. Most of the cattle slaughtered between 19 and 25 months of age would be spring born calves,

weaned at 6-8 months, backgrounded to 14-15 months, pastured to 17-19 months, and then fed a finishing diet until slaughter at 19-21+ months of age.) Basarab, Baron, & Darling (2007b) evaluated the quantification protocol for reducing the age at harvest in youthful beef cattle. The Baseline condition was steers harvested at 18.2 months, established because the average age at harvest of youthful cattle in western Canada is 18-19 months of age. The project condition was steers harvested at 14 months of age, since fewer days on feed has the potential to produce less manure and methane. They discovered that the reduction in GHG emissions from enteric fermentation from baseline to project conditions was 732.1 kg $CO_2$ eq per head. Assuming a carbon credit value of $10 per t $CO_2$ eq, reducing the age at slaughter by 4 months of age was valued at $7.32/head. As a result of 46.8% less manure produced under the project vs. baseline conditions, GHG emissions in the form of $CH_4$ and $N_2O$ from the manure were 4.03 kg $CO_2$ eq per head less, resulting in $4.03/head in carbon credit value. Project cattle had lower production costs, but slightly higher feeding costs, resulting in an overall reduction in costs of $23.48/head. The overall benefit of selling in June, plus the $11.35/head carbon credit value translated into project cattle returning $122.50/head more than the baseline cattle.

3. **Reducing days in the feedlot** (2011) – the project condition is the implementation of a revised feeding regime that results in a reduction in the number of days cattle are on a finishing diet before being sent to harvest. This quantification protocol deals with technologies that reduce the number of days in the feedlot while maintaining or improving feed efficiency, carcass weight and lean meat yield. Several approaches have been studied, including:
    a. Electron acceptors that compete for hydrogen (e.g. fumarate, malate, oxaloacetic, beta hydroxybutyric acid, propyonic acid, and butynoic acid).
    b. Compounds that that inhibit uptake of electrons and hydrogen by ruminal methanogens.
    c. Growth promotants and beta-agonists that improve the efficiency of lean tissue growth.

d. Genetic marker panels that reduce days on feed and/or improve feed efficiency (e.g. leptin genetic marker).

Within the first two approaches, several compounds have been evaluated, but issues such as toxicity, cost, and lack of research into their effectiveness to reduce methane emissions have left many unanswered questions (McGinn et al., 2004). Hormonal growth implants are well known to improve feed efficiency, growth rate and muscle growth in grazing and feedlot cattle and are common place throughout the industry (Basarab et al., 2012). The fourth approach to reducing GHG intensity in beef production deals with genomic technologies and in particular genetic markers. Unfortunately many of these marker panels have not been adequately validated, and would not stand up to the guidelines for protocol development. Overall, indications at this time suggest that there would be minimal carbon credit benefits from this protocol (Basarab et al., 2009).

4. **Selecting for improved efficiency of feed utilization in beef cattle** (2012) – the cattle industry continues to face challenges in competitiveness and environmental sustainability. Improving the efficiency of feed utilization and reducing the environmental impact are important components in the industries prosperity. Residual feed intake (RFI) is a robust measure of feed efficiency, is moderately heritable, and in beef cattle is defined as the difference between actual feed intake and the expected feed requirements for maintenance of body weight and production (Nkrumah et al., 2007). Canadian researchers, using a four chamber, open circuit calorimetry system to measure oxygen and methane production, reported that low (efficient) RFI steers emitted 28% less methane from enteric fermentation and produced 14% less fecal dry matter/kg dry matter intake and 19% less urine per kg of metabolic weight than high (inefficient) RFI steers (Nkrumah et al., 2006). The studies that have been done demonstrate that low RFI cattle emit less methane and manure, mainly because they consume less feed for the same level of production compared to high RFI cattle (Basarab et al., 2003). This makes genetic selection for low RFI a good candidate for GHG mitigation in beef cattle, particularly considering the cumulative nature of genetic

selection and the fact that GHG reduction can be accomplished without decreasing herd size.

This protocol is primarily based on work done in Australia by Arthur, Donoghue, Herd, & Hegarty (2008). Their baseline condition was no selection of breeding bulls or replacement heifers for RFI, and the project conditions consisted of four low RFI breeding bulls mated to 100 cows. The use of these four low RFI bulls on a 100 cow herd reduced GHG emissions by 24.25 t $CO_2$ eq, with enteric fermentation accounting for a reduction of 18.08 t $CO_2$ eq, and manure production storage and handling accounting for a reduction of 6.16 t $CO_2$ eq. Continued selection for low RFI males and females would result in the increased accumulation of genetic change and consequently carbon offset value, this in addition to significant savings in feed costs.

5. **Conversion to Perennials** (pending) **–** this protocol is expected to be implemented in 2013 or 2014. It is intended to reward net reductions and removals of GHG emissions through increased soil C sequestration, decreased combustion of fuels, and decreased use of fertilizers and crop protection products, associated with avoided cultivation of annual crops. It is anticipated these reductions and removals of GHG emissions will more than compensate for emissions of $CH_4$ (enteric and manure) and $N_2O$ associated with haying and grazing the perennials.

6. **Pasture Management Protocols** (under consideration) – on a global scale, grasslands have a valuable role to play in GHG emission mitigation discussions because of their ability to act as carbon sinks, and the fact that they serve as huge carbon stores. Carbon offset opportunities are about changing management practices to mitigate the release of GHG emissions into the atmosphere. Generally, long established grasslands are considered at equilibrium, or at a neutral carbon balance – neither storing nor releasing carbon into the atmosphere. Original conversion of grassland to cropland resulted in a loss of 22 – 24% of the soil organic carbon (SOC) in Western Canada (VandenBygaart, Gregorich, & Angers, 2003), and restoration back to perennial grassland might replace the original quantity at a rate of 1.01 Mg C ha/yr. (Conant et al., 2005). Improving

carbon sequestration on pastures is attainable to varying degrees by: improving the grass species; including more legumes; improving grazing methods and regimes; and by adding Nitrogen fertilizer (Conant et al., 2005). Ruminant $CH_4$ emission generally increases with increased forage maturity and decreases with legume content (Boadi & Wittenberg, 2002). Developing grazing systems that increase the longevity of both native and tame grass pasture means more carbon can be sequestered in the soil from the atmosphere. Higher rates of C sequestration are likely more attainable on tame pasture vs. native grasslands because of a more intensive management approach, i.e. enhanced forage species diversity, addition of fertilizer inputs, and more intensive grazing management. The argument could also be made that native grassland pastures could be more receptive to C sequestration due their potentially reduced SOM and soil fertility levels. Our modelling work as outlined in Chapter 3 suggests there are opportunities to enhance C sequestration on native grasslands, by improving pasture forage quality through interseeding grasses and legumes, and adding fertilizers to improve potentially depleted soil nutrient levels to enhance grassland productivity. Our modeling work also revealed the potential for concomitant increases in $N_2O$ and $CO_2$ emissions resulting from grassland pasture improvement strategies, but based on our work, they did not offset the significant C sequestration benefits.

In addition to the above described Alberta based offset protocols, BC producers may be able to spearhead development of their own protocols. Beauchemin et al. (2011) investigated a series of mitigation scenarios/strategies based on dietary modifications (aimed at reducing $CH_4$), and improved animal husbandry. The following provides a brief summary of their work:

1. Increased use of forages for growing cattle – in this scenario, feedlot cattle would be backgrounded in the feedlot over winter for 150 days on a high forage diet vs. a baseline practice of 110 days. The animals would then be moved onto native pasture in the spring for 120 days, then onto the feedlot to be finished on a high grain diet for 120 days vs. a baseline practice of feedlot finishing for 170 days. The result would have the cattle being marketed at approximately 20 months of age. As a result of the prolonged

period to slaughter, the animals would be slightly heavier, but it was found GHG intensity for beef production (kg. $CO_2$ eq/kg beef carcass) increased by 6% over the baseline or conventional management system. This would not be a strategy to pursue for offset benefits.

**2.** Extended grain finishing of cattle – this scenario evaluated an aggressive feedlot finishing program. Weaned calves would be backgrounded on a high forage diet for 40 days before being transitioned to a finishing diet for 210 days vs. the baseline of 110 days backgrounding and 170 days finishing. This scenario yielded lighter finish weights, and reduced GHG emission intensity (2% vs. baseline), reflecting shorter time to market.

**3.** Feeding oilseeds – this scenario investigates the effects of dietary supplementation with polyunsaturated lipids using canola seed to: 1) replace forage in the winter diet of cows, bulls, calves, pregnant heifers, growing bulls and lactating cows; and 2) replace barley grain in the feedlot diets. The investigation evaluated the effects of changes in nutritive value of the diets (canola seed has a digestible energy (DE) content 1.5 times that of barley grain). Their findings suggested that feeding canola seed to backgrounding cattle reduced GHG emission intensity of beef production by 1%, and feeding canola seed to finishing cattle reduced intensity by 2% vs. baseline. In both cases, enteric $CH_4$ decreased due to combined effects of the lower $CH_4$ conversion factor (Ym) diets supplemented with fat (canola) and the lower DM intake of higher NE diets. Conversely, feeding canola seed to the cow calf herd had a substantial impact on GHG emission intensity, reducing it by 8% vs. baseline. The reduction was mainly due to lower enteric $CH_4$ emissions because of the reduced DM intake of the higher NE diet (i.e. containing canola) and a lower Ym.

**4.** Feeding distillers dried grains – the effects of incorporating corn dried distillers grains (DDG) into: 1) the backgrounding and finishing diets of feedlot cattle; and 2) the diets of the breeding stock, was evaluated. Their results revealed that feeding DDG to backgrounding and finishing cattle each lowered GHG emission intensity by 1%. The enteric $CH_4$ emissions were reduced slightly because of the lower Ym and lower DM intake of diets containing fat. Feeding DDG to the breeding stock lowered GHG emission intensity by 6%. The net effect of feeding DDG was to lower enteric $CH_4$ and increase manure $N_2O$ emissions.

5. Improved forage quality for breeding stock – the effects of improving the nutritive value of the forage fed to the breeding stock during the winter was evaluated. The improved quality was as a result by harvesting the mixed hay at an earlier stage of physiological maturity. This was found to reduce the GHG emission intensity of the cow calf herd by 5%.

6. Increased longevity of the breeding stock – increasing the longevity of the cows and bulls by one year, with the resulting effect being an additional progeny from another calving season, was evaluated. GHG emission intensity was lowered by less than 1%.

7. Increased number of calves weaned – the effects of improved calf survival from 85 to 90%, hence increasing the total amount of beef produced, were evaluated. Although the GHG emissions increased as a result of higher animal numbers, the net effect was to lower GHG emission intensity by 4%.

8. Change in land management – the effects of seeding new pasture on previously cropped land was explored, with a focus on the carbon storage or sequestration effects. Their results indicated that seeding pasture onto previously cropped land more than offset the GHG emissions from the baseline, the net result was the beef production systems ability to become a net sink of C.

### 4.6 Conclusion

Agriculture can make a positive contribution to lowering GHG concentrations in the atmosphere in one of two ways: reduce emissions occurring at the source from fossil fuels, fertilizers and livestock, or enhance storage of GHG's from the atmosphere via biological sinks. Consistent with a number of global jurisdictions, the Government of Canada has reaffirmed their support for working on reducing GHG emissions. Both government and non-government agencies are looking at various initiatives to achieve the reduction of GHG's both from an emissions reduction standpoint, as well as increased carbon capture. It is recognized that one of the main ways agriculture can contribute to the overall reduction in GHG emissions is the effective management of soils as a carbon capture sink. In recent years, carbon trading has grown significantly with emissions trading nearly tripling from $10.9billion in 2005 to $30.1 billion in 2008 (King, 2008). Determining what portion of this economic activity is linked to agricultural involvement is currently not possible, but the potential for growth in this area seems to be significant. Carbon trading with respect to forage lands specifically is still very limited. This is largely due to a clear lack of protocols quantifying the impact on carbon balances of land management practices involving grazing and forage management. As pointed out, new protocols proposed and currently under development will potentially rectify this situation in the near future.

Markets for emissions trading have the potential to benefit both GHG emitters, by lowering the cost of reducing emissions, and for farmers, who can potentially increase their farm income by adopting practices that reduce emissions and enhance storage of GHG's. Though there appears to be significant opportunity in agriculture to benefit from carbon trading, caution must be exercised. Significant uncertainty pervades GHG policy worldwide, which has caused carbon trading activity to decrease and a collapse in prices for offsets. For example, the average value for carbon on the Chicago Climate Exchange (CCX) during 2008 was about $3.73/tonne while during 2009 the value dropped to about $0.95/tonne.

The results of this body of work showed that a number of mitigation strategies could be implemented separately or together in some cases, which could lower GHG emissions associated with producing beef without substantive changes to the typical cow/calf/feedlot production system. Most of the protocols and prospective scenarios could be feasible within the BC beef cattle sector. What would require further evaluation is the cost of implementation of these changes from the "business as usual" practice. The changes and resulting costs would vary amongst producers, and would have to be evaluated on an independent basis. Ultimately, any increase in costs would be an important consideration to adopting GHG mitigation practices on the farm, as carbon offset markets, especially voluntary markets, are not expected to substantially offset the incremental costs of their implementation (McCarl & Schneider, 2000).

# CHAPTER 5
# FINAL CONCLUSIONS

This study, investigating the carbon footprint of cattle grazing in the Lac Du Bois grasslands in the central interior of B.C., consisted of three interrelated components.

The initial phase of the study consisted of gathering empirical enteric methane measurements from cattle grazing the grasslands, using the $SF_6$ tracer technique. In addition, pasture samples were gathered and analyzed to evaluate the feed constituents from the study area. By comparing our empirical findings with peer reviewed research conducted in similar pasture/grazing scenarios the findings were validated, and positively assessed with respect to their use in future modeling efforts.

The second phase of the study was to conduct a life cycle assessment (LCA) of the cattle ranching activities on the Lac Du Bois grasslands using a whole systems modeling approach with Holos. The Holos model quantified the GHG emissions, and developed a baseline associated with cattle grazing the grasslands to provide a snapshot of seasonal pattern use. Empirical findings from the first component of the study were instrumental in validating the LCA model, as it was clearly demonstrated that the data gathered from the study area is consistent with GHG emissions data utilized in IPCC Tier 2 guidelines. The algorithms on which Holos is based are taken from IPCC methods, modified for Canadian conditions. Confident in the results of the model, three management induced GHG mitigation scenarios were explored to evaluate the impact these changes/improvements would have on the carbon footprint of the cattle on the grasslands.

The third component of the study was to provide a review of the GHG mitigation strategies as they relate to agriculture in general, and livestock production in particular. A brief working knowledge was provided of the carbon offset trading system and market, and how rigorous protocols must be created in order for BC livestock producers to potentially participate in benefits associated with reducing and removing GHG emissions from their ranching operations.

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 (Smith et al., 2008), and in 2007, animal production was estimated to use about one fourth of all ice-free land for pasture, and about one third of all cultivated land for forage production (FAO, 2009; Vergé, Worth, Desjardins, McConkey, & Dyer, 2012).

With the global population rising, agriculture is under increasing pressure to create efficiencies to accommodate the demand for food, while addressing the tremendous concerns of its environmental impact. Recent studies have suggested that food production will need to roughly double to keep pace with anticipated demands from population growth, dietary changes (esp. meat consumption), and increasing bioenergy use (FAO, 2009). As we look ahead, it has been suggested one of the greatest challenges of the twenty-first century will be meeting societies growing demands for food, while simultaneously reducing agriculture's environmental footprint (Foley et al., 2011).

The importance and scope of the agricultural sector, particularly the livestock sector, and its contribution to GHG emissions have resulted in significant research focused on reducing the livestock sectors carbon footprint. These initiatives have resulted in improvements in the environmental performance of the livestock sector in recent years. In Canada the mean carbon footprint of beef cattle at the exit gate of the farm decreased from 18.2 kg $CO_2$eq per kg live weight (LW) in 1981 to 9.5 kg $CO_2$eq per kg LW in 2006 mainly because of improved genetics, better diets, and more sustainable land management practices (Desjardins et al., 2012). At the same time, the livestock sector has been pushed on one side by the increasing global demand for animal protein, and on the other side by high economic growth rates and technical innovations. Agriculture in general, and livestock in particular, has become increasingly more specialized – the "family farm" is disappearing and being replaced by the industrial assembly line concept. As stated previously, the livestock production system is extremely complex, and evaluating its carbon footprint is very challenging. Intensification of agriculture, especially expansion of animal production, can lead to: increased GHG emissions; water degradation and excessive freshwater withdrawals; inefficient land utilization practices and degradation (Foley et al., 2011).

Industrialized livestock production systems, which rely heavily on mechanized high-output crop production for feed grains, also leads to impacts on biodiversity. Conversely, well managed grazing systems may have many beneficial environmental effects and can enhance biodiversity. Grazing systems, especially on lands unsuitable for other food production systems are an integral component to global food security and economic prosperity in many regions. Notwithstanding, the future demands for increased food production will require that land utilization will have to be critically evaluated, and ultimately productive croplands currently used for producing livestock feed may need to be transformed to produce food for direct human consumption.

Agriculture is a user of natural resources and it is an activity that can modify ecosystems. Agriculture's principle objective is to feed the population of the world, using management practices that achieve that goal sustainably. However, agriculture can create environmental problems, and solving these issues requires mitigation practices and changes in management methods. Mitigation practices should be based on well-defined sustainable management objectives. From a global perspective, for mitigating GHG emissions, diet manipulation is one of the best options for reducing emissions from ruminants. Economics will play a major role with respect to decision making on adopting this practice, as improved feeds may or may not be affordable.

As demonstrated in Chapter 3, reducing the carbon footprint by modifying the practice at the origin of the emissions is one approach. The other type of mitigation practice that can capture and remove GHG's already released is soil carbon sequestration. As important as carbon sequestration is, this type of mitigation practice will not solve all of the environmental issues and should be used in parallel with practices acting specifically on emission processes. In the case of GHG emissions, over time, the potential of carbon sequestration will decrease because the storage capacity of soils is limited. Therefore, it is a mitigation practice and not a true sustainable practice in the sense that it will not continue indefinitely; and second, because carbon sequestration is limited in time, although benefits are very important, this practice will not be able to solve the climate change issue as long as GHG emissions keep increasing.

Animal productivity or the rate of weight gain is an important determinant of the carbon footprint of beef production. Grass-finished cattle tend to reduce their carbon footprint by consuming forage already grown, requiring fewer inputs. This effect may be nullified from a carbon footprint perspective because their rate of weight gain is less than a grain-fed, feedlot finished animal, and they must spend more time on pasture, consuming feed and producing $CH_4$ in order to reach market weight. The fact that the $CH_4$ emission factor (Ym) per unit of feed consumed is substantially lower for grain-finished cattle compounds this effect (Van Haarlem, Desjardins, Gao, Flesch, & Li, 2008). In pasture based systems, such as the Lac Du Bois grasslands, an increase in animal productivity will be highly dependent on pasture management, with the goal of increasing forage productivity and feed digestibility, so as to maximize weight gain and animal density. In these systems, the forage species, as well as the time and duration of grazing are extremely important management decisions. The obvious environmental risk associated with extensive pasture-based systems is overgrazing.

As discussed in Chapter 4, there are several approved protocols which may be applicable to sectors of the B.C. livestock industry. Among these, it was determined once again that diet manipulation is probably the best option for B.C. cattle producers to mitigate GHG emissions. Implementing improvements in the diet in order to qualify for carbon trading benefits will likely need to take place in a feedlot, where diet manipulations can be stringently implemented and documented. In the case of a grass-fed beef operation and or backgrounding scenario, the potential to realize benefits may be reduced.

In addition to protocols currently approved, several GHG emission strategies were explored which may be applicable for B.C. cattle producers. Among these, there are two project types that have reached consideration for potential protocol development in Alberta. Of particular interest, the “Conversion to Perennials” protocol is intended to reward participants for achieving GHG emission removals and reductions associated with converting annual cropland to perennial grassland (Janzen & Haugen-Kozyra, 2012). Specifically, the protocol compares changes in GHG emissions from a "baseline" condition where land is managed for annual crops and a "project" condition where these annual crops are converted to perennial forage, which is harvested for hay or grazed by ruminants. There are a number of scenarios possible, and in all of them an increased removal of GHG emissions through sequestration is expected. On the surface, it would appear this protocol opportunity would not be very applicable to the majority of the BC cattle sector, in that there is little, if any, land currently managed for annual crop production in BC that would be appropriate for conversion to a perennial forage application. Notwithstanding, there is consideration within this protocol for "rejuvenation of tame grasslands", which specifies that any treatment to increase productivity or quality of an existing perennial forage stand will be considered rejuvenation, and will qualify for participation in the protocol. The protocol will use sequestration coefficients associated with land use change from cropland to perennials as have been derived for Canada's National Inventory Report (NIR), and are aligned with the methods used in Holos. The coefficients derived for Canada's NIR convert to 2.02 t $CO_2e$ $ha^{-1}$ $yr^{-1}$ for the Semi-arid prairies, and 2.05 t $CO_2e$ $ha^{-1}$ $yr^{-1}$ for the Parkland. (Holos modeling work as presented in Chapter 3 reported sequestration rates, as a consequence of the improvement scenarios modelled, of approximately 2.10 t $CO_2e$ $ha^{-1}$ $yr^{-1}$ from the Lac Du Bois grasslands). The new protocol will most likely use Canada NIR data and Holos to quantify coefficients for reductions in: energy emission factors; upstream fertilizer emissions; $N_2O$ emissions; and $CH_4$ emissions. This is essentially what was modelled in Chapter 3. It may be entirely possible to adapt the Lac Du Bois grassland improvement scenarios as outlined in our Holos model to conform to the guidelines in any new "Conversion to Perennials" protocol.

Management changes to reduce emissions at the source are important in addressing GHG emission issues in the BC livestock industry. This research has clearly demonstrated that practices complementing the reductions through removals associated with carbon sequestration are also of inordinate importance. A very relevant aspect of this work, that was not explored in this study (that every producer would have to evaluate), is the "willingness to pay/adapt", decision making process. Producers may have very positive attitudes toward sustainability and the environment, but because of concerns about financial cost/benefits, implementation, and risk, the acceptance levels of adopting practices that may reduce the carbon footprint of beef production in the Lac Du Bois grasslands ultimately needs to be examined more closely in the future.

Implementing changes to existing practices requires careful evaluation of the potential costs and benefits, but methods of evaluating the trade-offs and consequences of implementation are not well understood in many cases. Better data, improved government farm extension services, and utilization of models such as Holos, will help producers make informed decisions regarding the implementation of improvements toward enhancing agricultural productivity and environmental stewardship. The challenges facing agriculture are unprecedented, and overcoming these challenges will require revolutionary approaches to solve concurrent global food production and sustainability issues. In short, new agricultural approaches must deliver more human value, to those that need it most, with the least environmental damage (Foley et al., 2011).

## REFERENCE LIST


Ahmed, M. T. (2002). Millennium ecosystem assessment. *Environmental Science and Pollution Research*, *9*(4), 219–220. doi:10.1007/BF02987493

Alberta Environment. (2008). Specified gas emitters regulation: Offset credit project guidance document. Version 1.2. Alberta Environment, Edmonton, Alta. Retrieved from www.carbonoffsetsolutions.ca

Alemu, A., Ominski, K. H., & Kebreab, E. (2011). Estimation of enteric methane emissions trends (1990–2008) from Manitoba beef cattle using empirical and mechanistic models. *Canadian Journal of Animal Science*, *91*(2), 305–321. doi:10.4141/cjas2010-009

Ambrosi, P., & Janzen, H. H. (2005). Towards a revised coefficient for estimating $N_2O$ emissions from legumes. *Nutrient Cycling in Agroecosystems*, *73*(2-3), 171–179. doi:10.1007/s10705-005-0357-9

Andrew, R., & Forgie, V. (2008). A three-perspective view of greenhouse gas emission responsibilities in New Zealand. *Ecological Economics*, *68*(1–2), 194–204. doi:10.1016/j.ecolecon.2008.02.016

Arthur, P. F., Donoghue, K. A., Herd, R. M., & Hegarty, R. S. (2008). The role of animal genetic improvement in reducing greenhouse gas emissions from beef cattle. *Association for Advancement in Animal Breeding Genetics*, *18*, 472–475.

Aulakh, M. S., Wassmann, R., & Rennenberg, H. (2001). Methane emissions from rice fields—quantification, mechanisms, role of management, and mitigation options. In *Advances in Agronomy* (Vol. Volume 70, pp. 193–260). Academic Press. Retrieved from http://www.sciencedirect.com/science/article/pii/S0065211301700065

Basarab, J. A., Baron, D., & Darling, T. (2007a). Carbon credit potential of feeding edible oils to feedlot cattle. What is the size of the prize? Alberta Agriculture and Rural Development, Lacombe Research Centre.

Basarab, J. A., Baron, D., & Darling, T. (2007b). Carbon credit potential of reducing the age at slaughter in beef cattle. What is the size of the prize? Alberta Agriculture and Rural Development, Lacombe Research Centre.

Basarab, J. A., Baron, V., López-Campos, Ó., Aalhus, J., Haugen-Kozyra, K., & Okine, E. (2012). Greenhouse gas emissions from calf- and yearling-fed beef production systems, with and without the use of growth promotants. *Animals*, *2*(2), 195–220. doi:10.3390/ani2020195

Basarab, J. A., Baron, V. S., & Okine, E. K. (2009). Discovering nutrition related opportunities in the carbon credit system for beef cattle. 30th Western Nutrition Conference, Winnipeg, Manitoba, Canada.

Basarab, J. A., Price, M. A., Aalhus, J. L., Okine, E. K., Snelling, W. M., & Lyle, K. L. (2003). Residual feed intake and body composition in young growing cattle. *Canadian Journal of Animal Science*, *83*(2), 189–204. doi:10.4141/A02-065

Beauchemin, K. A., Janzen, H. H., Little, S. M., McAllister, T. A., & McGinn, S. M. (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. doi:10.1016/j.anifeedsci.2011.04.047

Beauchemin, K. A., Janzen, H., Little, S. M., McAllister, T. A., & McGinn, S. M. (2010). Life cycle assessment of greenhouse gas emissions from beef production in western Canada: A case study. *Agricultural Systems*, *103*(6), 371–379. doi:10.1016/j.agsy.2010.03.008

Beauchemin, K. A., Kreuzer, M., O'Mara, F., & McAllister, T. A. (2008). Nutritional management for enteric methane abatement: a review. *Australian Journal of Experimental Agriculture*, *48*(2), 21–27.

Beauchemin, K. A., McAllister, T. A., & McGinn, S. M. (2009). Dietary mitigation of enteric methane from cattle. *CAB Reviews: Perspectives in Agriculture, Veterinary Science, Nutrition and Natural Resources*, *4*(035), 1–18. doi:10.1079/PAVSNNR20094035

Beauchemin, K. A., & McGinn, S. M. (2005). Methane emissions from feedlot cattle fed barley or corn diets. *Journal of Animal Science*, *83*(3), 653–661.

Beauchemin, K. A., & McGinn, S. M. (2006). Methane emissions from beef cattle: Effects of fumaric acid, essential oil, and canola oil. *Journal of Animal Science*, *84*(6), 1489–1496.

Boadi, D. A., Benchaar, C., Chiquette, J., & Massé, D. (2004). Mitigation strategies to reduce enteric methane emissions from dairy cows: Update review. *Canadian Journal of Animal Science*, *84*(3), 319–335. doi:10.4141/A03-109

Boadi, D. A., & Wittenberg, K. M. (2002). Methane production from dairy and beef heifers fed forages differing in nutrient density using the sulphur hexafluoride ($SF_6$) tracer gas technique. *Canadian Journal of Animal Science*, *82*(2), 201–206. doi:10.4141/A01-017

Boadi, D. A., Wittenberg, K. M., & Kennedy, A. D. (2002). Validation of the sulphur hexafluoride ($SF_6$) tracer gas technique for measurement of methane and carbon dioxide production by cattle. *Canadian Journal of Animal Science*, *82*(2), 125–131. doi:10.4141/A01-054

Boadi, D. A., Wittenberg, K. M., & McCaughey, W. (2002). Effects of grain supplementation on methane production of grazing steers using the sulphur ($SF_6$) tracer gas technique. *Canadian Journal of Animal Science*, *82*(2), 151–157. doi:10.4141/A01-038

Bouwman, A. F., Boumans, L. J. M., & Batjes, N. H. (2002). Modeling global annual $N_2O$ and NO emissions from fertilized fields. *Global Biogeochemical Cycles*, *16(4)*, 28–1–28–9. doi:200210.1029/2001GB001812

British Columbia Ranching Task Force. (2009). British Columbia ranching task force report to government. Retrieved from http://www.ranchingtaskforce.gov.bc.ca/attachments/ranching_task_force_2009.pdf

Bruce, J. P., Frome, M., Haites, E., Janzen, H., Lal, R., & Paustian, K. (1999). Carbon sequestration in soils. *Journal of Soil and Water Conservation*, *54*(1), 382–389.

Canadell, J. G., Quéré, C. L., Raupach, M. R., Field, C. B., Buitenhuis, E. T., Ciais, P., … Marland, G. (2007). Contributions to accelerating atmospheric $CO_2$ growth from economic activity, carbon intensity, and efficiency of natural sinks. *Proceedings of the National Academy of Sciences*, *104*(47), 18866–18870. doi:10.1073/pnas.0702737104

Capoor, K., & Ambrosi, P. (2007). State and trends of the carbon market 2007. World Bank Carbon Finance Unit. Retrieved from http://carbonfinance.org/docs/Carbon_Trends_2007- _FINAL_-_May_2.pdf

Chaves, A. V., Thompson, L. C., Iwaasa, A. D., Scott, S. L., Olson, M. E., Benchaar, C., … McAllister, T. A. (2006). Effect of pasture type (alfalfa vs. grass) on methane and carbon dioxide production by yearling beef heifers. *Canadian Journal of Animal Science*, *86*(3), 409–418. doi:10.4141/A05-081

Clark, H., Pinares-Patiño, C., De Klein, C., & McGilloway, D. A. (2005). Methane and nitrous oxide emissions from grazed grasslands. *Grassland a global resource. Plenary and invited papers from the XX International Grassland Congress, Dublin, Ireland, 26 June-1 July 2005*, 279–293.

Clemens, J., Trimborn, M., Weiland, P., & Amon, B. (2006). Mitigation of greenhouse gas emissions by anaerobic digestion of cattle slurry. *Agriculture, Ecosystems & Environment*, *112*(2–3), 171–177. doi:10.1016/j.agee.2005.08.016

Cole, C. V., Duxbury, J., Freney, J., Heinemeyer, O., Minami, K., Mosier, A., … Zhao, Q. (1997). Global estimates of potential mitigation of greenhouse gas emissions by agriculture. *Nutrient Cycling in Agroecosystems*, *49*(1), 221–228. doi:10.1023/A:1009731711346

Conant, R. T., Paustian, K., Del Grosso, S. J., & Parton, W. J. (2005). Nitrogen pools and fluxes in grassland soils sequestering carbon. *Nutrient Cycling in Agroecosystems*, *71*(3), 239–248. doi:10.1007/s10705-004-5085-z

Conant, R. T., Paustian, K., & Elliott, E. T. (2001). Grassland management and conversion into grassland: effects on soils carbon. *Ecological Applications*, *11*(2), 343–355. doi:10.1890/1051-0761(2001)011[0343:GMACIG]2.0.CO;2

Conant, R. T., Six, J., & Paustian, K. (2003). Land use effects on soil carbon fractions in the southeastern United States. I. Management-intensive versus extensive grazing. *Biology and Fertility of Soils*, *38*(6), 386–392. doi:10.1007/s00374-003-0652-z

Davies, B., Baulcombe, D., Crute, I., Dunwell, J., Gale, M., Jones, J., … Toulmin, C. (2009). Reaping the benefits: science and the sustainable intensification of global agriculture. Report. Retrieved from http://eprints.lancs.ac.uk/56034/

DeFries, R. S., Foley, J. A., & Asner, G. P. (2004). Land-use choices: balancing human needs and ecosystem function. *Frontiers in Ecology and the Environment*, *2*(5), 249–257. doi:10.1890/1540-9295(2004)002[0249:LCBHNA]2.0.CO;2

Derner, J. D., Boutton, T. W., & Briske, D. D. (2006). Grazing and ecosystem carbon storage in the North American Great Plains. *Plant and Soil*, *280*(1-2), 77–90. doi:10.1007/s11104-005-2554-3

Derner, J. D., Briske, D. D., & Boutton, T. W. (1997). Does grazing mediate soil carbon and nitrogen accumulation beneath C4, perennial grasses along an environmental gradient? *Plant and Soil*, *191*(2), 147–156. doi:10.1023/A:1004298907778

Derner, J. D., Schuman, G. E., Jawson, M., Shafer, S. R., Morgan, J. A., Polley, H. W., … Harper, L. A. (2005). USDA-ARS global change research on rangelands and pasturelands. *Rangelands*, *27*(5), 36–42. doi:10.2111/1551-501X(2005)27[36:UGCROR]2.0.CO;2

Desjardins, R. L., Kulshreshtha, S. N., Junkins, B., Smith, W., Grant, B., & Boehm, M. (2001). Canadian greenhouse gas mitigation options in agriculture. *Nutrient Cycling in Agroecosystems*, *60*(1), 317–326. doi:10.1023/A:1012697912871

Desjardins, R. L., Worth, D., Vergé, X., Maxime, D., Dyer, J., & Cerkowniak, D. (2012). Carbon Footprint of Beef Cattle. *Sustainability*, *4*(12), 3279–3301. doi:10.3390/su4123279

Eckard, R. J., Grainger, C., & de Klein, C. A. M. (2010). Options for the abatement of methane and nitrous oxide from ruminant production: A review. *Livestock Science*, *130*(1-3), 47–56. doi:10.1016/j.livsci.2010.02.010

Environment Canada. (2008). Greenhouse gas sources and sinks in Canada. National Inventory Report 1990-2006. Published on the website: http:/www.ec.gc.ca/pdb/GHG/inventory_report/2006_report/tdm-toc_eng.cfm.

Eswaran, H., Van Den Berg, E., & Reich, P. (1993). Organic carbon in soils of the world. *Soil Science Society of America Journal*, *57*(1), 192–194. doi:10.2136/sssaj1993.03615995005700010034x

FAO. (2009). The state of food in agriculture: Livestock in the balance. Food and Agriculture Organization of the United Nations, Rome, Italy.

Foley, J. A., DeFries, R., Asner, G. P., Barford, C., Bonan, G., Carpenter, S. R., … Snyder, P. K. (2005). Global consequences of land use. *Science*, *309*(5734), 570–574. doi:10.1126/science.1111772

Foley, J. A., Ramankutty, N., Brauman, K. A., Cassidy, E. S., Gerber, J. S., Johnston, M., … Zaks, D. P. M. (2011). Solutions for a cultivated planet. *Nature*, *478*(7369), 337–342. doi:10.1038/nature10452

Follett, R. F. (2001). Soil management concepts and carbon sequestration in cropland soils. *Soil and Tillage Research*, *61*(1–2), 77–92. doi:10.1016/S0167-1987(01)00180-5

Follett, R. F., Kimble, J. M., & Lal, R. (2001). *Potential of US grazing lands to sequester soil carbon.* Lewis Publishers, Boca Ratan, Florida.

Freibauer, A., Rounsevell, M. D. ., Smith, P., & Verhagen, J. (2004). Carbon sequestration in the agricultural soils of Europe. *Geoderma*, *122*(1), 1–23. doi:10.1016/j.geoderma.2004.01.021

Gao, Y. H., Luo, Wu, N., Chen, H., & Wang, G. X. (2008). Impacts of grazing intensity on nitrogen pools and nitrogen cycle in an alpine meadow on the Eastern Tibetan Plateau. *Applied Ecology and Environmental Research*, *6*(3), 69–79.

Government of Canada. (2011). 2011 Census of Agriculture. Retrieved from http://www.statcan.gc.ca/ca-ra2011/index-eng.htm

Gregorich, E. G., Rochette, P., VandenBygaart, A. J., & Angers, D. A. (2005). Greenhouse gas contributions of agricultural soils and potential mitigation practices in Eastern Canada. *Soil and Tillage Research*, *83*(1), 53–72. doi:10.1016/j.still.2005.02.009

Hassink, J. (1994). Effects of soil texture and grassland management on soil organic C and N and rates of C and N mineralization. *Soil Biology and Biochemistry*, *26*(9), 1221–1231. doi:10.1016/0038-0717(94)90147-3

Hutchinson, J. J., Campbell, C. A., & Desjardins, R. L. (2007). Some perspectives on carbon sequestration in agriculture. *Agricultural and Forest Meteorology*, *142*(2–4), 288–302. doi:10.1016/j.agrformet.2006.03.030

Ingram, L. J., Stahl, P. D., Schuman, G. E., Buyer, J. S., Vance, G. F., Ganjegunte, G. K., … Derner, J. D. (2008). Grazing impacts on soil carbon and microbial communities in a mixed-grass ecosystem. *Soil Science Society of America Journal*, *72*(4), 939–948. doi:10.2136/sssaj2007.0038

IPCC. (2006a). Guidelines for National Greenhouse Gas Inventories, Chapter 10: Emissions from livestock and manure management. Retrieved from http://www.ipcc-nggip.iges.or.jp/public/2006gl/pdf/4_10_Ch10_Livestock.pdf.

IPCC. (2006b). 2006 IPCC Guidelines for National Greenhouse Gas Inventories. Retrieved from http://www.ipcc-nggip.iges.or.jp/public/2006gl/index.html

IPCC. (2007). Climate Change 2007: The Physical Science Basis. Contribution of Working Group 1 to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press; Cambridge, UK.

Iwaasa, A. D. (2007). Strategies to recuce greenhouse gas emissions through feeding and grazing management. 19th Annual Conference of the Saskatchewan Soil Conservation Association, Saskatoon, SK, Canada.

Izaurralde, R. C., Williams, J. R., McGill, W. B., Rosenberg, N. J., & Jakas, M. C. Q. (2006). Simulating soil C dynamics with EPIC: Model description and testing against long-term data. *Ecological Modelling*, *192*(3–4), 362–384. doi:10.1016/j.ecolmodel.2005.07.010

Janzen, H. (2004). Carbon cycling in earth systems—a soil science perspective. *Agriculture, Ecosystems & Environment*, *104*(3), 399–417. doi:10.1016/j.agee.2004.01.040

Janzen, R., & Haugen-Kozyra, K. (2012). Workshop report for proposed conversion to perennials protocol. Alberta Agriculture and Rural Development.

Jayasundara, S., Wagner-Riddle, C., Parkin, G., Bertoldi, P., Warland, J., Kay, B., & Voroney, P. (2007). Minimizing nitrogen losses from a corn–soybean–winter wheat rotation with best management practices. *Nutrient Cycling in Agroecosystems*, *79*(2), 141–159. doi:10.1007/s10705-007-9103-9

Jenkinson, D. S., Andrew, S. P. S., Lynch, J. M., Goss, M. J., & Tinker, P. B. (1990). The turnover of organic carbon and nitrogen in soil [and discussion]. *Philosophical Transactions of the*

*Royal Society of London. Series B: Biological Sciences*, *329*(1255), 361–368. doi:10.1098/rstb.1990.0177

Johnson, D. E., Ward, G. M., & Torrent, J. (1992). The environmental impact of bovine somatotropin use in dairy cattle. *Journal of Environmental Quality*, *21*(2), 157–162. doi:10.2134/jeq1992.00472425002100020001x

Johnson, J. M.-F., Franzluebbers, A. J., Weyers, S. L., & Reicosky, D. C. (2007). Agricultural opportunities to mitigate greenhouse gas emissions. *Environmental Pollution*, *150*(1), 107–124. doi:10.1016/j.envpol.2007.06.030

Johnson, K. A., & Johnson, D. E. (1995a). Methane emissions from cattle. *Journal of Animal Science*, *73*(8), 2483 –2492.

Johnson, K., Huyler, M., Westberg, H., Lamb, B., & Zimmerman, P. (1994). Measurement of methane emissions from ruminant livestock using a sulfur hexafluoride tracer technique. *Environmental Science & Technology*, *28*(2), 359–362. doi:10.1021/es00051a025

Johnston, A. E., Poulton, P. R., & Coleman, K. (2009). Chapter 1 Soil organic matter: its importance in sustainable agriculture and carbon dioxide fluxes. In Donald L. Sparks (Ed.), *Advances in Agronomy* (Vol. Volume 101, pp. 1–57). Academic Press. Retrieved from http://www.sciencedirect.com/science/article/pii/S0065211308008018

Jordan, E., Lovett, D. K., Monahan, F. J., Callan, J., Flynn, B., & O'Mara, F. P. (2006). Effect of refined coconut oil or copra meal on methane output and on intake and performance of beef heifers. *Journal of Animal Science*, *84*(1), 162 –170.

Karlen, D. L., Rosek, M. J., Gardner, J. C., Allan, D. L., Alms, M. J., Bezdicek, D. F., … Staben, M. L. (1999). Conservation Reserve Program effects on soil quality indicators. *Journal of Soil and Water Conservation*, *54*(1), 439–444.

Kasimir-Klemedtsson, Å., Klemedtsson, L., Berglund, K., Martikainen, P., Silvola, J., & Oenema, O. (1997). Greenhouse gas emissions from farmed organic soils: a review. *Soil Use and Management*, *13*, 245–250. doi:10.1111/j.1475-2743.1997.tb00595.x

Kebreab, E., Johnson, K. A., Archibeque, S. L., Pape, D., & Wirth, T. (2008). Model for estimating enteric methane emissions from United States dairy and feedlot cattle. *Journal of Animal Science*, *86*(10), 2738–2748. doi:10.2527/jas.2008-0960

King, M. R. (2008). An overview of carbon markets and emissions trading: lessons for Canada. Bank of Canada Discussion Paper 2008-1.

Koneswaran, G., & Nierenberg, D. (2008). Global farm animal production and global warming: Impacting and mitigating climate change. *Environmental Health Perspectives*, *116*(5), 578–582. doi:10.1289/ehp.11034

Kopp, J. C., McCaughey, W. P., & Wittenberg, K. M. (2003). Yield, quality and cost effectiveness of using fertilizer and/or alfalfa to improve meadow bromegrass pastures. *Canadian Journal of Animal Science*, *83*(2), 291–298. doi:10.4141/A01-074

Kruger, C., & Vigil, F. (1979). Interseeding alfalfa for grassland improvement in the Northern Great Plains [USA]. In *Agricultural Reviews and Manuals ARM NC*. Presented at the 26. Alfalfa Improvement Conference. South Dakota State University (USA). 1978. Retrieved from http://agris.fao.org/agris-search/search/display.do?f=2012/OV/OV201201719001719.xml;US19810605147

Lal, R. (2004). Soil carbon sequestration impacts on global climate change and food security. *Science*, *304*(5677), 1623 –1627. doi:10.1126/science.1097396

Lassey, K. R. (2007). Livestock methane emission: From the individual grazing animal through national inventories to the global methane cycle. *Agricultural and Forest Meteorology*, *142*(2–4), 120–132. doi:10.1016/j.agrformet.2006.03.028

Lassey, K. R. (2008). Livestock methane emission and its perspective in the global methane cycle. *Australian Journal of Experimental Agriculture*, *48*(2), 114–118.

Lassey, K. R., Walker, C. F., McMillan, A. M. S., & Ulyatt, M. J. (2001). On the performance of $SF_6$ permeation tubes used in determining methane emission from grazing livestock. *Chemosphere - Global Change Science*, *3*(4), 367–376. doi:10.1016/S1465-9972(01)00017-4

Liebig, M. A., Morgan, J. A., Reeder, J. D., Ellert, B. H., Gollany, H. T., & Schuman, G. E. (2005). Greenhouse gas contributions and mitigation potential of agricultural practices in northwestern USA and western Canada. *Soil and Tillage Research*, *83*(1), 25–52. doi:10.1016/j.still.2005.02.008

Little, S., Linderman, J., Maclean, K., & Janzen, H. (2008). HOLOS - a tool to estimate and reduce greenhouse gas emissions from farms. Methodology and algorithms for versions 1.1.x. Agriculture and Agri-Food Canada. Retrieved from http://www4.agr.gc.ca/AAFC-AAC/display-afficher. do?id=1226606460726&lang=eng#s1)

Lovett, D. K., Shalloo, L., Dillon, P., & O'Mara, F. P. (2006). A systems approach to quantify greenhouse gas fluxes from pastoral dairy production as affected by management regime. *Agricultural Systems*, *88*(2–3), 156–179. doi:10.1016/j.agsy.2005.03.006

Mangino, J., Peterson, K., & Jacobs, H. (2002). Development of an emissions model to estimate methane from enteric fermentation in cattle. *In 12$^{th}$ International Emission Inventory Conference- "Emission Inventories-Applying New Technologies*.

McAllister, T. A., Cheng, K.-J., Okine, E. K., & Mathison, G. W. (1996). Dietary, environmental and microbiological aspects of methane production in ruminants. *Canadian Journal of Animal Science*, *76*(2), 231–243. doi:10.4141/cjas96-035

McCarl, B. A., & Schneider, U. A. (2000). U.S. Agriculture's Role in a Greenhouse Gas Emission Mitigation World: An Economic Perspective. *Review of Agricultural Economics*, *22*(1), 134–159. doi:10.1111/1058-7195.t01-1-00011

McCaughey, W. P., Wittenberg, K., & Corrigan, D. (1997). Methane production by steers on pasture. *Canadian Journal of Animal Science*, *77*(3), 519–524. doi:10.4141/A96-137

McCaughey, W. P., Wittenberg, K., & Corrigan, D. (1999). Impact of pasture type on methane production by lactating beef cows. *Canadian Journal of Animal Science*, *79*(2), 221–226. doi:10.4141/A98-107

McGinn, S. M., Beauchemin, K. A., Coates, T., & Colombatto, D. (2004). Methane emissions from beef cattle: Effects of monensin, sunflower oil, enzymes, yeast, and fumaric acid. *Journal of Animal Science*, *82*(11), 3346 –3356.

McGinn, S. M., Beauchemin, K. A., Iwaasa, A. D., & McAllister, T. A. (2006). Assessment of the Sulfur Hexafluoride ($SF_6$) Tracer Technique for Measuring Enteric Methane Emissions from Cattle. *Journal of Environment Quality*, *35*(5), 1686–1691. doi:10.2134/jeq2006.0054

Melvin, G. R. (2003). Carbon sequestration and biomass energy offset: theoretical, potential and achievable capacities globally, in Europe and the UK. *Biomass and Bioenergy*, *24*(2), 97–116. doi:10.1016/S0961-9534(02)00103-4

Metz, B., Davidson, O., de Coninck, H., Loos, M., & Meyer, L. (2005). IPCC special report on carbon dioxide capture and storage. Intergovernmental Panel on Climate Change, Geneva (Switzerland). Working Group lll.

Miller, R. W., & Donahue, R. L. (1990). *Soils: an introduction to soils and plant growth*, (Ed. 6), xiv + 768 pp. Prentice-Hall International Inc..

Ministry of Environment, Lands and Parks. (2000). Lac Du Bois Grasslands Park. Management plan background document. Retrieved from http://www.env.gov.bc.ca/bcparks/planning/mgmtplns/lacdubois/lacdubois.pdf

Monteny, G.-J., Bannink, A., & Chadwick, D. (2006). Greenhouse gas abatement strategies for animal husbandry. *Agriculture, Ecosystems & Environment*, *112*(2–3), 163–170. doi:10.1016/j.agee.2005.08.015

Mortenson, M. C., Schuman, G. E., & Ingram, L. J. (2004). Carbon sequestration in rangelands interseeded with yellow-flowering alfalfa (Medicago sativa ssp. falcata). *Environmental Management*, *33*(1), S475–S481. doi:10.1007/s00267-003-9155-9

Mosier, A. R., Duxbury, J. M., Freney, J. R., Heinemeyer, O., Minami, K., & Johnson, D. E. (1998). Mitigating agricultural emissions of methane. *Climatic Change*, *40*(1), 39–80. doi:10.1023/A:1005338731269

Newbold, C. J., López, S., Nelson, N., Ouda, J. O., Wallace, R. J., & Moss, A. R. (2005). Propionate precursors and other metabolic intermediates as possible alternative electron acceptors to methanogenesis in ruminal fermentation in vitro. *British Journal of Nutrition*, *94*(01), 27–35. doi:10.1079/BJN20051445

Nkrumah, J. D., Okine, E. K., Mathison, G. W., Schmid, K., Li, C., Basarab, J. A., … Moore, S. S. (2006). Relationships of feedlot feed efficiency, performance, and feeding behavior with metabolic rate, methane production, and energy partitioning in beef cattle. *Journal of Animal Science*, *84*(1), 145 –153.

Nkrumah, J. D., Sherman, E. L., Li, C., Marques, E., Crews, D. H., Bartusiak, R., … Moore, S. S. (2007). Primary genome scan to identify putative quantitative trait loci for feedlot growth rate, feed intake, and feed efficiency of beef cattle. *Journal of Animal Science*, *85*(12), 3170 –3181. doi:10.2527/jas.2007-0234

Nyborg, M., Malhi, S. S., Solberg, E. D., & Izaurralde, R. C. (1999). Carbon storage and light fraction C in a grassland Dark Gray Chernozem soil as influenced by N and S fertilization. *Canadian Journal of Soil Science*, *79*(2), 317–320. doi:10.4141/S98-048

Oelbermann, M., Voroney, P. R., & Gordon, A. M. (2004). Carbon sequestration in tropical and temperate agroforestry systems: a review with examples from Costa Rica and southern Canada. *Agriculture, Ecosystems & Environment*, *104*(3), 359–377. doi:10.1016/j.agee.2004.04.001

Ogle, S. M., Breidt, F. J., & Paustian, K. (2005). Agricultural management impacts on soil organic carbon storage under moist and dry climatic conditions of temperate and tropical regions. *Biogeochemistry*, *72*(1), 87–121. doi:10.1007/s10533-004-0360-2

Ogle, S. M., Conant, R. T., & Paustian, K. (2004). Deriving grassland management factors for a carbon accounting method developed by the intergovernmental panel on climate change. *Environmental Management*, *33*(4), 474–484. doi:10.1007/s00267-003-9105-6

Ominski, K. H., Boadi, D. A., & Wittenberg, K. M. (2006). Enteric methane emissions from backgrounded cattle consuming all-forage diets. *Canadian Journal of Animal Science*, *86*(3), 393–400. doi:10.4141/A05-051

Ominski, K. H., Boadi, D. A., Wittenberg, K. M., Fulawka, D. L., & Basarab, J. A. (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. doi:10.4141/CJAS06034

Parton, W. J., Stewart, J. W. B., & Cole, C. V. (1988). Dynamics of C, N, P and S in grassland soils: a model. *Biogeochemistry*, *5*(1), 109–131. doi:10.1007/BF02180320

Paustian, K., Antle, J., Sheehan, J., & Paul, E. (2006). Agriculture's role in greenhouse gas mitigation. Pew Center on Global Climate Change. Arlington VA. Retrieved from http://www.pewclimate.org/global-warming-in-depth/all_reports/agriculture_s_role_mitigation/index.cfm

Paustian, K., Six, J., Elliott, E. T., & Hunt, H. W. (2000). Management options for reducing $CO_2$ emissions from agricultural soils. *Biogeochemistry*, *48*(1), 147–163.

Pelletier, N., Pirog, R., & Rasmussen, R. (2010). Comparative life cycle environmental impacts of three beef production strategies in the Upper Midwestern United States. *Agricultural Systems*, *103*(6), 380–389. doi:10.1016/j.agsy.2010.03.009

Peters, G. M., Rowley, H. V., Wiedemann, S., Tucker, R., Short, M. D., & Schulz, M. (2010). Red meat production in Australia: life cycle assessment and comparison with overseas studies. *Environmental science & technology*, *44*(4), 1327–1332.

Pinares-Patiño, C. S., Machmüller, A., Molano, G., Smith, A., Vlaming, J. B., & Clark, H. (2008). The $SF_6$ tracer technique for measurements of methane emission from cattle – effect of tracer permeation rate. *Canadian Journal of Animal Science*, *88*(2), 309–320. doi:10.4141/CJAS07117

Post, W. M., Izaurralde, R. C., Jastrow, J. D., McCARL, B. A., Amonette, J. E., Bailey, V. L., … Zhou, J. (2004). Enhancement of carbon sequestration in US soils. *BioScience*, *54*(10), 895. doi:10.1641/0006-3568(2004)054[0895:EOCSIU]2.0.CO;2

Rabe, B. G. (2007). Beyond Kyoto: Climate change policy in multilevel governance systems. *Governance*, *20*(3), 423–444. doi:10.1111/j.1468-0491.2007.00365.x

Ramankutty, N., Evan, A. T., Monfreda, C., & Foley, J. A. (2008). Farming the planet: 1. Geographic distribution of global agricultural lands in the year 2000. *Global Biogeochemical Cycles*, *22*(1), n/a–n/a. doi:10.1029/2007GB002952

Rance, L. (2010). How green is grass-fed beef? Debate ongoing. Retrieved from http://www.winnipegfreepress.com/opinion/columnists/how-green-is-grass-fed-beef-debate-ongoing-81060342.html

Reeder, J., & Schuman, G. (2002). Influence of livestock grazing on C sequestration in semi-arid mixed-grass and short-grass rangelands. *Environmental Pollution*, *116*(3), 457–463. doi:10.1016/S0269-7491(01)00223-8

Reeder, J., Schuman, G., & Bowman, R. (1998). Soil C and N changes on conservation reserve program lands in the Central Great Plains. *Soil and Tillage Research*, *47*(3–4), 339–349. doi:10.1016/S0167-1987(98)00122-6

Richter, B. (2004). Using ethanol as an energy source. *Science*, *305*(5682), 340. doi:10.1126/science.305.5682.340b

Rochette, P., Worth, D. E., Lemke, R. L., McConkey, B. G., Pennock, D. J., Wagner-Riddle, C., & Desjardins, R. J. (2008). Estimation of $N_2O$ emissions from agricultural soils in Canada. I. Development of a country-specific methodology. *Canadian Journal of Soil Science*, *88*(5), 641–654. doi:10.4141/CJSS07025

Saidur, R., Islam, M. R., Rahim, N. A., & Solangi, K. H. (2010). A review on global wind energy policy. *Renewable and Sustainable Energy Reviews*, *14*(7), 1744–1762. doi:10.1016/j.rser.2010.03.007

Samson, F. B., Knopf, F. L., & Ostlie, W. R. (2004). Great Plains ecosystems: past, present, and future. *Wildlife Society Bulletin*, *32*(1), 6–15. doi:10.2193/0091-7648(2004)32[6:GPEPPA]2.0.CO;2

Schlesinger, W. H. (1999). Carbon sequestration in soils. *Science 25*, *Vol. 284*(no. 5423), p. 2095.

Schuman, G. ., Janzen, H. ., & Herrick, J. . (2002). Soil carbon dynamics and potential carbon sequestration by rangelands. *Environmental Pollution*, *116*(3), 391–396. doi:10.1016/S0269-7491(01)00215-9

Schuman, G. E., Ingram, L. J., & Parkin, T. B. (2004). Nitrous oxide emissions from a northern mixed-grass rangeland interseeded with yellow-flowering alfalfa (Medicago sativa ssp. falcata). *Society for Range Management Meeting Abstracts*, p. 323.

Schuman, G. E., Reeder, J. D., Manley, J. T., Hart, R. H., & Manley, W. A. (1999). Impact of grazing management on the carbon and nitrogen balance of a mixed-grass rangeland. *Ecological Applications*, *9*(1), 65–71. doi:10.1890/1051-0761(1999)009[0065:IOGMOT]2.0.CO;2

Sejian, V., Lal, R., Lakritz, J., & Ezeji, T. (2010). Measurement and prediction of enteric methane emission. *International Journal of Biometeorology*, *55*(1), 1–16. doi:10.1007/s00484-010-0356-7

Shantz, H. L. (1954). The place of grasslands in the Earth's cover. *Ecology*, *35*(2), 143–145. doi:10.2307/1931110

Smeets, E. M. W., Faaij, A. P. C., Lewandowski, I. M., & Turkenburg, W. C. (2007). A bottom-up assessment and review of global bio-energy potentials to 2050. *Progress in Energy and Combustion Science*, *33*(1), 56–106. doi:10.1016/j.pecs.2006.08.001

Smith, K. A., & Conen, F. (2004). Impacts of land management on fluxes of trace greenhouse gases. *Soil Use and Management*, *20*(2), 255–263. doi:10.1111/j.1475-2743.2004.tb00366.x

Smith, P., Martino, D., Cai, Z., Gwary, D., Janzen, H., Kumar, P., … Smith, J. (2008). Greenhouse gas mitigation in agriculture. *Philosophical Transactions of the Royal Society B: Biological Sciences*, *363*(1492), 789 –813. doi:10.1098/rstb.2007.2184

Smith, P., Martino, D., Cai, Z., Gwary, D., Janzen, H., Kumar, P., … Towprayoon, S. (2007). Policy and technological constraints to implementation of greenhouse gas mitigation options in agriculture. *Agriculture, Ecosystems & Environment*, *118*(1–4), 6–28. doi:10.1016/j.agee.2006.06.006

Smith, W. N., Grant, B., Desjardins, R. L., Lemke, R., & Li, C. (2004). Estimates of the interannual variations of $N_2O$ emissions from agricultural soils in Canada. *Nutrient Cycling in Agroecosystems*, *68*(1), 37–45. doi:10.1023/B:FRES.0000012230.40684.c2

Soussana, J.-F., Loiseau, P., Vuichard, N., Ceschia, E., Balesdent, J., Chevallier, T., & Arrouays, D. (2004). Carbon cycling and sequestration opportunities in temperate grasslands. *Soil Use and Management*, *20*(2), 219–230. doi:10.1111/j.1475-2743.2004.tb00362.x

Spatari, S., Zhang, Y., & MacLean, H. L. (2005). Life cycle assessment of switchgrass- and corn stover-derived ethanol-fueled automobiles. *Environ. Sci. Technol.*, *39*(24), 9750–9758. doi:10.1021/es048293+

Steinfeld, H., & Wassenaar, T. (2007). The role of livestock production in carbon and nitrogen cycles. *Annual Review of Environment and Resources*, *32*(1), 271–294. doi:10.1146/annurev.energy.32.041806.143508

Subak, S. (1999). Global environmental costs of beef production. *Ecological Economics*, *30*(1), 79–91.

Swift, R. (2001). Sequestration of carbon by soil. *Soil Science November 2001*, *166*(11), 858–871.

Turner, C. L., Blair, J. M., Schartz, R. J., & Neel, J. C. (1997). Soil N and plant responses to fire, topography, and supplemental N in tallgrass prairie. *Ecology*, *78*(6), 1832–1843. doi:10.2307/2266105

Ulyatt, M. J., Lassey, K. R., Shelton, I. D., & Walker, C. F. (2002). Methane emission from dairy cows and wether sheep fed subtropical grass-dominant pastures in midsummer in New Zealand. *New Zealand Journal of Agricultural Research*, *45*(4), 227–234. doi:10.1080/00288233.2002.9513513

Ulyatt, M. J., McCrabb, G. J., Baker, S. K., & Lassey, K. R. (1999). Accuracy of $SF_6$ tracer technology and alternatives for field measurements. *Australian Journal of Agricultural Research*, *50*(8), 1329–1334.

Van Haarlem, R. P., Desjardins, R. L., Gao, Z., Flesch, T. K., & Li, X. (2008). Methane and ammonia emissions from a beef feedlot in western Canada for a twelve-day period in the fall. *Canadian Journal of Animal Science*, *88*(4), 641–649. doi:10.4141/CJAS08034

Van Nevel, C., & Demeyer, D. I. (1995). Lipolysis and biohydrogenation of soybean oil in the rumen in vitro: inhibition by antimicrobials. *Journal of Dairy Science*, *78*(12), 2797–2806. doi:10.3168/jds.S0022-0302(95)76910-7

VandenBygaart, A. J., Gregorich, E. G., & Angers, D. A. (2003). Influence of agricultural management on soil organic carbon: A compendium and assessment of Canadian studies. *Canadian Journal of Soil Science*, *83*(4), 363–380. doi:10.4141/S03-009

Vergé, X. P. C., De Kimpe, C., & Desjardins, R. L. (2007). Agricultural production, greenhouse gas emissions and mitigation potential. *Agricultural and Forest Meteorology*, *142*(2–4), 255–269. doi:10.1016/j.agrformet.2006.06.011

Vergé, X. P. C., Dyer, J. A., Desjardins, R. L., & Worth, D. (2008). Greenhouse gas emissions from the Canadian beef industry. *Agricultural Systems*, *98*(2), 126–134. doi:10.1016/j.agsy.2008.05.003

Vergé, X. P. C., Worth, D. E., Desjardins, R. L., McConkey, B. G., & Dyer, J. A. (2012). LCA of animal production. In J. I. Boye & Y. Arcand (Eds.), *Green Technologies in Food Production and Processing* (pp. 83–113). Springer US. Retrieved from http://link.springer.com.ezproxy.tru.ca/chapter/10.1007/978-1-4614-1587-9_5

Wright, A. D. G., Kennedy, P., O'Neill, C. J., Toovey, A. F., Popovski, S., Rea, S. M., … Klein, L. (2004). Reducing methane emissions in sheep by immunization against rumen methanogens. *Vaccine*, *22*(29–30), 3976–3985. doi:10.1016/j.vaccine.2004.03.053

Wright, T., & Lackey, R. (2008). Definitions of feed manufacturing and livestock nutrition terms. Ontario Ministry of Agriculture, Food and Rural Affairs. Retrieved from http://www.omafra.gov.on.ca/english/livestock/dairy/facts/08-039.htm

Yan, X., Ohara, T., & Akimoto, H. (2003). Development of region-specific emission factors and estimation of methane emission from rice fields in the East, Southeast and South Asian countries. *Global Change Biology*, *9*(2), 237–254. doi:10.1046/j.1365-2486.2003.00564.x

Yates, A. G., Bailey, R. C., & Schwindt, J. A. (2007). Effectiveness of best management practices in improving stream ecosystem quality. *Hydrobiologia*, *583*(1), 331–344. doi:10.1007/s10750-007-0619-4

Yungblut, D. (2012). National forage & grassland assessment. Canadian Forage & Grassland Association, Brandon, Manitoba, Canada.