Assessment of GHGs from Animal Agriculture with a Focus on Manure Application and Dairy Operations

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Executive Summary

Coping with global warming is one of the most important concerns today since it profoundly affects all living and non-living things. A global consensus has long been accepted that to relieve the impacts of global warming, the emissions of greenhouse gases must be reduced. In 2015, 195 countries signed the Paris Agreement, aiming at keeping global warming well below 2°C.

It is widely acknowledged that greenhouse gas is the major contributor to global warming. The linkage between the burning of fossil fuels and global warming might be the first to come to mind when talking about global warming. Globally, carbon dioxide emission from the burning of fossil fuels is indeed the top source of greenhouse gas emissions, other types of greenhouse gas emissions are also noteworthy because gases, such as methane and nitrous oxide, have much greater warming potential than carbon dioxide.

This study is primarily a summary of the globe's, Canada's and British Columbia's greenhouse gas emissions with a focus on animal agriculture. To have a better understanding of the greenhouse gas emissions from animal agriculture, a case study of a dairy farm was conducted, focusing on manure management of the farm.

Introduction

Global warming is the continuous rise, including the average temperature of the earth's climate system. The phenomenon has been observed since the pre-Industrial Age (approximately 1850-1900) and is recognized as one of today's toughest challenges. The World Meteorological Organization (WMO) reported in 2019 that compared to the pre-Industrial Age, the average global temperature has increased by 1.1°C since 2011-2015. An independent analysis conducted by the National Aeronautics and Space Administration (NASA) and National Oceanic and Atmospheric Administration (NOAA) indicated that in 2019, global surface temperatures were the second warmest since 1880 when data was first recorded. The Intergovernmental Panel on Climate Change (IPCC) confirmed that the mean global warming rate was 0.6°C ± 0.2°C during the 20th century (IPCC, 2001). Many long-term monitoring studies give evidence of anomalous climate in the past few decades compared with past climate variation. Global warming has been profoundly affecting every aspect of the planet and human society. Immediate impacts include, but are not limited to, shrinking ice, sea-levels rising, ocean heat, wildfires, and other extreme weather events. Further impacts of global warming can affect the survival of almost all species on the earth. For human society, living on warmer earth means being faced with the direct threats of losing habitats, the change in food and water resources, and coping with many subsequent impacts on agriculture, economy, politics, and culture.

According to a report from the Government of Canada (2019), by the year 2016, Canada's mean annual temperature has increased by 1.7 °C. This is compared to 1948, which is almost double that of the world's warming rate. Based on the existing data, the projection of a 1.8 °C to 6.3 °C increase in Canada's mean annual temperature by the end of the century was suggested.

In 2015, British Columbia had the fifth-highest GHG emissions among all the provinces in Canada—the top four provinces with the highest GHG emissions being Alberta, Ontario, Quebec, and Saskatchewan. Together, these five provinces released GHGs to an amount of 656 Mt CO_2 eq that accounts for 91% of Canada's total GHGs.

The most fertile land in British Columbia is the Fraser River Delta, where the most agricultural operations take place within the province. It is important to have an understanding that agricultural operations are a large source of GHGs. Animal agriculture contributes to lots of GHG emissions, especially when it comes to methane and nitrous oxide emissions. According to Levelton (2005), 27% of Fraser Valley's agricultural GHG emissions were estimated to be from manure management.

1 Objectives

1) To conduct a meta-analysis of greenhouse gas emissions (GHG) by various sectors in Canada and British Columbia and compare these to global values,
2) To identify the major sources and types of GHG's in British Columbia,
3) To use agriculture, in particular animal agriculture, as a case study to assess its effects on GHG potential, and
4) Using a recent study, to suggest one potential management practice that has the potential for reduction of GHG's from animal agriculture.

2 Methods

2.1 Data Source

FAO (Food and Agriculture Organization) database

IPCC (Intergovernmental Panel on Climate Change) reports

EPA (United States Environmental Protection Agency) reports

Government of Canada database

The data of CO_2, CH_4 and N_2O emissions from the UBC Dairy Education and Research Center were provided by Patrick Pow

2.2 Methods

1) Literature review

Assess GHG emissions on six different scales:

a) GHG emissions in the world,

b) GHG emissions in Canada,

c) GHG emissions in British Columbia,

d) GHG emissions from animal agriculture in the world,

e) GHG emissions from animal agriculture in Canada and

f) GHG emissions from animal agriculture in British Columbia

2) Case study

The case study from the UBC Dairy Education and Research Center is aimed at making a preliminary assessment of GHG emissions from animal agriculture in BC, focusing on manure treatment and daily operations at the dairy farm. The assessment is based on data provided by Patrick Pow (2020). Based on the existing data and the assumption that all the dairy farms employ the same operations as UBC Dairy Education and Research Center, an estimation of GHG emissions from animal agriculture is conducted.

3 GHG Emissions

Greenhouse gases (GHGs) are the cause of the greenhouse effect, and it refers to any gas that is capable of taking in infrared radiation and giving it back to the earth's surface. It is in this way that greenhouse gases trap heat in the atmosphere and contribute to global warming. The increasing concentration of greenhouse gases in the atmosphere is a major contributor to global climate change (Shurpali et al, 2018). The increasing anthropogenic activities are the likely cause of temperature rise in the last 50 years (IPCC, 2001).

Main sources of GHGs are the burning of fossil fuels, transportation, industrial production, agriculture production, garbage and wastewater and forestry. By breaking down the global GHG emissions by sections of economic activities, the sources leading to GHG emissions are electricity and heat production, agriculture, forestry and other land use industries, transportation, other energy and buildings. As can be seen from Figure 1, generating energy and land uses together contributed almost half of the global GHG emissions. The largest source of GHGs is electricity and heat production accounted for a quarter of global emissions. GHG emissions from agriculture, forestry, and other land use are mainly the result of the cultivation of crops, livestock production, and deforestation. CO_2 that was removed from the atmosphere was not included in this sector and was estimated to offset 20% of the emission (FAO, 2014). The third-largest contributor to global GHG emissions is the industry sector. Greenhouse gas emissions from industry primarily arose from fossil fuels burned on-site at energy facilities. GHGs generated from industrial electricity use were not calculated in this sector and were included in the electricity and heat production sector. GHGs in the transportation sector were mostly from the burning of petroleum-based fuels for marine, road, rail, and air transportation. GHGs in the buildings sector largely came from the burning of fuels to support heat, onsite energy, and cooking. Emissions from other energy sectors refer to the rest of the GHG emissions that concern energy production was not linked directly with electricity or heat production.

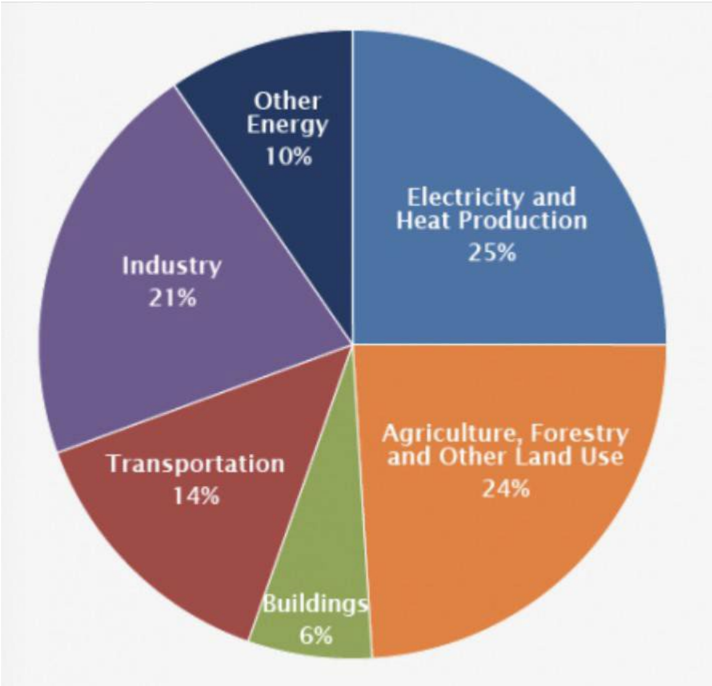

Fig. 1 Global GHG Emissions by Economic Sector

(IPCC, 2014) data were based on the global GHG emissions in 2011, retrieved from https://www.ipcc.ch/report/ar5/wg3/

3.1 GHG Emissions by Components

Carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), hydrofluorocarbons (HFCs), perfluorocarbons (CFCs), and sulphur hexafluoride (SF_6) are the six greenhouse gases covered in the Tokyo Protocol. Carbon dioxide is emitted mainly by the burning of fossil fuels, such as coal, natural gas, and oil. It also comes from other sources such as solid waste, trees, and other biological materials. Methane can be generated during the production and transport process of fossil fuels (coal, natural gas, and oil). Other main sources of methane include domestic animals, the decay of organic waste, and agricultural productions. Agricultural and industrial activities account for most of the nitrous oxide emissions. Specifically, nitrous oxide is generated during the treatment of solid waste and wastewater and the combustion of fossil fuels. Hydrofluorocarbons, perfluorocarbons, and sulphur hexafluoride are all called fluorinated gases. They are emitted in smaller quantities compared to other

GHGs but because of their potent warming potential, they are also listed as major GHGs.

Carbon dioxide, methane, and nitrous oxide are three dominant greenhouse gases that are closely tied with anthropogenic activities, each having a different warming potential. The Global Warming Potential (GWP) is used to describe and compare the warming impacts of the GHG's. CO_2 has a GWP of 1 and is used as the reference. Methane is estimated to have a Global Warming Potential (GWP) of 34 over 100 years. Nitrous oxide has 298 times greater GWP than that of CO_2 over a 100-year time horizon (Myhre et al. 2013). The increasing concentration of CO_2 in the atmosphere can last for thousands of years due to the long life cycle of CO_2. Methane lasts for much less time than CO_2 once emitted into the atmosphere. However, it has a greater capacity to absorb energy and trap heat. In addition, methane is a precursor to ozone, which is also a GHG. N_2O can remain in the atmosphere for more than 100 years once emitted.

3.1.1 Global GHG Emissions

Since 1850, there is a general growing trend in GHG emissions globally, resulting from population growth and industrialization. In 2018, the growth of global total GHG emissions was estimated to be about 2% and reached 51.8 gigatonnes of CO_2 equivalent (Gt CO_2 eq) (FAO, 2014). The calculation did not include GHG emissions from land use changes. It is suggested that GHG emissions from land use changes were about 3.8 Gt CO_2 eq in 2018 (Jos & Jeroen, 2020). Figure.2 shows that only the global carbon emissions from fossil fuels itself reached about 10,000 million metric tons by the year 2010, which was more than 10 times of that in 1900. There appears to be a continuing growth trend in emissions. Figure 3 shows that methane emission had a gradual increase since 1970. The global methane emission in 2018 was 9.7 Gt CO_2 eq. In the same year, global nitrous oxide reached a total of 2.8 Gt CO_2 eq. Figure 4 indicates the proportion of global GHG emissions in 2010. CO_2 emissions together took up 76% of total GHG emissions. Methane emission came second and accounted for 16% of total GHG emissions. Nitrous oxide accounted for 6% of total GHG emissions. The rest of the GHG emissions were owed to fluorinated gases (F-gases).

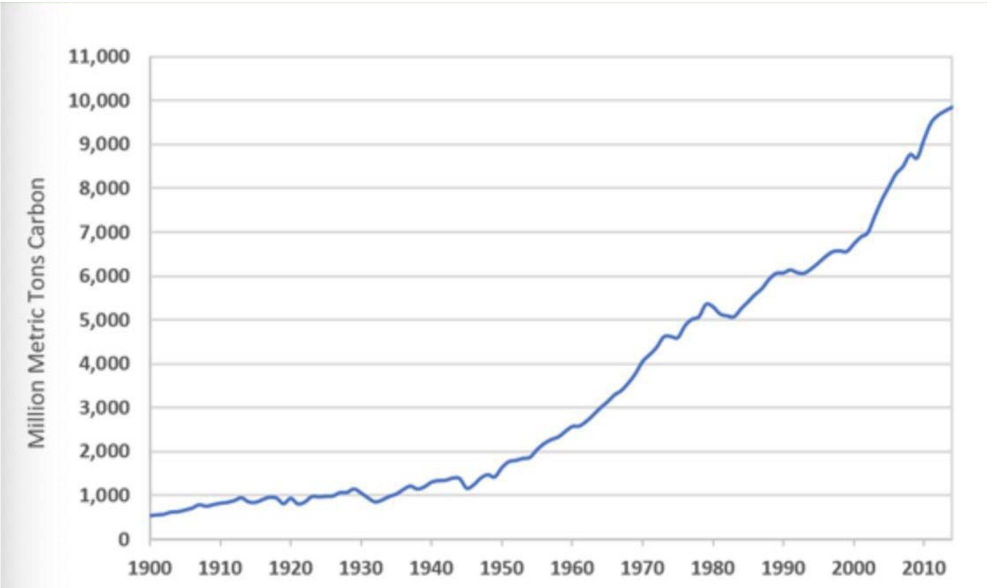

Fig. 2: Global Carbon Emissions from Fossil Fuels, 1900- 2014

(Boden, T.A., Marland, G., and Andres, R.J. 2017)

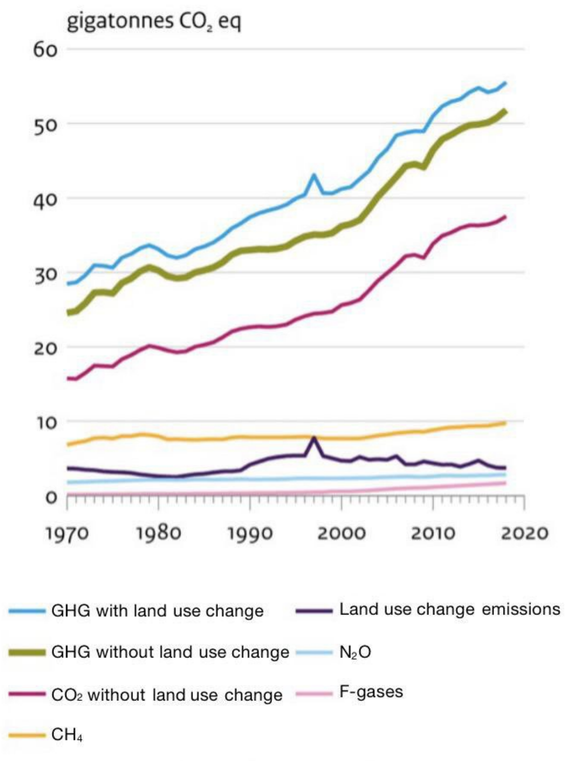

Fig. 3: Global Greenhouse Gas Emissions Per Type of Gas

(Jos, O. & Jeroen, P. 2020)

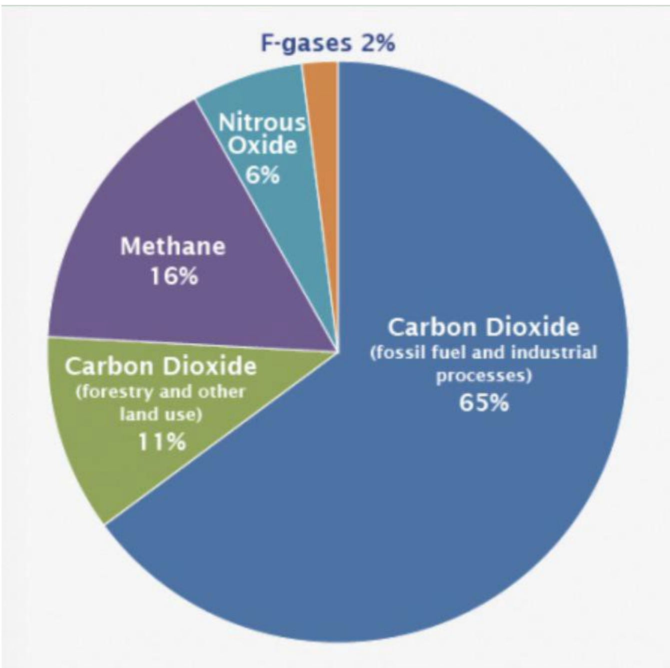

Fig. 4: Global GHG Emissions by Gas

(IPCC, 2014) data were based on global GHG emissions from 2010. Retrieved from https://www.ipcc.ch/report/ar5/wg3/

3.1.2 Canada’s GHG Emissions

In 2013 Canada was the 36th highest GHG emitting nation in the world and ranked the first in terms of emission intensity per person. In total Canada accounted for 1.63% of global GHG emissions in 2013(Government of Canada, 2016). According to Government of Canada(2020) in 2018 the total GHG emissions in Canada was 729 megatonnes of carbon dioxide equivalent (Mt CO_2 eq). Figure.5 summarizes Canada’s total GHG emissions over a 29 years’ span from 1990 to 2018. The highest emissions occurred around 2014**.** GHG emissions had increased by 20.9% in 2019 compared to 1990(126 Mt CO_2 eq), Mostly driven by more intensive practices in mining, oil and gas production and transport. In recent years total GHG emissions did not reach the highest in history but still higher than those in the 1990s. Figure.6 provides information on the proportions of Canada’s major GHG emissions. Carbon dioxide emission is the largest part and takes up 77% of the total GHG emissions. Methane comes second and is responsible for about 15% of total GHG emissions. Nitrous oxide is the third most common GHG and takes up 6% of total national emissions(Government of Canada, 2020). The result shows a high similarity to global GHG emissions in terms of the proportion of different GHGs.

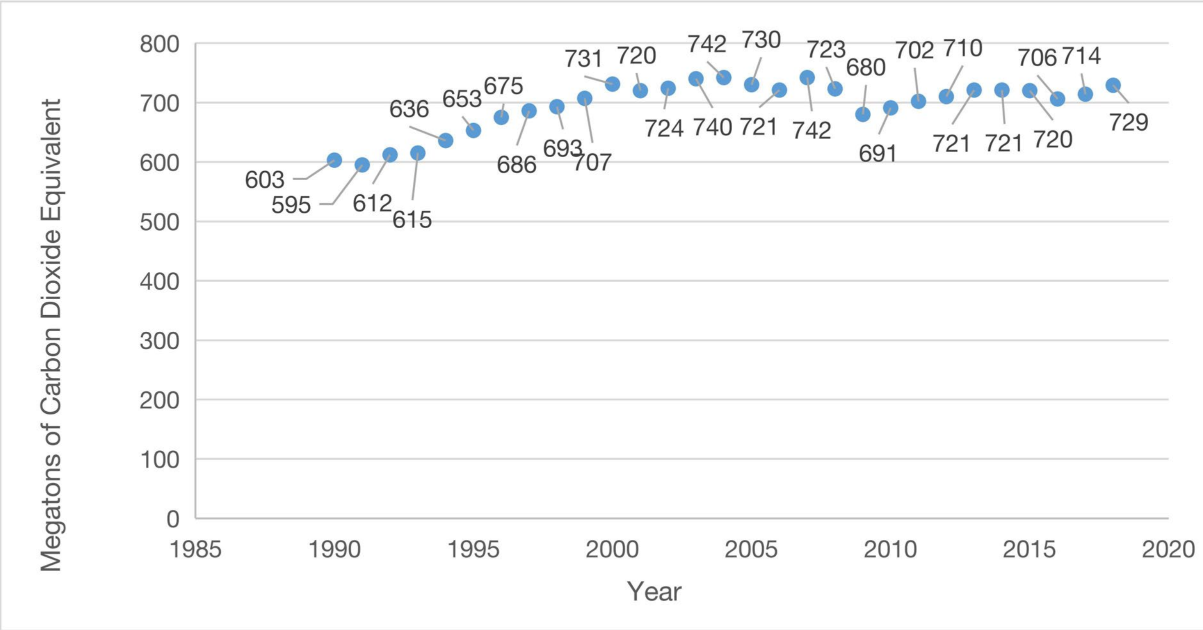

Fig. 5: Greenhouse gas emissions, Canada, 1990 to 2018

*All the data were rounded figures. In this calculation, seven of the greenhouse gases were tracked as the indicators, which are carbon dioxide, methane, nitrous oxide, sulphur hexafluoride, perfluorocarbons, hydrofluorocarbons and nitrogen trifluoride. Emissions in some of the years were modified due to the availability of data and changes in estimation. Emissions from land use changes and forestry were not included in national totals.

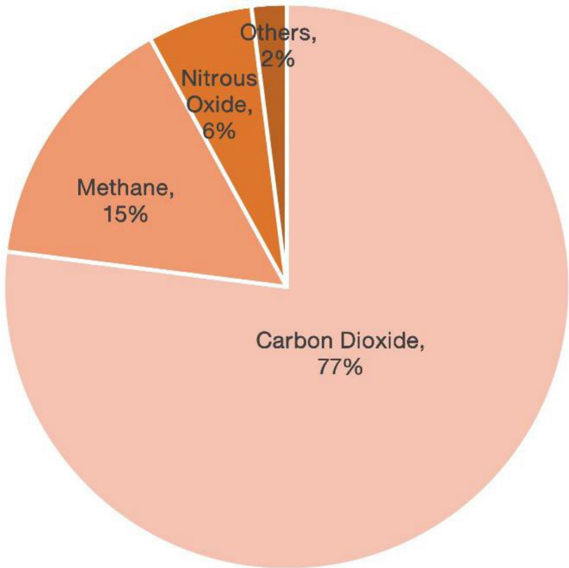

Fig.6: Canada's GHG Emissions by Gas

*The original data were acquired from open data provided by the Government of Canada. The calculations were based on the emission data from 1992-2012

3.1.3 British Columbia's GHG Emissions

British Columbia's total GHG emissions account for less than 10% of Canada's total GHG emissions. The provincial government reported that BC's total GHG emissions were 64.5 million tonnes of carbon dioxide equivalent (Mt CO_2 eq) in 2017. A 1.0 Mt CO_2 eq offset from forestry projects was not included in the calculation. That made the net GHG emissions 63.5 Mt CO_2 eq in 2017 (Government of British Columbia, 2019). There was a 0.5% drop in total GHG emissions compared to BC's total GHG emissions in 2007 (64.76 Mt CO_2 eq). The emissions in 2007 are used as a baseline for comparison. According to Davis and Kumar (2018), the emission intensity per person in BC is 35% below the Canadian average. Figure 7 shows the change in BC's total GHG emissions from 1990 to 2017. The total emissions were below the baseline (64.76 Mt CO_2 eq) since 2009. As is shown in Figure 8, BC's GHG emissions came from five sectors, the energy sector being the largest contributor to GHG emissions, making up approximately 75% of the total GHG emissions.

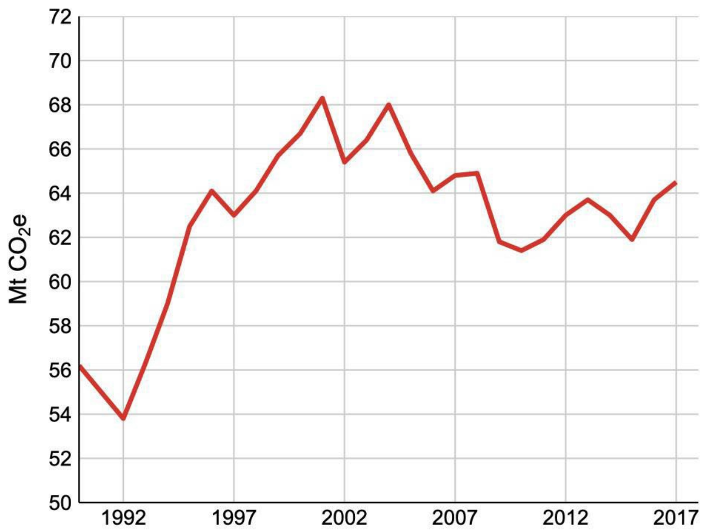

Fig. 7: BC's Total GHG emissions, 1990-2017

(Government of British Columbia, 2019)

* GHG offsets from forest management were not included in the calculation of total GHG emissions

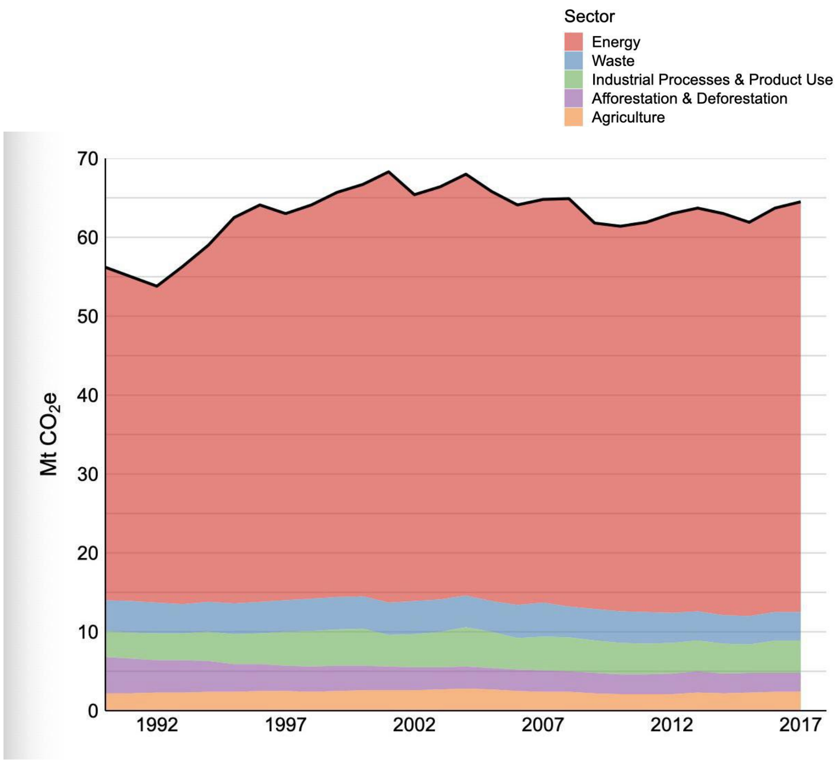

Fig. 8: BC's GHG Emissions by Sector

(Government of British Columbia, 2019)

3.2 GHG Emissions from Animal Agriculture

Figure 9 gives an illustration of how livestock themselves can be a source of CO_2, CH_4 and N_2O. The GHG's are generated mainly by the animals' physiological activities.

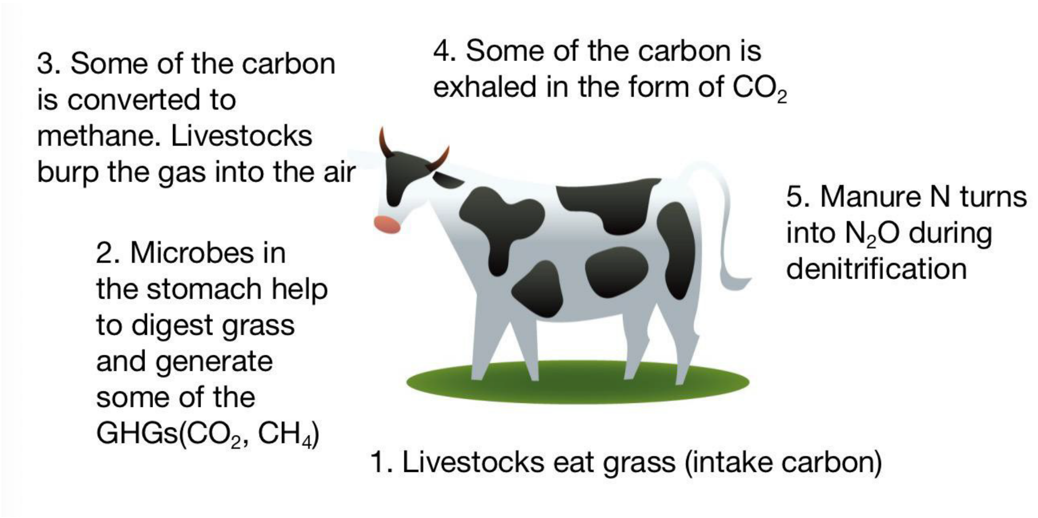

Fig. 9: Livestock as a GHG Emission Source

CO_2 emission is primarily the result of the feeding of high-energy crops, such as corn (Steinfeld et al, 2006). The FAO estimates that the global annual CO_2 emission from producing the fertilizers for feeding crops is 41 million metric tons. The intensive animal confinement operations at the farms consume huge quantities of fossil fuel-based energy to support the on-site cooling, heating, and ventilation systems. In addition, the operation of farm machinery is also responsible for the carbon emission from the farms. Another issue is that CO_2 can be released from the soil, risking soil degradation due to grazing. According to Steinfeld (2006), every year, up to 100 million metric tons of CO_2 is emitted into the atmosphere globally.

It is common knowledge that ruminant animals, such as beef, dairy cows, and goats, are responsible for methane emission through their digestion of feeding crops. During the process called enteric fermentation, methane is produced in their rumen (also known as forestomach) and is emitted into the atmosphere, mostly by burping. A relatively small portion of methane (13%) produced in the rumen is emitted into the atmosphere by the small intestine flatulence (Murray et al, 1976). Manure decomposition may also release methane.

N_2O is emitted during the nitrification and denitrification process as is shown in Figure 10. Nitrification is a series of biological oxidation of ammonia or ammonium transforming it to nitrate or nitrite (Norton and Stark, 2011). Denitrification is a process where nitrate or nitrite is reduced to gaseous nitrogen in the form of molecular nitrogen or any oxide of nitrogen by microbial activities (Soil Science Society of America, 1979). It can be seen in Figure 11 that N_2O is an intermediate gas emitted during the denitrification process. Applying manure to soil provides ideal conditions for nitrification and denitrification, thus gives rise to N_2O emission. Excess manure application needs to be considered, as manure supplies denitrifying bacteria and manure ammonium can be converted to N_2O in the process of nitrification (Kebreab et al. 2006).

According to the United States Environmental Protection Agency (USEPA, 2006), manure is the second-largest source of GHG emissions on a dairy farm, making up 7% of agricultural CH_4 and N_2O emissions. Manure management is a major activity that affects GHG emissions. Research shows that using different manure treatments have impacts on GHG emissions. According to Aguirre-Villegas et al. (2017), liquid manure that is stored for a long time without processing contributes the most to GHG emissions. Sand separation, solid-liquid separation (SLS), and anaerobic digestion (AD) can significantly reduce GHG emissions. However, AD is the most effective one. GHG emissions on dairy farms are also related to the size of the farm, as large farms commonly have long term storage of liquid manure, while small farms land-apply solid manure daily. According to Chadwick et al. (2011), bedding materials can either decrease or increase GHG emissions as a result of different ventilation conditions and temperatures. Michel et al. (2004) concluded that straw amended composts' relatively low initial bulk density resulted in higher free air space values (75-93%), and near-ambient interstitial oxygen concentrations. It

also had a lower temperature during composting compared to sawdust amended composts. Sand bedding is relatively less aerobic.

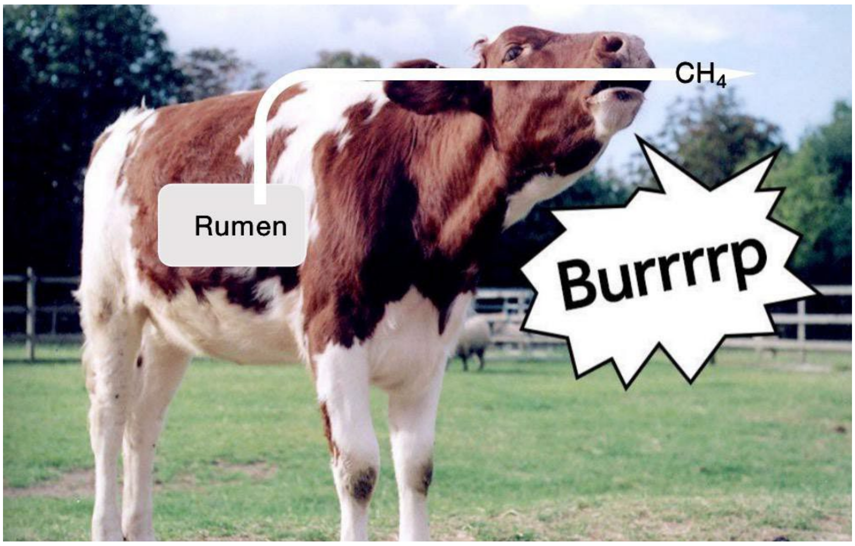

Fig. 10: "Burp" Emission

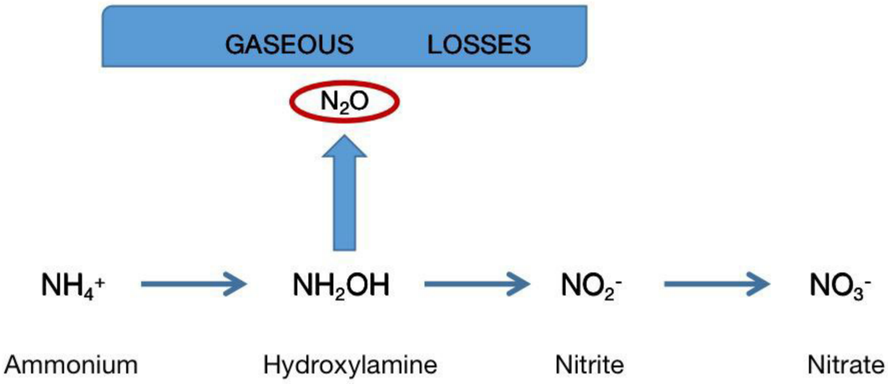

Fig.11: Nitrification Process

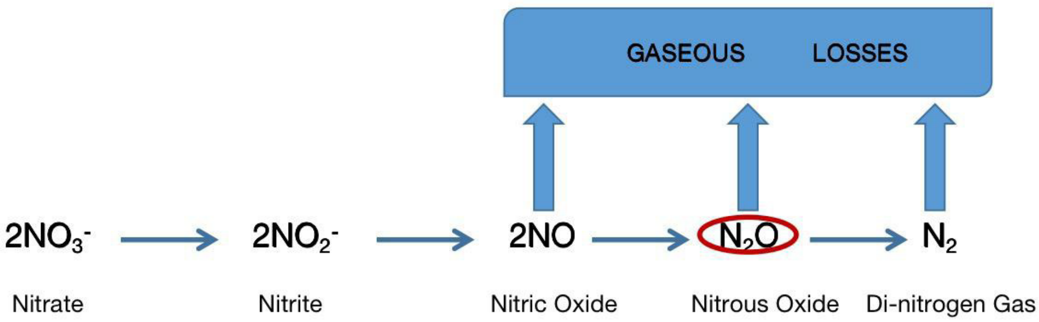

Fig. 12: Denitrification Process

3.2.1 Global GHG Emissions from Animal Agriculture

As stated below, agricultural production is responsible for 10-12% of global total GHG emissions (Smith et al. 2007). To examine the emissions by type of gas, agricultural production takes up approximately 60% of global N_2O emission and half of the global CH_4 emission. According to an FAO (2003) projection, the global agricultural nitrous oxide emission would increase by 35-60% by the year 2030 and methane was estimated to increase by 60%.

Animal agriculture contributes significantly to global GHG emissions. FAO estimates that the global total GHG emissions from livestock are 7.1 gigatonnes CO_2 eq per year. This uses a Life Cycle Assessment (LCA) approach, which represents 14.5 percent of all global anthropogenic GHG emissions. Beef, milk, pork, and poultry production are expected to be responsible for 41%, 20%, 9% and 8% of the GHG emissions in the animal agriculture sector (emissions from transportation and storage are included in the estimation). When it comes to the management operations on a farm, manure storage and treatment contribute 10% of the GHG emissions and are responsible for 4.3% of methane emission and 5.2% of nitrous oxide emission in the animal agriculture sector. Two major sources of GHG emissions are emissions related to feeding crops (including land use change) and enteric fermentation from ruminants, representing 45% and 39% of the GHG emissions respectively. The rest of the emissions are from the processing and transportation of livestock products. To examine the GHG emissions by gas, methane emission takes about 44% of total livestock production GHG emissions. In the animal agriculture sector, CH_4, N_2O, and CO_2 are the three major types of GHGs that are emitted. Nitrous oxide accounts for 29% of the emissions and the rest 27% of the emissions are from carbon dioxide.

3.2.2 Canada’s GHG Emissions from Animal Agriculture

According to Kebreab et al. (2006), in 2002, 8% of the national GHG emissions were taken by agricultural production in Canada. Specifically, agriculture-related N_2O, which accounted for 65% of Canada's emissions and agriculture-related CH_4, made up 26% of Canada's total GHG emissions.

Across entire North America, manure treatment of cattle, poultry and swine and manure application are two major actuators accounting for the increasing nitrous oxide and methane emissions. Livestock themselves are responsible for 32% of Canada's agricultural GHG emissions, initially methane emission from ruminant animals. Of all the GHG emissions from animal agriculture, 17% come from manure treatment and 50% from soils(primarily N_2O). Animal agriculture contributes over half of the agricultural GHG emissions national wide. According to McGeough et al. (2012), based on the study in the dairy industry in eastern Canada, methane emission from the rumen is estimated to be responsible for 48% of Canada's total methane emission and manure management contributes 8% of Canada's total methane emission.

3.2.3 British Columbia's GHG Emissions from Animal Agriculture — Using the Case Study of UBC Dairy Education and Research Center as an example

In British Columbia, 4% of the provincial total GHG emissions are contributed by the agriculture sector, emitting approximately 2.4 million tonnes CO_2 eq annually. Enteric fermentation of ruminant animals and manure management are two of the greatest contributors to agricultural GHGs, apart from emissions from agricultural soils for crop production (BC Ministry of Environment, 2014). The Fraser River Delta has the most suitable natural settings for agricultural activities and is the most agricultural area in BC. It is estimated that of all the GHG emissions from the Fraser Valley, manure is responsible for 38% of the methane emission and 29% of the nitrous oxide emission. Livestock is responsible mainly for methane emission, which makes up 61% of the total methane emissions. In terms of manure

GHGs, the greatest contributor is poultry manure. Cattle manure is responsible for 31% of the manure GHGs.

To illustrate the effects that animal production has impacts on GHG emissions, a case study was reviewed. The case study focused on a recent study about dairy farm management.

Case Study of UBC Dairy Education and Research Center

Location:

UBC Dairy Education and Research Center, Agassiz, BC

Agassiz is a small community that lies in the Eastern Fraser Valley region of British Columbia, Canada. The University of British Columbia's Dairy Education and Research Center is located in Agassiz. The UBC Dairy Education and Research Center is operated both as a typical modern dairy farm and as an intensive dairy cattle research center. Approximately 230 cows are milked each day. It provides an appropriate sample size for the center's teaching and research requirements. The location of the UBC Dairy Education and Research Center is shown in Figure 13. Figures 14 and 15 are photos of the research site at UBC Dairy Education and Research Center (Pow, 2020).

Background:

The Agassiz Dairy operation has substituted sand as an alternative to wood shavings for animal bedding. This has resulted in a decrease in the amount of carbon in the manure (Dinn, 2020). This conversion has modified the manure management system by removing the sand bedding from the manure solids and then composting the washed manure, before land application.

Results and Discussions:

The original data are reported in the flux of CO_2, N_2O, and CH_4 for every half an hour from 0:00 on April 16th, 2020 to 00:00 on May 21st, 2020 at the UBC Dairy

Education and Research Center. No abnormal value was removed due to the limited data size. The fluxes of the GHGs are shown in Table 1. (The results in the table are rounded to tenths unit but the calculation of annual total GHGs used the original calculations that remained were not rounded.)

Table 1: Fluxes of CO_2, N_2O and CH_4 at UBC Dairy Education and Research Center

	CO_2	N_2O	CH_4
Net Total Flux in (umol m^{-2} s^{-1})	**-164.2**	**3.1**	**46.9**
Net Emission (g m^{-2} s-1)	**$-1.4 \cdot 10^{-7}$**	**$2.7 \cdot 10^{-9}$**	**$1.5 \cdot 10^{-8}$**

Assuming that the emissions during the recorded period could represent the GHG emissions under normal conditions at the study area, the net total annual emission of CO_2, N_2O, and CH_4 at the UBC Dairy Education and Research Center is -45.2 kg ha, 0.8 kg ha, and 4.7 kg ha respectively. Using the equation:

CO_2 equivalent = CO_2 + 298 x N_2O + 34 x CH_4,

Net total annual GHG emission intensity at the UBC Dairy Education and Research Center is estimated to be 368.8 kg·ha CO_2 eq.

Cattle farms cover a land area of about 5 million acres (including for beef and milk) in BC (British Columbia Cattlemen's Association, 2015). Assuming that all the cattle enterprises could achieve the GHG emission intensity as the UBC Dairy Education and Research Center using the same manure management method and practicing the same daily operations, the total GHG emissions from cattle production in BC would be approximately $7.376 \cdot 10^5$ tonne CO_2 eq. The total GHG emissions from animal agriculture in BC would be 1.134 million tonnes CO_2 eq. Thus, by using the management at the analogous operations, the current total GHG emissions from animal agriculture in BC could be decreased by $1.652 \cdot 10^5$ tonne CO_2 eq. Hypothetically, the current manure management method and daily operations at the UBC Dairy Education and Research Center should be assessed and applied within the province to reduce GHGs from animal agriculture, especially for practical use for dairy farms.

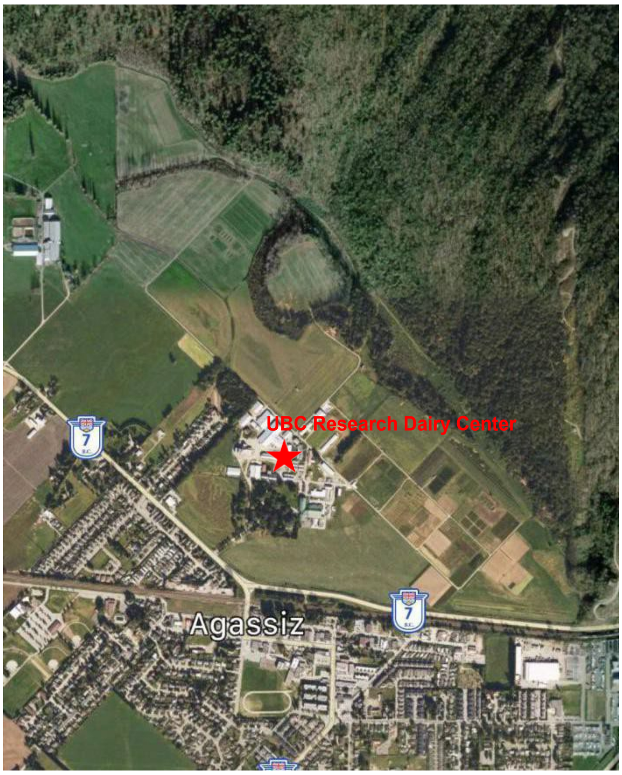

Fig. 13: UBC Dairy Education and Research Center

Fig. 14: Photo 1 from UBC Dairy Education and Research Center

Fig. 15: Photo 2 from UBC Dairy Education and Research Center

4 Conclusions and Recommendations

In conclusion, although agriculture, particularly animal agriculture, is not the major source of GHG in British Columbia, beneficial management practices can still reduce the GHG emissions, relieving the negative impacts of the GHGs. Recent studies and data support that innovative land and manure management have the potential to reduce GHG production. For instance, at least for dairy production, the shift from conventional animal bedding to a sand base is a feasible management strategy to reduce GHG emissions.

The Government of Canada recommends Best Management Practices to the producers to combat GHG emissions. By applying the Best Management Practices, the producers can expect an increase in the land's carbon storage, restoring their land's performance. It is suggested that high efficient feeding works well in reducing methane and nitrous oxide emissions. Also, selecting suitable forages(local productions, crops with low energy consumption, regionally appropriate crops) can reduce carbon emissions. Another attempt is to use feed additives. It is already shown that some feed additives can reduce GHG emissions by dairy cows and there are existing practices in Canada. At most 20% methane emission from cattle is expected to be reduced using feed additives (Boadi et al. 2004, McGeogh et al. 2010).

Another option is to manage manure as manure is a huge contributor to GHGs from animal agriculture. Providing coverage to manure storage facilities helps to keep the manure storage facilitates under low temperature, resulting in repressing the accumulation of methane. When applying manure to the soil, it is crucial to optimize the applications. The BC Ministry of Agriculture (2012) suggests applying manure during the growing season because manure is a great natural fertilizer for crops to meet nutrient needs with proper management. The BC Ministry of Agriculture (2010) also suggests emptying manure storage facilities before the rainy season. For different agricultural lands, the BC Ministry of Agriculture has different guidelines for producers to follow. For example, at most a quarter of the manure generated in a year is suggested to be applied in late February or early March to the grassland. After cutting the rest of the manure can be applied. It is beneficial to follow the guidance since excess manure provides an ideal condition for more nitrous oxide emission. From the perspective of reducing methane emission, it is important to follow the guidance since the suggested time for emptying the manure storage tanks and applying manure to soil minimizes the time for methane to be accumulated.

Judging from the results of the case study, changing the manure bedding materials from wood shavings to sand seems to be effective in terms of reducing manure GHGs. But further study is needed to examine how effective the practice is. From the results and estimations alone it is worthy of promotion in BC, potentially resulting in preferable outcomes.

Acknowledgments

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