

# Dryland crop production and greenhouse gas emissions in Canada: a regional comparison

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## Abstract

Agricultural production systems produce several environmental impacts, including emissions of greenhouse gases. The objective of this paper is to investigate differences in greenhouse gas emissions from various crops grown under dryland production system in various regions of Canada. Results indicate that the emissions intensity varies depending upon the measure adopted – whether it is on per unit of area or production. In addition there is wide variability across regions of production. In the Prairie region, the greenhouse gas emissions intensity on a per hectare basis ranged from 378 kg for Alfalfa in Alberta to 1,837 kg for durum wheat in Saskatchewan. Generally, central Canada emits the highest GHG level on a per hectare basis but not on a tonne of production basis.

*Keywords:* crop production, greenhouse gas emissions, emission intensity, dryland production systems.

## 1 Introduction

### 1.1 Background

Greenhouse gas (GHG) emission reduction has been accepted by most countries as an important activity in helping to safeguard against future climate change. With this in mind, the international community has initiated measures to curb the rising trend in GHG emissions, and in fact, reduce them to a point where these



are less harmful to society. Although compared to other industrial countries, Canada is not a major contributor of GHG emissions, with the 1990 total GHG emissions levels having represented just 1.8% of the global total, but on a per-capita basis Canada ranks second-highest in emissions, exceeded only by the United States, Environment Canada [1]. Of the total GHG emissions of 734 megatonnes (Mt) of carbon dioxide equivalent ( $\text{CO}_2\text{e}$ ), the contribution of Canadian agriculture is only 8% of this total, Environment Canada [2]. This equivalency is calculated by converting methane ( $\text{CH}_4$ ) by using its global warming potential of 21, and nitrous oxide ( $\text{N}_2\text{O}$ ) of 310 times that of carbon dioxide ( $\text{CO}_2$ ). Although the contribution level of GHG emissions from Canadian agriculture may be small in relation to other emission sources, as shown in figure 1, on an absolute scale, the total agricultural GHG emissions in 2008 were estimated to be 62 Mt of  $\text{CO}_2\text{e}$ . Agriculture is not a large contributor of  $\text{CO}_2$  but a large proportion of  $\text{CH}_4$  and  $\text{N}_2\text{O}$  is emitted by agricultural production activities. In addition, agriculture contributed to total GHG emission indirectly through manufacturing of farm inputs, including off-farm transportation (Dyer and Desjardins [3]).

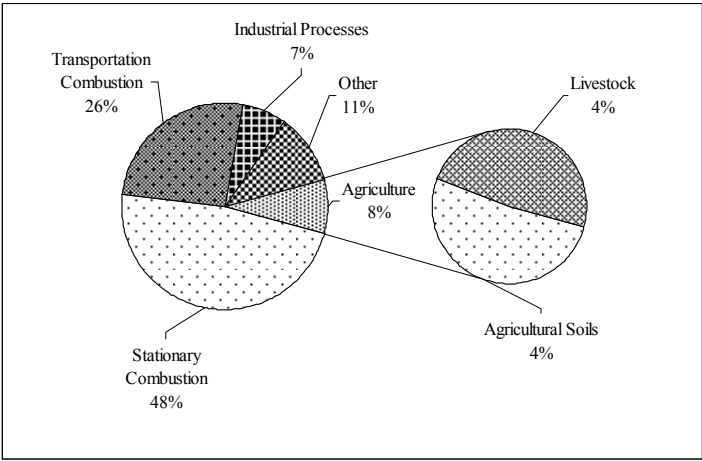


Figure 1: Distribution of greenhouse gas emissions in Canada by source, in  $\text{CO}_2\text{e}$ .

### 1.2 Need for the study

Since the signing of the Kyoto Protocol by Canada and other countries, identification of GHG-emissions reduction potential of various sectors is an important activity. In this context, Canadian agriculture is viewed as playing a role in GHG emission mitigation as well as in sequestration. Crop production activities are major contributors to total Canadian agriculture GHG emissions. However, in order to develop effective mitigation and sequestration strategies, knowledge of the nature of GHG emissions from various crop production activities is required. Since crop enterprises may vary in terms of their GHG



emission efficiency, such measures could focus on either improving resource use efficiency and/or product substitution as possible strategies for reducing GHG emissions.

Many studies in Canada and the U.S.A. have addressed issues surrounding GHG emissions. Addressing mitigation of GHG emissions is the starting point in many of these studies, where the best opportunities are investigated (Garnett [4]). Study of soil carbon sequestration has been addressed by Gregorich *et al.* [5], Curtin *et al.* [6], while Bergstrom *et al.* [7], Liang *et al.* [8], and Sainju *et al.* [9] have also reported the effect of tillage on soil carbon sequestration. Several studies (McGinn and Akinremi [10]; Gregorich *et al.* [11]; and Paul *et al.* [12]) have also reported GHG emissions in the context of crop rotations. Some studies have estimated livestock GHG emissions (see Vergé *et al.* [13]). However, these studies have not addressed the issue of relative contribution of various crops in different regions of Canada. Such information may be important for developing strategies for reducing GHG emissions.

The objective of this study was to estimate the regional GHG Emissions Intensity Coefficient (GHG-EIC) of various crops in Canada. Emphasis was placed on dryland production systems and on conventional tillage systems. Although irrigation production systems are also responsible for GHG emissions, they are relatively small in comparison to total production.

## 2 Methods and material

Within Canada, most crop production activities are localized in the Prairie Provinces (Manitoba, Saskatchewan, and Alberta) and Central Canada (Ontario and Quebec). Together these two regions constitute 97.6% of total cropped area of Canada. British Columbia and Atlantic Canada were, relatively speaking, minor players.

GHG emissions from dryland production systems in various regions are typically a result of two sets of factors: crop mix and technology of production. Although both of these factors need to be captured in a comparison of GHG-EIC, the latter is left for future research in this area. Thus, this study is limited to differences in GHG-EIC for various crops and major regions of agricultural production in Canada. This consideration was captured in the development of a model called the Greenhouse Gas Emissions Model (GHGEM), which was calibrated for the base year 2006 (Census of Agriculture in Canada year). The model was an update of the model described by Sobool and Kulshreshtha [14]. Results were aggregated at the provincial level. Although the GHGEM included both crop and livestock production activities, as well as dryland and irrigated method of crop production, in this study only dryland crop production activities are included.

GHG emissions from agriculture are generated in three ways: (1) Direct emissions from agricultural production related activities; (2) Indirect emissions through ecosystem level changes, and (3) Induced emissions, which are the economic activities resulting from the production of farm commodities. For example, in the production of wheat, use of fertilizer would be a source of direct



emissions. It results in atmospheric deposition and leaching into groundwater, and which are classified as indirect emissions. Production of wheat requires manufacturing of fertilizer, which generates further emissions; in addition, this production is mostly exported to outside regions and has to be transported. These two sources are called induced emissions.

In order to estimate these three types of emissions, the GHGEM was designed in a modular fashion. Each module represents a set of related activities. Although soil carbon sequestration is an activity included in the model, since it is not crop specific, it has been shown as a separate activity. Various modules in the GHGEM are shown in table 1. The main source of data for emission factors was the IPCC Tier-1 methodology as described in Houghton *et al.* [15], supplemented with those from Olsen *et al.* [16] and Nyboer and Laurin [17].

Table 1: GHGEM modules and activities along with their association by type of gas.

Module	Module Activity	CO <sub>2</sub>	CH <sub>4</sub>	N <sub>2</sub> O
Crop Production Emissions Module	Crop Residues			X
	Nitrogen Fertilizers			X
Energy Use Emissions Sub-Module	Machinery Fuel Use	X	X	X
On-Farm Transportation & Stationary Combustion Emissions Module	On-Farm Transportation	X	X	X
	Other On-Farm Fuel Use	X	X	X
<i>Sub-total Direct GHG Emissions</i>		X	X	X
Indirect Emissions Module	Atmospheric Deposition			X
	Nitrogen Leaching			X
<i>Total Direct &amp; Indirect Production-Related Emissions</i>		X	X	X
Farm Inputs	Manufacturing, Transportation and Storage	X	X	X
Off-farm Transportation		X	X	X
<i>Total Agricultural GHG Emissions</i>		X	X	X

Direct crop-production-related emissions included those from crop production activities (such as decomposition of crop residues and application of nitrogen-based fertilizers), and use of fossil fuels for farm machinery and transportation. The On-Farm Transportation and Stationary Combustion Emissions Module was divided into two areas of fuel use, namely the consumption of fossil fuels related to the transport of the crops after harvest from the field to the bins and the energy requirements for all other activities (limited to those related to crop production, such as crop drying) on the farm Dyer *et al.* [18]. The Indirect Emissions Module contained emissions resulting from the application of nitrogen-based fertilizers that subsequently resulted in nitrogen being either volatilized into the air or



leached into the soil and subsequently into groundwater. The induced emissions contained two modules – Farm input manufacturing and off-farm transportation. All emissions were converted into CO<sub>2e</sub>, and are not shown by individual gases. As noted above, crop production also leads to either soil carbon source or sequestration. However, these emissions could not be estimated for each crop and therefore, are not included in the total GHG emissions Dyer *et al.* [18]. H

Estimation of GHG emission intensity coefficients (GHG-EIC) was done for three Prairie Provinces (Manitoba, Saskatchewan and Alberta) in western Canada, and for Ontario and Quebec in eastern Canada. These were estimated using two criteria: on per unit of land (ha), and per tonne of production. In total, five crops (alfalfa, spring wheat, durum wheat, barley, and canola) in western Canada and four crops (alfalfa, wheat, corn for grain, and soybeans) in eastern Canada were included.

### 3 Results and discussion

#### 3.1 Distribution of greenhouse gas emissions from wheat production in Saskatchewan

To illustrate the nature of GHG emissions from crop production, wheat in Saskatchewan was selected. Saskatchewan is a major contributor to wheat production in the Prairies. Composition of total GHG emitted ha<sup>-1</sup> and on per tonne (t<sup>-1</sup>) is shown in table 1. A distribution of these emissions is shown in figure 2.

To produce wheat in Saskatchewan, a total of 530 kg of GHG ha<sup>-1</sup> is released, of which the majority comes from fuel use and fertilizers. As shown in figure 2, these emissions are only 62% of the total emissions. After all wheat- production-

Table 2: The distribution of total GHG in CO<sub>2e</sub> from spring wheat production in Saskatchewan on per ha and per tonne basis.

Source	Emissions (kg ha <sup>-1</sup> )	Emissions (kg t <sup>-1</sup> )
Fertilizer	53.92	13.65
Other Crop Sources	155.16	39.28
Fuel for farm machinery	216.89	54.91
On-farm Transportation and other uses	104.07	26.35
<b>Total Farm Level Emissions</b>	<b>530.03</b>	<b>134.18</b>
Indirect Emissions	31.22	7.90
Farm Input Production, Transportation, Storage	254.93	64.54
Off-farm Transportation	41.79	10.58
<b>Total Emissions excl. Soil Organic Matter</b>	<b>857.96</b>	<b>217.20</b>



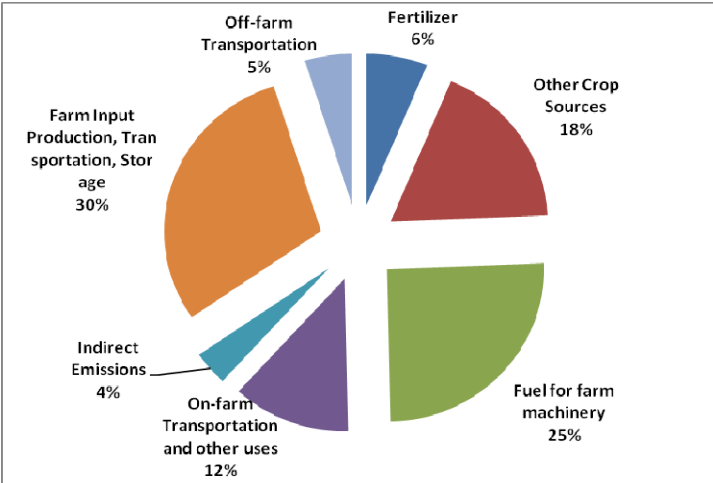


Figure 2: Distribution of total wheat-production-related GHG emissions.

related activities are accounted for, a hectare of wheat generates a total of 858 kg of CO<sub>2e</sub> GHG emissions. The remaining 38% are through activities beyond the farm level. These include manufacturing of farm input which contributes 30% to the total and the remaining through off-farm transportation activity.

The above set of estimates does not include the soil carbon sequestration potential of various crops. Part of the reason for this is that sequestration estimates in Canada are available only at a Census Agriculture Region (CAR) level and not by crops. Furthermore, carbon sequestration in soils changes from one time period to another, depending on cultural practices and soil characteristics. For these reasons, this estimate was excluded from the total.

**3.2 Estimated area-based GHG-EIC for crops in the Prairies**

As noted above, five crops were selected for the estimation of GHG-EICs in the Prairie Provinces. Results are shown in table 2. Both direct farm level emissions and total system (farm and beyond-farm activities) were included here. For alfalfa, GHG emissions from farm level activities ranged from 141 to 351 kg ha<sup>-1</sup>. One of the crops with the highest emissions level was durum wheat production in Saskatchewan, where 1.1 t of GHG are emitted from every hectare of durum wheat production.

Although all the estimates in table 2 are for crops grown using intensive (or conventional) tillage, provincial differences in GHG-EIC show variability caused by differences in soil type as well as cultural practices. For crops such as alfalfa and barley, Manitoba has a higher GHG-EIC than other provinces. Differences in fertilization and fuel use (resulting from the soil characteristics) may be partial answer to these differences.



Table 3: Area-based greenhouse gas emission intensity ( $\text{CO}_2\text{e kg ha}^{-1}$ ) of crops in Prairie Provinces.

Crop	Level	Alberta	Saskatchewan	Manitoba
Alfalfa	Direct Farm	140.9	231.2	351.3
	Total	378.7	803.5	644.4
Spring Wheat	Direct Farm	530.0	701.1	642.6
	Total	858.0	1,179.6	981.6
Durum wheat	Direct Farm	558.3	1,127.1	742.0
	Total	885.2	1,837.0	1,088.7
Barley (Feed)	Direct Farm	529.6	538.3	757.7
	Total	909.1	885.6	1,140.6
Canola	Direct Farm	386.0	390.6	445.3
	Total	744.7	720.8	618.4

### 3.3 Production based GHG-EIC for crops in Prairie provinces

Comparison of area-based emissions may be misleading if yields of various crops are different across the three provinces Dyer *et al.* [18]. For this reason, area-based coefficients were converted to a per-tonne basis to take into account regional production efficiencies that may exist. Doing so allows for a regional comparison of intensity coefficients. While the area-based estimates may be significantly higher for one crop or region compared to another, the input requirements may result in an optimal yield for the specific crop or region. This optimal yield may help to overcome the high area-based intensity coefficient estimates, resulting in a production coefficient that is more efficient when compared to other regions where yields are relatively lower. However, climate plays an important role in determining yields, and this fact makes these coefficients vary over time. The results are shown in table 3.

When production efficiencies are captured, GHG-EICs show a different pattern across the Prairies. For example, for alfalfa production, Manitoba had the

Table 4: Production-based greenhouse gas emission intensity ( $\text{CO}_2\text{e kg t}^{-1}$ ) of crops in Prairie Provinces, under intensive tillage system.

Crop	Level	Alberta	Saskatchewan	Manitoba
Alfalfa	Direct Farm	56.6	162.4	86.7
	Total	152.1	294.3	159.1
Spring Wheat	Direct Farm	134.2	214.0	241.6
	Total	217.2	358.5	369.0
Durum wheat	Direct Farm	126.3	272.3	175.8
	Total	200.3	443.7	258.0
Barley (Feed)	Direct Farm	133.7	138.7	158.9
	Total	229.6	228.2	239.1
Canola	Direct Farm	273.7	241.1	247.4
	Total	528.2	444.9	343.6



highest area-based coefficients (table 3), but such is not the case when these are adjusted for higher yields in that province. To produce a tonne of alfalfa emits only 159 kg of GHG in Manitoba, as against 294 kg in Saskatchewan, when all crop-production-related activities are accounted for. Canola production seems to have a relatively higher GHG-EIC in all three provinces, compared to cereal crops. Most of the increase in emissions is a result of higher fuel use for this production.

**3.4 Crop production GHG-EIC for eastern Canada**

Although the crop mix in western Canada is not exactly comparable to that in eastern Canada, every attempt was made to select similar crops. Alfalfa, being a major source of forage, provided no problem. Wheat in Ontario could be considered similar to that in the western region. In eastern Canada, corn is used as a major feedgrain and is comparable to barley in western Canada. Canola is an oilseed crop and is similar to production of soybeans in eastern Canada. For these crops, GHG-EIC is presented in table 4.

Corn is an input-intensive crop, as the GHG-EIC shows. For just the farm level, every hectare of corn in Ontario produces 2.2 t of GHGs in carbon dioxide equivalent. This is the highest GHG-EIC among all crops. These coefficients also show that crop production in Quebec is less GHG-emitting than in Ontario. These differences are a result of different cultural practices followed in the two provinces.

Table 5: Area and production based greenhouse gas emission intensity of crops in eastern Canada.

Crop	Level	Ontario		Quebec	
		kg ha <sup>-1</sup>	kg t <sup>-1</sup>	kg ha <sup>-1</sup>	kg t <sup>-1</sup>
Alfalfa	Direct Farm	563.8	79.8	484.7	86.4
	Total	957.3	135.6	669.0	119.3
Wheat	Direct Farm	1,240.5	153.5	1,017.1	174.5
	Total	1,770.5	219.1	1,257.0	215.6
Corn for Grain	Direct Farm	2,197.5	147.5	1,872.4	155.8
	Total	3,085.9	207.1	2,271.0	188.9
Soybean	Direct Farm	630.8	241.7	622.1	249.9
	Total	839.7	321.7	731.1	294.6

**3.5 Comparison of crop-production-related GHG-EIC between western and eastern Canadian provinces**

Comparison of selected crops for Saskatchewan and Ontario is shown in figure 2. In both regions, corn production is the highest GHG-emitting crop on a per ha basis, but not on the basis of its total production.





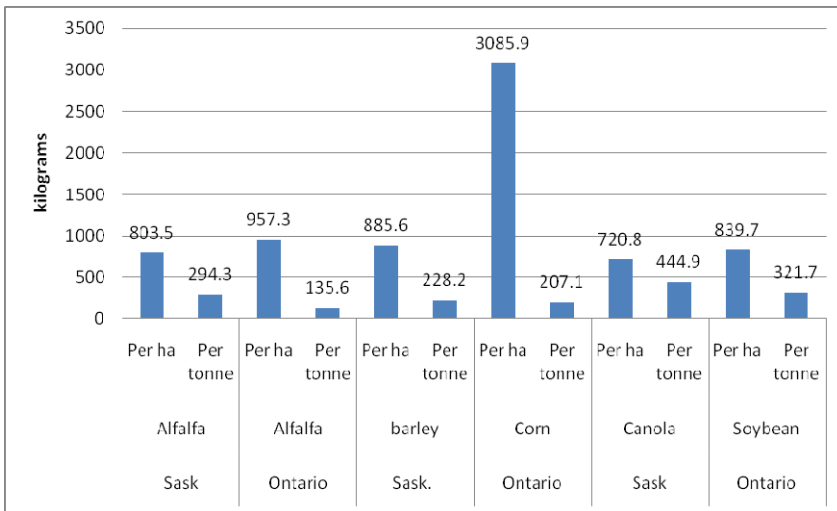


Figure 3: Comparison of GHG-EIC on area and production basis between Saskatchewan and Ontario, selected crops.

Both corn and alfalfa produce a higher yield per unit of land, and therefore, on a production basis, they are not as high a GHG emitter as barley. In general, on account of yield differences, Saskatchewan's GHG emissions rates are higher than those in Ontario.

The above analysis also shows that regional variation in the production-based GHG-EICs is less than that of the area-based estimates. One of the main reasons for this reduction is the differences in allocation of inputs, particularly fertilizer. The contribution level of the fertilizer related GHG-EIC to total GHG-EIC ranged from a high of 32% for Ontario corn production to a low of 14% for Saskatchewan barley production. The optimal level of fertilization is positively correlated to crop yield; thus, higher fertilization rates for various crops result in higher yields. The end result is that for various crop types, increasing the fertilization rate will increase crop yields by a greater amount, thus decreasing the GHG-EIC on a production basis relative to an area basis.

#### 4 Summary and implications

This study has demonstrated a wide variability in the greenhouse gas emission intensity among regions and crops under dryland production. Such information needs to be taken into account in the formulation of regional agricultural GHG emission reduction measures. However, the picture of EICs changes whether one examines these emissions on the basis of area or production. When estimated on an area basis, the GHG-EICs in Central Canada are higher than those for the Prairie Provinces, but on a basis of tonnes of production, Ontario crop production is more GHG-friendly than that in the Prairies.



Table 6: Estimated solid carbon sequestration potential in Prairies and central region of Canada.

Region	Amount in kg ha <sup>-1</sup>		
	Source	Sink	Net amount
Prairies	15.35	-99.10	-83.75
Central Canada	112.02	0	112.02

Source: Sobool and Kulshreshtha [14].

These conclusions are based on a methodology where soil carbon sequestration is not taken into account. Regionally there are wide differences in the level of carbon that is sequestered on an annual basis, as shown in table 4.

For the Prairies, it is estimated that overall the region has a potential for sequestration at 83.75 kg ha<sup>-1</sup>, but for Central Canada, crop production emits 112 kg ha<sup>-1</sup> over all CARs within these provinces. There is a significant intraregional variability in these estimates, since in the Prairie Provinces, some CARs emit CO<sub>2</sub> whereas others provide sequestration. In the Central Canada no CAR does sequestering of CO<sub>2</sub>. If these estimates were to be included in the estimation of the GHG-EIC, crop production in the Prairies would be more GHG-emissions-friendly than that in Central Canada.

Overall, while the absolute value of the GHG-EICs is an important factor in determination of overall damage to environment (through climate change), the regional and crop-specific comparisons also provide the greatest insight as to emission efficiencies. In addition, there is a large variability among crops and for the same crop among regions.

While certain regions or crop types may be a significant source of GHG emissions on an absolute scale, these values really do not provide any insights as to formulating GHG mitigation policies that are the most efficient. These emission coefficients should prove to be useful for developing an efficient GHG-mitigation policy for agriculture (crop production), or at least allow for the prioritizing of GHG-mitigation strategies based on region and crop types. One of the limitations of these results is the partial nature of estimation. For example, pasture and forages are typically associated with livestock production. Similarly, the rotation followed for various crops is also different from region to region. Further studies could focus on these issues related to GHG emissions from dryland production systems.

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