GHG emission estimates from the agriculture sector

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Outline

1. Main agricultural sources
2. Measurement and estimation techniques
3. GHG emissions intensity of agricultural products
4. Total radiative forcing also includes change in albedo
5. Summary/ recommendations
1. Main agricultural sources of GHG

- Livestock
- Manure
- Crop Management
- Plants

Gas emissions:
- CH$_4$
- N$_2$O
- CO$_2$
The net contribution that agriculture makes to global GHG emissions will depend on what emissions are counted.

Direct farming activities only: 13-15% of Global Emissions

Direct farming activities + land use change: 18-32% of Global Emissions

2. Space and time scales of GHG measuring techniques

Representative Area of Measurement

- $1 \text{ m}^2$
- 1 Hectare
- $1 \text{ km}^2$
- 10 km$^2$

Representative Time of Measurement

- 1 hour
- 1 Day
- 1 Month
- 1 Year

Aircraft  
Atmospheric Inversion  
Tower  
Soil Cores
Measuring and modeling GHG emissions

There’s no such thing as a perfect measurement!!
Objective:

- A scientific, transparent, and verifiable accounting system for reporting soil carbon stocks, carbon stock changes, nitrous oxide and methane emissions for Canadian agriculture to meet international commitments and in support of sustainable agriculture.
Greenhouse gas emissions from Canadian agroecosystems
What is the impact of these changes on soil carbon?
Annual to Perennial
Intensive to reduced-till
Reduction in Fallow
Woody Biomass
Histosols
GL-CL
FL-CL (SOC only)
Liming
Net
1990
2004
C Change Mt CO₂ yr⁻¹
Global sources of nitrous oxide

**Global N₂O Emissions (1990s)**

<table>
<thead>
<tr>
<th>Source</th>
<th>Emissions (Tg N yr⁻¹)</th>
<th>Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fossil fuel combustion and industrial processes</td>
<td>2.8</td>
<td>42%</td>
</tr>
<tr>
<td>Agriculture</td>
<td>0.7</td>
<td>11%</td>
</tr>
<tr>
<td>Biomass and biofuel burning</td>
<td>0.7</td>
<td>10%</td>
</tr>
<tr>
<td>Human excreta</td>
<td>0.6</td>
<td>9%</td>
</tr>
<tr>
<td>Rivers, estuaries and coastal zones</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Atmospheric deposition</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Source: Denman et al. (2007)
Major sources of agricultural N\textsubscript{2}O emissions in Canada

- **N\textsubscript{2}O Emissions from Agriculture**
  - Direct Emissions
    - Agricultural soils
    - Manure storage
  - Indirect Emissions
    - NH\textsubscript{3} + NO\textsubscript{x}
    - Leaching/Runoff

**Major sources of agricultural N\textsubscript{2}O emissions in Canada**

- Histosols
- Synthetic fertilizer
- Animal Manure as Fertilizer
- Crop residue
- Summerfallow
- Grazing animals
- Burning of Residues
- Management (irrigation and tillage)
Regional N$_2$O emission factors

Emission factors are Ecodistrict specific, and are dependent upon regional climate, expressed as the ratio of precipitation (P) to potential evaporation (PE) or P/PE.

\[ EF = 0.022 \times \frac{P}{PE} - 0.0048 \]

Therefore, as climate is dryer, EF decreases.
Low P/PE associated with dryer climate, high P/PE associated with wet climates.
Eco-stratification of $N_2O$ emission factors

<table>
<thead>
<tr>
<th>Category</th>
<th>NCGAVS Tier II Mt CO₂ Equivalents</th>
<th>Tier I Mt CO₂ Equivalents</th>
<th>Change Mt CO₂ Equivalents</th>
</tr>
</thead>
<tbody>
<tr>
<td>Synthetic N</td>
<td>7.84</td>
<td>9.32</td>
<td>-1.48</td>
</tr>
<tr>
<td>Crop Residue</td>
<td>5.83</td>
<td>6.57</td>
<td>-0.74</td>
</tr>
<tr>
<td>Animal Manure</td>
<td>2.10</td>
<td>1.92</td>
<td>0.18</td>
</tr>
<tr>
<td>Pasture, Range and Paddock</td>
<td>3.79</td>
<td>3.25</td>
<td>0.54</td>
</tr>
<tr>
<td>Summerfallow</td>
<td>0.65</td>
<td>N/A</td>
<td>0.65</td>
</tr>
<tr>
<td>Irrigation</td>
<td>0.39</td>
<td>N/A</td>
<td>0.39</td>
</tr>
<tr>
<td>Organic Soils</td>
<td>0.06</td>
<td>0.06</td>
<td>0.00</td>
</tr>
<tr>
<td>Animal Waste Management</td>
<td>4.67</td>
<td>4.12</td>
<td>0.55</td>
</tr>
<tr>
<td>Indirect Emissions</td>
<td>11.79</td>
<td>7.48</td>
<td>4.31</td>
</tr>
<tr>
<td>Total</td>
<td>37.1</td>
<td>32.5</td>
<td>4.6</td>
</tr>
</tbody>
</table>

*Source: Rochette et al. (2008); Hutchinson et al (2007)*

Uncertainty in national Tier II estimates is approximately +/- 40%
Verification of N$_2$O emissions at a regional scale

LEGEND
- cereals
- pasture/grass
- alfalfa
- forest
- soy
- corn
- town

Map of Casselmore and Morewood with various land uses color-coded.
Aircraft REA system

Laboratory TDL Laser

Diaphragm Pump 12 l/min

Relief valve

2-μm Filter

Mass-Flow Controller

3-way Valve

DC Power supply

Vent (Dead band)

PTFE Sample Bag

¼” PTFE tubing

Inlet

UP

DOWN

Relaxed eddy accumulation system
Large scale verification of N\textsubscript{2}O fluxes during and right after snowmelt from two regions in Eastern Canada in 2001

Each data point represents the average of 3 runs 10 km in length collected from two regions each about 100 square kilometers in area approximately 20 km apart.
Multi-year comparison of $\text{N}_2\text{O}$ emissions using aircraft-based systems and model estimates (Desjardins et al. 2010)

**2000**
- **DNDC**: 0.34
- **Aircraft**: 0.53

**2001**
- **DNDC**: 0.76
- **Aircraft**: 0.55

**2003**
- **Total emissions (kg $\text{N}_2\text{O}$-N ha$^{-1}$)**
  - **DNDC**: 1.44
  - **Aircraft**: 1.87

**2004**
- **Total emissions (kg $\text{N}_2\text{O}$-N ha$^{-1}$)**
  - **DNDC**: 1.11
  - **Aircraft**: 1.77
# Measured and modeled N$_2$O flux estimates

<table>
<thead>
<tr>
<th>Year</th>
<th>Measured</th>
<th>Modeled (DNDC)</th>
<th>% difference</th>
</tr>
</thead>
<tbody>
<tr>
<td>2000</td>
<td>0.53</td>
<td>0.34</td>
<td>+20</td>
</tr>
<tr>
<td>2001</td>
<td>0.55</td>
<td>0.76</td>
<td>-38</td>
</tr>
<tr>
<td>2003</td>
<td>1.87</td>
<td>1.44</td>
<td>+22</td>
</tr>
<tr>
<td>2004</td>
<td>1.77</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

In three out of the four measurement years, measured emissions exceeded modeled emissions by an average of 26%. In 2001, DNDC predicted a longer ‘spring burst’ than was measured, and total modeled emissions were 38% greater than measured emissions.

Measurements incorporate indirect emissions, whereas DNDC does not. The IPCC methodology assumes that indirect emissions are in the range of 25 to 30% of total emissions.

Use of process based models to generate emission factors for changes in management practices (Ecodistrict Level)

**DNDC-MFT Interface**

- Construct default input files from database
- Combined and reversible factors
- Estimate Tier II/III factors

**Ecodistrict Database**
- Daily Meteorological Data
- Soil Properties
- Crop Rotations

**OutPut**
- Estimated $\text{N}_2\text{O}$, $\text{CO}_2$ and Net GHG emission factors
  ecodistrict level
  for each management practice and rotation

**DNDC Simulation processes**

**Compare model estimates to Tier II factors**

Comparison of linearly additive factors for conversion of CT to NT and removal of fallow versus factors for the combined management change

<table>
<thead>
<tr>
<th>Rotation</th>
<th>Combined (kg ha(^{-1}) y(^{-1}))</th>
<th>Additive (kg ha(^{-1}) y(^{-1}))</th>
<th>Change (%)</th>
<th>Combined (Mg C ha(^{-1}) y(^{-1}))</th>
<th>Additive (Mg C ha(^{-1}) y(^{-1}))</th>
<th>Change (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>A-A-A-A-Sf-Ws-C</td>
<td>-0.14</td>
<td>-0.19</td>
<td>29.5</td>
<td>0.122</td>
<td>0.129</td>
<td>5.4</td>
</tr>
<tr>
<td>Gr-Sf-Ws</td>
<td>0.47</td>
<td>0.60</td>
<td>26.1</td>
<td>0.085</td>
<td>0.080</td>
<td>-5.2</td>
</tr>
<tr>
<td>P-C-Sf</td>
<td>-0.06</td>
<td>-0.10</td>
<td>53.7</td>
<td>0.091</td>
<td>0.092</td>
<td>0.4</td>
</tr>
<tr>
<td>Ws-Sf-P</td>
<td>-0.11</td>
<td>-0.14</td>
<td>22.2</td>
<td>0.091</td>
<td>0.091</td>
<td>0.3</td>
</tr>
</tbody>
</table>

Note: A, alfalfa; Sf, summer-fallow; Ws, spring wheat; P, peas; C, canola; Gr, grain.

Source: Smith et al. (2010)
METHANE BUDGET: 2000-09

Global Carbon Project 2013; Figure based on Kirschke et al. 2013, Nature Geoscience
Methane is emitted where organic material decomposes without enough oxygen. Ruminants produce about 2 billion tons of carbon dioxide equivalent per year. This is equal to about 4% of the anthropogenic emissions of GHGs. Ruminants accounts for about 44% of the global anthropogenic methane emissions.

National scale uncertainty in agricultural CH$_4$ emissions was estimated at 38 and 73% for enteric fermentation and manure management, respectively (Karimi-Zindashty et al. 2012).
Measuring methane emissions from livestock

- Diet
- Inventories

Tracers
- Johnson et al. 1994
- Lassey et al. 1997
- Boadi et al. 2002

Chambers
- Young 1974
- Kelley et al. 1994
- Amon et al. 2001

Micrometeorology - Isolated Groups of Cattle
- Leuning et al. 1999
- Harper et al. 2000
- Van Haarlem et al. 2008

Modelling Dispersion
Methodology for inverse modeling technique

- bLS inverse-dispersion technique

- CH$_4$ concentration and wind data synchronized
- WindTrax model

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Flesch 2011

Unknown

Measured

Boreal lasers and reflectors

Anemometer ultrasonic
CH$_4$ emissions from animals in a feedlot

Diurnal Cycle in CH$_4$ emissions, corresponding with feeding times

Average daily emission rate: 320 g CH$_4$ animal$^{-1}$ d$^{-1}$

The CH$_4$ emission factor estimated using the IPCC methodology is approximately 240 g CH$_4$ animal$^{-1}$ d$^{-1}$

\[ \text{EF}_{\text{CH}_4} = \text{GEI} \times Y_m \]

Source: Van Haarlem, Desjardins et al. (2008)
<table>
<thead>
<tr>
<th>Enteric Fermentation</th>
<th>Tier 1</th>
<th>Tier 2</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td><strong>Hogs</strong> - <strong>Sheep</strong>&lt;br&gt;<strong>Goats</strong> - <strong>Horses</strong></td>
<td><strong>Cattle (dairy &amp; non dairy)</strong></td>
</tr>
<tr>
<td>Manure emission</td>
<td><strong>Tier 2</strong>&lt;br&gt;<strong>Cattle (dairy &amp; non dairy)</strong> - <strong>Hogs</strong>&lt;br&gt;<strong>Sheep</strong> - <strong>Goats</strong> - <strong>Horses</strong> - <strong>Poultry</strong></td>
<td></td>
</tr>
</tbody>
</table>
CH$_4$ emission estimates at a regional scale (2011)
The NRC Twin Otter

Instrumented nose boom

CH$_4$ Analyzer (G2301) and real-time display

in-flight REA sample collection & post-flight REA sample analysis using Picarro G1301
Location of the 7 transects flown at 150 m high

Comparing Inventory-based and Measurement-based Estimates of CH$_4$ Emissions

- Flight track
- Farms
- Wastewater treatment

- 50% of footprint
- 80% of footprint
- 99% of footprint

30 ppb
11 km

mg CH$_4$ m$^{-2}$ d$^{-1}$

REA 21
EC 18
INV 15
Continental sites with multiples years of observations and multiple GHG tracers

Source: Chan (2015)
Use atmospheric dispersion model(s) to link observations to GHG sources and sinks
GHG emission estimates using inversion techniques compared to EC National Inventory - Preliminary results

Source: Chan (2015)
3. GHG emissions intensity of agricultural products

Presentation of the three calculators (Unified Lifestock Industry and Crop Emission Estimation Systems – ULICEES, Canadian Food Carbon Footprint – (cafoo)$^2$ and Fossil Fuel for Farm Fieldwork Energy and Emissions – F4E2) and the way they interact between each other. Verge et al. 2015
Fossil Fuel for Farm Fieldwork Energy and Emissions (F4E2) Model

Schematic diagram of controlling resources and activities of fossil fuel use for farm fieldwork that affect the GHG emissions from fossil fuel on a typical farm in Canada.

Fossil fuel consumption by agriculture is a source of GHG emissions, however these emissions are usually allocated to other sectors of the economy (transportation, industrial processes).

1981
- Field operations: 34%
- Farm transport: 8%
- Heating: 6%
- Electricity: 7%
- Machinery supply: 24%
- Chemical supply: 21%

2011
- Field operations: 37%
- Farm transport: 19%
- Heating: 6%
- Electricity: 7%
- Machinery supply: 5%
- Chemical supply: 26%

Source: Dyer et al. 2008
Two Calculators: On-Farm and Off-Farm

Cradle
Unified Livestock Industry and Crop Emissions Estimation System (ULICEES)

Farm-Gate
Canadian Food Carbon Footprint calculator (Cafoo)²

Processor-Gate
Carbon footprint calculations using ULICEES and (cafoo)$^2$

“Top-down” approaches using national and provincial statistical data.

**Unified Livestock Industry and Crop Emissions Estimation System (ULICEES)**
- GHG emissions from:
  - all crops used to feed animals
  - fertilizer production
  - animals and manure management
- Allocation of co-products (e.g., oil and meal)
- Allocation of linked sectors (e.g., dairy cattle → beef)

**Canadian Foods Carbon Footprint (cafoo)$^2$**
- GHG emissions from:
  - Transportation from the farm to the processor
  - Electricity and Natural gas use at processor
  - Inputs of water, chemicals
  - Wastewater management
  - Other emissions (refrigerants)
- Allocation: economic, mass
On an area basis, crops that are heavily fertilizer (e.g. corn) tend to have a high carbon footprint, where as crops that can fix nitrogen and are not fertilized (e.g. soybean and alfalfa) tend to have a small carbon footprint.

On a dry matter production basis, the heavily fertilized crops do not have the highest carbon footprint, as they are also highly productive crops.

“Crop Complex”: Linking Livestock and Crops

- A central concept in the model.
- Uses animal diets on a regional basis (from periodic surveys).
- Determines hectares of crop, pasture, and rangeland for feed.

### Herd Size + Animal Diet + Crop Yields

<table>
<thead>
<tr>
<th>Alberta Beef cattle (2001) Crops</th>
<th>(tonnes/yr)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wheat</td>
<td>0.5</td>
</tr>
<tr>
<td>Oats</td>
<td>3.8</td>
</tr>
<tr>
<td>Barley</td>
<td>13.5</td>
</tr>
<tr>
<td>Corn</td>
<td>0</td>
</tr>
<tr>
<td>Dry peas</td>
<td>0.2</td>
</tr>
<tr>
<td>Soybean</td>
<td>0.2</td>
</tr>
<tr>
<td>Canola</td>
<td>0.2</td>
</tr>
<tr>
<td>Straw-Silage Pasture</td>
<td>Census</td>
</tr>
</tbody>
</table>

### Crop Emission Factors

- CO₂
- N₂O
- CH₄

### Animal Emission Factors

- CO₂
- N₂O
- CH₄
Improved breeds, adoption of BMPs such as no-tillage and increased feeding of leguminous crops have led to a reduction in emissions intensity of dairy, beef and pork production in Canada.
GHG emissions intensity: $\text{kg CO}_2\text{e} / \text{kg of protein}$


Doi:10.1080/10440046.2010.493376.
This decrease in emissions intensity has been possible through the breeding of higher yielding and more productive animals, improved crop production, feeding of leguminous crops, and the adoption of improved land management practices. Due to a drastic industrialization GHG emission intensities have decreased enormously during the last 25 years.

Many of these gains in productivity have not yet been achieved in the developing world, where significant increases in productivity and decreases in GHG emissions intensity can be achieved.
An estimate of the carbon footprint of milk production in Canada

Crop and milk production represent about 80% of total emissions

- Enteric fermentation, CH₄
- Manure management, CH₄ + N₂O
- Electricity, CO₂
- All emissions, CO₂ (estimated)

It is now pretty clear that big food company (General Mills, etc.) are now in the camp of believers that climate change is real and a threat to business. Substantial reduction in GHG emissions are promised but most companies have no idea how to achieve these reductions.
4. Total radiative forcing also includes change in albedo

Source: IPCC (2007)
How can we assess the impact of agricultural land management on biophysical forcing?

1. Identify fields with known crop type and management, estimate annual albedo from satellite imagery and scale up to national scale using crop/management distribution.
Anticipated results: Albedo for corn under conventional and no-tillage in eastern Canada

Desjardins et al. 2016 Impact of management practices on radiative forcing. (to be submitted)
Anticipated results: Albedo for corn under conventional and no-tillage in eastern Canada

Average annual difference in radiative forcing

4 Wm$^{-2}$
### Biophysical and Biochemical Forcing of Agricultural Management Practice

<table>
<thead>
<tr>
<th>Agricultural Practice</th>
<th>Biogeophysical effect</th>
<th>Biogeochemical effect</th>
<th>Net Effect</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reduced tillage</td>
<td>−</td>
<td>−</td>
<td>−</td>
</tr>
<tr>
<td>Afforestation</td>
<td>+ + +</td>
<td>−</td>
<td>+</td>
</tr>
<tr>
<td>Deforestation</td>
<td>− −</td>
<td>− −</td>
<td>−</td>
</tr>
<tr>
<td>Plant forage crops</td>
<td>−</td>
<td>− −</td>
<td>−</td>
</tr>
<tr>
<td>Irrigation</td>
<td>− −</td>
<td>− +</td>
<td>−</td>
</tr>
<tr>
<td>Biochar</td>
<td>+</td>
<td>− −</td>
<td>−</td>
</tr>
<tr>
<td>Leaf albedo bio-geoengineering</td>
<td>−</td>
<td>− −</td>
<td>−</td>
</tr>
<tr>
<td>Biofuel</td>
<td>− −</td>
<td>− +</td>
<td>−</td>
</tr>
<tr>
<td>Reduce meat consumption</td>
<td>− −</td>
<td>− −</td>
<td>− − −</td>
</tr>
<tr>
<td>Reduced fallow</td>
<td>− −</td>
<td>− −</td>
<td>− − −</td>
</tr>
<tr>
<td>Plant fall crops</td>
<td>− −</td>
<td>− −</td>
<td>− − −</td>
</tr>
<tr>
<td>Leave long stubble for snow trapping</td>
<td>− −</td>
<td>− −</td>
<td>− − −</td>
</tr>
</tbody>
</table>
Summary

- The agriculture sector accounts for 10 - 30% of the total national GHG emissions.
- Enclosures, tower-based systems and models have been very useful to quantify nitrous oxide, carbon dioxide and methane emissions as a function of management practices.
- The inverse modeling technique is very useful to quantify methane emissions from point sources such as manure storage and/or animals in a feedlot or in a barn.
- The combination of aircraft-based flux measurements of nitrous oxide and models provided an independent estimate of indirect nitrous oxide emissions.
- Aircraft-based flux measurements of methane emissions provides a verification of methane inventory at the regional scale. Use of inversion techniques for quantifying regional methane emission estimates is providing interesting results but unlikely to provide emission estimates by sector.
- Presented estimates of the C footprint / emission intensity (GHG/unit protein) of agricultural products.
- Big food suppliers are announcing goals to reduce GHG emissions from farm to fork to landfill. Example: General Mills just announced its reduction goal of 28% within 10 years but the food industry is a very complex system because of the 7 billion players.
- In order to minimize the impact of agriculture on climate change, the impact of a change in albedo needs to be considered because of its importance in radiative forcing.
Potential recommendations to WMO

• To promote an “integrated system approach” toward environmental and societal impacts of mitigation strategies that incorporates all geophysical and biochemical processes. This would include linkages between:
  – crop and animal productions, including e.g. manure digestion to produce biogas
  – integrated (CO₂ equivalent) GHG emissions
  – land-use change (albedo, etc) and GHG production/absorption
  – model verification through measurement programs
  – achievement of the “best estimate” of a GHG inventory or a mitigation strategy by judicious integration of models and measurement.

• to continue to promote the synergism between CAgM and CAS. CAgM scientists have excellent experience in flux measurements (data sets) and crop modelling and CAS scientists have excellent experience in concentration measurements (data sets) and atmospheric transport models.
Thank you very much for your attention