Calculation of the carbon footprint of Ontario wheat

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Increasing consumer awareness of the environmental impact of food production has prompted interest in locally grown food in Ontario. The research reported here had the objective of quantifying the carbon footprint of Ontario grown wheat. A spreadsheet was developed and populated with data and emission coefficients gathered through consultation of the literature. The spreadsheet expresses the carbon footprint in the life cycle of Ontario wheat in CO₂ equivalent (kg CO₂). The life cycle of wheat includes production, transportation, the use of machinery and application of agricultural chemicals such as pesticides and fertilizers. Since there are insufficient industrial data of manufacture of machines, they were not included in the calculations. The accuracy of this spreadsheet was examined by comparing its results with results of the Agriculture and Agri-Food Canada (AAFC) Greenhouse Gas (GHG) Calculator. The total farm emission of the AAFC GHG Calculator was 3960.2 Mg CO₂, while the created spreadsheet had a result of 2963.1 Mg CO₂. The spreadsheet has a lower emission than AAFC GHG Calculator because machine manufacture was not included in the spreadsheet. For individual categories agreement was quite close, most categories are within 90% agreement. As a conclusion, results between AAFC GHG Calculator and spreadsheets are similar hence demonstrate the accuracy of the spreadsheet created. Fertilizer production and direct emission from the soil were responsible for 89% of the GHG emissions from Ontario grown wheat.

Life-cycle analysis (LCA) is a computational tool used to assess the greenhouse gas budget of an end-product throughout its whole life cycle. The life cycle of wheat includes production, transportation, use of machinery and application of agricultural chemicals such as pesticides and fertilizers.

Greenhouse gas (GHG) is released during the manufacture of pesticides, which formulation, packaging and transportation of herbicides, insecticides and fungicides from manufacture to farm according to West and Marland [1] and Nagy [2].

Machinery use and manufacture release GHGs through burning of fossil fuel during field operations and manufacture of farm equipment (e.g. tractors). All on-farm operations including application of pesticides and fertilizers are integrated into this LCA.

Production of fertilizer includes the extraction of nutrients, manufacture of fertilizer and transportation of minerals to the production facility, supply centre, and the site of application. Energy used in transportation is 0.7 and 1.4 MJ/Mg-km by railroad and truck respectively according to West and Marland [1]. When fertilizers are added to agricultural soil, they undergo transformation through nitrification and denitrification, which releases N₂O into the atmosphere. Also, the crop residue contains nitrogen, which decomposes to release nitrogen. All formulas and emission factors were obtained from Rochette et al [3].

After fertilizers are applied, some portion leaches while some is volatilized, and these nitrogen losses can result in indirect N₂O emission. Transportation releases greenhouse gas by burning fuels such as gasoline and diesel. On-road transportation such as trucks and non-road transportation such as railway are necessary in agriculture for transferring the crop product from the farmland to the market. Care was taken to avoid double counting of the transportation of pesticides and fertilizers from factory to farmland.

This paper will detail the methodologies and emission factors used in the spreadsheet to quantify the carbon footprint of wheat. The results are compared with Agriculture and Agri-Food Canada (AAFC) calculator for accuracy assurance.

METHODOLOGY

Pesticides

Pesticides are input as the active ingredient application rate (kg a.i./ha). The formula used is:

$$\begin{aligned} CO_2eq \text{ emission } & \left(\frac{kg \text{ CO}_2}{ha} \right) \\ &= \text{Emission Factor } \left(\frac{kg \text{ CO}_2}{kg \text{ a.i.}} \right) \\ &\times \text{Application rate } \left(\frac{kg \text{ a.i.}}{ha} \right) \end{aligned}$$

Emission factors for insecticides and fungicides used are 4931.9 kg C/Mg and 5177.5 kg C/Mg respectively [1].

Emission factors for herbicide were derived from Nagy[2], who divided the emission factor by the average carbon content (kg C/MJ a.i.) to obtain the kilograms of carbon per kilogram of active ingredients (kg C/kg a.i.) (Table 1).

All emission factors were converted to kilograms of carbon dioxide equivalent per kilogram of active ingredient (kg CO₂/kg a.i.). For example, the emission factor for insecticide is 4391.9 kg C/Mg, to convert it to CO₂ equivalent per kilograms of active ingredient (kg CO₂/kg a.i.):

$$4391.9 \left(\frac{\text{kg C}}{\text{Mg a.i.}} \right) \times \frac{1}{1000} \left(\frac{\text{Mg a.i.}}{\text{kg a.i.}} \right) \times \frac{1}{12} \left(\frac{\text{mol}}{\text{g C}} \right) \times \frac{44}{1} \left(\frac{\text{g CO}_2}{\text{mol}} \right) = 18.1 \left(\frac{\text{kg CO}_2}{\text{kg a.i.}} \right)$$

As another example, the herbicides Achieve 80 DG has an emission of 2.9 kg C/kg a.i. (Table 1), so to convert it to CO₂ equivalent:

$$2.9 \left(\frac{\text{kg C}}{\text{kg a.i.}} \right) \times \frac{44}{1} \left(\frac{\text{g CO}_2}{\text{mol}} \right) \times \frac{1}{12} \left(\frac{\text{mol}}{\text{g C}} \right) = 10.6 \left(\frac{\text{kg CO}_2}{\text{kg a.i.}} \right)$$

Machinery Use

Machinery use and manufacture releases GHGs through burning of fossil fuel during field operations and manufacture of farm equipment (e.g. tractors). All on-farm

operations including application of pesticides and fertilizers are discussed in this section. All fuel consumptions (L/ha) for different operations were collected from Bowers [4] and Dyer and Desjardins [5]. The number of times of operation performed annually is specified by spreadsheet users. The formula is:

$$\begin{aligned} & CO_2eq \left(\frac{\text{kg CO}_2}{\text{ha}} \right) \\ &= \text{Emission factor} \left(\frac{\text{kg CO}_2}{\text{L}} \right) \\ &\times \text{Fuel Consumption for each operation} \left(\frac{\text{L}}{\text{ha}} \right) \\ &\times \text{Times of operation performed} \\ &\times \text{Fuel production ratio} \end{aligned}$$

The fuel production ratio is the ratio of energy content in fuel to energy used to mine, refine and transport fuel to farmers. The energy content and production values were obtained from Cervinka [6]. An example of the derivation of ratio for gasoline is shown below:

$$\begin{aligned} \text{Ratio} &= \text{Total energy cost} \div \text{Energy content} \\ &= 42.3 \div 32.2 = 1.24 \end{aligned}$$

Canada's Greenhouse Gas Inventory 1990-2001 lists all the emission factors for on-road transportation, non-road vehicles and diesel rail transportations [7]. For example, the emission factor for Heavy-Duty Diesel Vehicles (HDDV) is 2730 g CO₂/L and was converted to 2.73 kg CO₂/L. The range of carbon equivalent emission for moldboard plowing is 13.4 to 20.1 kg CE/ha, which is also equivalent to 49.1-73.7 kg CO₂/ha [7]. In the spreadsheet, for moldboard plowing:

$$\begin{aligned} \text{Fuel consumption} &= 17.49 \left(\frac{\text{L}}{\text{ha}} \right) \\ \text{Emission factor} &= 2.73 \left(\frac{\text{kg CO}_2}{\text{L}} \right) \\ \text{Fuel production ratio} &= 1.24 \end{aligned}$$

Using the values above, the CO₂eq emission would be:

$$\begin{aligned} CO_2eq \text{ emission} &= 2.73 \left(\frac{\text{kg CO}_2}{\text{L}} \right) \times 17.49 \left(\frac{\text{L}}{\text{ha}} \right) \times 1.24 \\ &= 59.2 \left(\frac{\text{kg CO}_2}{\text{ha}} \right) \end{aligned}$$

This emission for moldboard plowing was compared with Lal[8], who stated emissions are within the range of 49.1-73.7 kg CO₂/ha [7].

Machine Manufacture

The weight of machinery in kilograms is user-specific in our spreadsheet. The formula for emission is shown below:

$$\begin{aligned} & CO_2eq \text{ emission (kg CO}_2) \\ &= \text{Energy content} \\ &\times \text{Emission factor} \left(\frac{\text{kg CO}_2}{\text{GJ}} \right) \\ &\times \text{Weight of machine (kg)} \end{aligned}$$

All the energy contents of equipment were obtained from Bower [4].

Table 1 Herbicide Emission Factor obtained from Nagy [2]

Herbicides	year 2000		year 1996	
	MJ/kg a.i.	kg C/kg a.i.	MJ/kg a.i.	kg C/kg a.i.
Achiever 80 DG	229	2.9	313.8	3.9
Amber	267.3	3.3	366.2	4.6
Aatrex Nine-O	158.2	2	216.7	2.7
Bladex 90 DF	168.6	2.1	231	2.9
Lexone DF	437.3	5.5	599.1	7.5
Odyssey (1997)	152.1	1.9	208.4	2.6
Secor 75 DF	146	1.8	200	2.5
Venture	437.3	5.5	599.1	7.5
Bladex L	168.6	2.1	231	2.9
Glean	309.3	3.9	423.7	5.3
Lorox DF	237.9	3	325.9	4.1
Muster	246.3	3.1	337.4	4.2
Refine Extra	246.3	3.1	337.4	4.2
Stampede EDF	184.4	2.3	252.6	3.2
Assert	234.2	2.9	320.8	4
Avenge	369.7	4.6	506.5	6.3
Banvel	245.3	3.1	336	4.2
Basagran	359.9	4.5	493	6.2
Dyvel DS	104.5	1.3	143.2	1.8

Fertilizer Production and Direct and Indirect Emission from Fertilizer

The emissions related to fertilizers are divided into three sections.

Part A: Methodology for Nitrogen, Potassium and Potash Fertilizer Production

Part B: Methodology for Direct Emission from Nitrogen Fertilizers

Part C: Methodology for Indirect Emissions from Nitrogen Fertilizers

Part A: Nitrogen, Potassium and Potash Fertilizer Production

Production of fertilizer includes the extraction of nutrients, manufacture fertilizer and transportation of the mineral to the production facility, supply centre, and the site of application. Energy used in transportation is 0.7 and 1.4 MJ/Mg/km by railroad and truck respectively [1].

The nutrient application rate in kilogram of nutrient per hectare is user-specified in the spreadsheet. The formula for emission calculation is shown below:

$CO_2eq \text{ emission (kg } CO_2)$

$$= \text{Application rate} \left(\frac{\text{kg nutrient}}{\text{ha}} \right) \times \text{Emission factor} \left(\frac{\text{kg } CO_2}{\text{kg nutrient}} \right)$$

Emission factors were collected from West and Marland [1] and Nagy [2]. For nitrogen based fertilizers, emission factors range from 2.6 kg CO_2 /kg N to 4.3 kg CO_2 /kg N. Potash (62% K_2O) has an emission factor of 0.24 kg CO_2 /kg K_2O while Phosphorus (55% P_2O_5) has an emission factor of 0.57 kg CO_2 /kg P_2O_5 .

Emission factors for nitrogen fertilizer range from 0.9 to 1.8 kg C/kg, which is equivalent to 3.3-3.6 kg CO_2 /kg [7]. The fertilizer range of the spreadsheet is less than Lal [7], who however, has less updated sources than Nagy [2]. Therefore, advanced technology has created more efficient fertilizer which release fewer emissions.

Part B: Direct Emission from Nitrogen Fertilizers

When fertilizers are added to agriculture soil, they undergo transformation through nitrification and denitrification, which releases N_2O into the atmosphere. Also, the crop residue contains nitrogen, which decomposes to release nitrogen. All formulas and emission factors were obtained from estimation of soil N_2O emission by Rochette et al [3].

Direct emissions are influenced by many factors such as amount of fertilizer applied (N_2O fertilizer), amount of crop residue returned to soil (N_2O residue), soil tillage (N_2O till) and soil texture (N_2O text) [3]. Therefore, each category has its own formula for emission calculation.

The inputs specified by the spreadsheet user include nitrogen application rate (kg/ha), mass of nitrogen in crop residue returned to soil (kg/ha), fraction of farm area with fine (F fine), medium (F med) and coarse (F co) textured soil

and Fraction of farm area under tillage (F till). To classify each texture, fine texture stands for clay, medium texture corresponds to loamy clay, loamy sand and loam, while coarse texture represents sand.

The formulas for each category are shown below:

1. $N_2O_{input} \left(\frac{\text{kg } N_2O-N}{\text{ha}} \right) = N_2O_{residue} + N_2O_{fertilizer}$
 - a. $N_2O_{residue} \left(\frac{\text{kg } N_2O-N}{\text{ha}} \right) = EF \left(\frac{\text{kg } N_2O-N}{\text{kg N}} \right) \times \text{Weight of crop residue} \left(\frac{\text{kg N}}{\text{ha}} \right)$
 - b. $N_2O_{fertilizer} \left(\frac{\text{kg } N_2O-N}{\text{ha}} \right) = EF \left(\frac{\text{kg } N_2O-N}{\text{kg N}} \right) \times \text{Nitrogen application rate} \left(\frac{\text{kg N}}{\text{ha}} \right)$
2. $N_2O_{text} \left(\frac{\text{kg } N_2O-N}{\text{ha}} \right) = N_2O_{input} \times \{[(RF_{fine} - 1) \times F_{fine}] + \{[(RF_{medium} - 1) \times F_{medium}] + \{[(RF_{coarse} - 1) \times F_{coarse}]\}\}$
3. $N_2O_{till} \left(\frac{\text{kg } N_2O-N}{\text{ha}} \right) = N_2O_{input} \times \{[(RF_{till} - 1) \times F_{till}]\}$

Emission factors vary with regions (Table 2). Also, all formulas were expressed in kg N_2O , to express the results in CO_2 equivalent. The formula was multiplied by ratio of molar mass of N_2O and N_2O-N , which are 44 kg N_2O and 28 kg N_2O-N respectively. In addition, the global warming potential unit of N_2O is 310 CO_2 thus the formula was multiplied by 310 to express the emission in terms of CO_2 [8].

An example of calculation is given using $RF_{till}=1.1$ and with soil texture in Ontario-Quebec region ($EF=0.012$):

$$N_2O_{residue} \left(\frac{\text{kg } N_2O-N}{\text{ha}} \right) = 0.012 \left(\frac{\text{kg } N_2O-N}{\text{kg N}} \right) \times 0 \left(\frac{\text{kg N}}{\text{ha}} \right)$$

Table 2 Emission Factors for different regions [3].

Region		Ontario-Quebec	Prairies (Brown and Dark Brown)	Prairies (Black and Gray)
EF (kg N_2O-N /kg N)		0.012	0.0016	0.0008
RF _{till}	conventional tillage	1	1	1
	minimum tillage and no-till	1.1	0.8	0.8
RF _{text}	conventional tillage	1.2		
	minimum tillage and no-till	0.8	1	1
R _{leaching crop}		0.25	0.05	0.1
EF _{leaching}		0.0125	0.0125	0.0125
R _{volatilization crop}		0.1	0.1	0.1
EF _{volatilization crop}		0.01	0.01	0.01

$$\begin{aligned}
 N_2O_{fertilizer} \left(\frac{kg \ N_2O-N}{ha} \right) &= 0.012 \left(\frac{kg \ N_2O-N}{kg \ N} \right) \times 90 \left(\frac{kg \ N}{ha} \right) \\
 &= 1.08
 \end{aligned}$$

Hence,

$$\begin{aligned}
 N_2O_{input} \left(\frac{kg \ N_2O-N}{ha} \right) &= 0 + 1.08 = 1.08 \\
 N_2O_{text} \left(\frac{kg \ N_2O-N}{ha} \right) &= 1.08 \times (1.2 - 1) \times 1.08 \times (0.8 - 1) \\
 &\quad \times 0 + 1.08 \times (0.8 - 1) = 0.216
 \end{aligned}$$

$$N_2O_{till} \left(\frac{kg \ N_2O-N}{ha} \right) = 1.08 \times (1.1 - 1) \times 1 = 0.108$$

Therefore,

$$\begin{aligned}
 \text{Direct } N_2O \text{ emission in } CO_2eq &= \left(1.08 + 0.216 + 0.108 \left(\frac{kg \ N_2O-N}{ha} \right) \right) \\
 &\quad \times \frac{44kgN_2O}{28kgN_2O-N} \times \frac{310kgCO_2}{1kgN_2O} \\
 &= 683.9 \frac{kg \ CO_2}{ha}
 \end{aligned}$$

Part C: Methodology for Indirect Emission from fertilizers

After fertilizers are applied, some portion leaches while some is volatilized. These nitrogen losses are described as indirect N_2O emissions. Indirect N_2O emission followed the methodology described in Helgason et al [9].

Nitrogen fertilizer applied in kilograms per hectare is input by spreadsheet users. The emission formulas are listed below:

$$\begin{aligned}
 N_2O \text{ leached} \left(\frac{kg \ N_2O-N}{ha} \right) &= N \text{ fertilizer applied} \left(\frac{kg}{ha} \right) \\
 &\quad \times R_{leaching \ crop} \times EF_{leaching \ crop} \\
 N_2O \text{ volatilized} \left(\frac{kg \ N_2O-N}{ha} \right) &= N \text{ fertilizer applied} \left(\frac{kg}{ha} \right) \\
 &\quad \times R_{volatilization \ crop} \times EF_{volatilization \ crop}
 \end{aligned}$$

Emission factors vary with region (Table 2). Similarly to direct emissions, N_2O leached and volatilized were both expressed in $kg \ N_2O-N$. In order to express the results in CO_2 equivalent, the formula was multiplied by ratio of the molar mass of N_2O and N_2O-N and the global warming potential unit of N_2O : $44 \ kg \ N_2O / 28 \ N_2O-N \times 310 \ N_2O / 1 \ CO_2$

For example, if $90 \ kg/ha$ of N fertilizer is applied:

$$\begin{aligned}
 N_2O \text{ leached} \left(\frac{kg \ N_2O-N}{ha} \right) &= 90 \frac{kg}{ha} \times 0.25 \times 0.125 \\
 &= 0.28
 \end{aligned}$$

$$\begin{aligned}
 N_2O \text{ volatilized} \left(\frac{kg \ N_2O-N}{ha} \right) &= 90 \frac{kg}{ha} \times 0.1 \times 0.01 \\
 &= 0.09
 \end{aligned}$$

Hence,

$$\begin{aligned}
 \text{Total indirect } N_2O \text{ emission in } CO_2eq &= \left(0.28 + 0.09 \left(\frac{kg \ N_2O-N}{ha} \right) \right) \\
 &\quad \times \frac{44kgN_2O}{28kgN_2O-N} \times \frac{310kgCO_2}{1kgN_2O} \\
 &= 12.3 \left(\frac{kg \ CO_2}{ha} \right)
 \end{aligned}$$

Transportation

Transportation releases greenhouse gas by burning fuels such as gasoline and diesel. On-road transportation such as railway are necessary in agriculture for transferring the crop product from the farmland to the market. Please note that transportation of pesticides and fertilizer from the manufacture to the farmland are included in Pesticide category and Fertilizer category discussed above.

Canada's Greenhouse Gas Inventory 1990-2001 [8] and Bushi list the emissions from transportation [10]. Canada's Greenhouse Gas Inventory 1990-2002 lists the emission factor for gasoline-based vehicles as $2.36 \ kg \ CO_2/L$, and for diesel-based vehicles as $2.73 \ kg \ CO_2/L$.

Inputs by spreadsheet users include the distance travelled in kilometers and the number of cars. The formulas used are listed below:

$$\begin{aligned}
 \text{Emission} \left(\frac{kg \ CO_2}{Mg \ wheat} \right) &= \text{Emission in } CO_2eq \ (kg \ CO_2) \\
 &\div \text{Weight of wheat transported} \ (Mg \ wheat)
 \end{aligned}$$

Fuel efficiencies were derived from SGA [11], while bulk density and load capacities were obtained from Börjesson [12].

RESULTS AND DISCUSSION

The results of the spreadsheet were compared with the results from the AAFC GHG Calculator. The results are discussed in the order that displayed in the AAFC GHG Calculator.

AAFC GHG Calculator Inputs

For the location tab, the province Ontario (Ecodistrict 413) with soil type as Humo-Ferric Podzol and soil texture as Loamy Clay are selected as inputs. For land use tab, the total farm area and crop is set as 2000 hectares, while pasture, yard, roadways and other are set as zero. As for history of the land use, we set there are zero crop land converted to permanent cover. Also, the tillage intensity is set as intensive 20 years ago and presently. For the crop information, 2000 hectares of winter wheat is selected with $90 \ kgN/ha$ of nitrogen fertilizer rate applied in the spring.

The yield is 3534 kg/ha with zero percent straw removal. The rest of the tabs (Manure and Livestock) were not applicable to this study.

AAFC GHG Calculator Results

Cropping N₂O (Mg CO₂ eq)

Direct N₂O emissions (Mg CO₂ eq)

+/- <60% Units: kg N₂O-N

Fertilizer: 3907.8

Residue: 1062.3

Fallow: 0.0

Improved Pasture: 0.0

Organic Soil: 0.0

Total Direct N₂O emissions (Mg CO₂ eq): 2311.8

Indirect N₂O emissions (Mg CO₂ eq)

+/- >60% Units: kg N₂O-N

Leaching: 562.5

Volatilization: 180.0

Total Indirect N₂O emissions (Mg CO₂ eq): 345.4

Energy CO₂ (Mg CO₂ eq)

+/- <20% Units: kg CO₂

Fuel, Herbicide and Machinery: 857220.0

Production of Fertilizers: 460744.0

Total Energy CO₂ (Mg CO₂ eq): 1318.0

Total farm emissions (Mg CO₂ eq) +/- <60%

Total farm emissions (Mg CO₂ eq): 3960.2

Spreadsheet Inputs

The input for the spreadsheet was the same as the input of the AAFC GHG Calculator. However, some input such as pesticide weights (kg a.i.) is not required for the AAFC GHG Calculator. Hence, a reasonable input for pesticide was entered into the spreadsheet.

For direct N₂O emission, when 90 kgN/ha fertilizer rate and 2000 ha of crop area are entered in the AAFC GHG Calculator, the direct N₂O emission is 3907.8 kg N₂O-N as shown above. To convert the results in CO₂ equivalent:

$$3907.8 \text{ kg N}_2\text{O-N} \times \frac{44\text{N}_2\text{O}}{28\text{N}_2\text{O-N}} \times \frac{310\text{CO}_2}{1\text{N}_2\text{O}} \\ = 1,903,657 \text{ kg CO}_2$$

Hence, the direct N₂O emission in CO₂ equivalent is 1,903.7 Mg CO₂ in the AAFC GHG Calculator, which is similar to the results in the spreadsheet of 2,092 Mg CO₂.

For indirect N₂O emission, the output is 361.7 Mg CO₂ with the same inputs. This is similar to the AAFC GHG Calculator (345.4 Mg CO₂).

For fuel, herbicide and machinery, since the total emission of fuel, herbicide and machinery are combined in the AAFC GHG Calculator, the calculation follows for comparison purposes. The Ontario input of fuel machinery were obtained from Dyer and Desjardin [5]. In addition, SGA provides the regional mean of GHG emissions in kg CO₂ equivalent per hectare for major farm machinery operations, without any adjustment for specific farm types. For comparison purposes, a few operations were used as input: moldboard plow, disc-tilled soil, field sprayer, spread

fertilizer, rotary hoe, broadcast seeder, combine, harvester and grain wagon [11]. As a consequence, emission for machinery fuel is 572.2 Mg CO₂. For pesticides, the input are obtained from Lal, who provides the carbon budget of weed control in carbon equivalent per hectare (kg CE/ha) for different intensity of tillage. Weed control for wheat with high tillage is 9.1 kg CE/ha, which is equal to 33.4 kg CO₂/ha. Consequently, the calculation gives an emission of total 199.5 Mg CO₂. To sum up fuel, herbicide, and machinery, the calculation resulted in a total of 771.8 Mg CO₂, which is approximately 100 Mg CO₂ less than AAFC GHG Calculator's result (852.2 Mg CO₂). The difference between the two results is possibly due to manufacture of machinery, as the calculation has excluded manufacture of machinery while the AAFC GHG Calculator has included that factor. As a result, it is reasonable for the spreadsheet calculation to results in less than that of the AAFC GHG's calculation.

For production of fertilizer, the application rate is 90 kg/ha for each category including nitrogen, phosphate and potash. The area applied for each category is less than 2000 ha, which is 1300, 1000 and 1000 ha respectively. Similarly to the AAFC GHG Calculator's result (460.4 Mg CO₂), the spreadsheet calculation shows the subtotal emission to be 461.5 Mg CO₂.

CONCLUSION

The total farm emission in the AAFC GHG Calculator is 3,960.2 Mg CO₂ eq while the total farm emission of the spreadsheet is 2,963.1 Mg CO₂ eq (Table 3). The spreadsheet total farm emission is less than the AAFC GHG Calculator because machine manufacture is not included in the spreadsheet. For the same categories, the AAFC GHG Calculator and spreadsheet agree within approximately 90%.

This calculation and the Ontario case study shown below both demonstrate that the use of fertilizer contributes the most GHG emission thus the judicious use of nitrogen fertilizer is recommended.

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Table 3 GHG emission results from spreadsheet.

Pesticides		Emission (kg CO2)		
Fungicides		66430		
Insecticides		66534.4		
Herbicides		66543.8		
	Subtotal (Mg CO2)	199.51		
Operations		Emission (kg CO2)		
Primary Tillage		204730.944		
Secondary Tillage		60166.784		
Chemical Application		21421.248		
Cultivation		11471.488		
Planting		73745.28		
Harvesting		200702.184		
	Subtotal (Mg CO2)	572.24		
Fertilizer Production & Direct Emission		Fertilizer Production (kg CO2)	Direct Emission (kg CO2)	Indirect emission (kg CO2)
Nitrogen		367380		
Phosphate		54450		
Potash		39690		
	Subtotal (kg CO2)	461520	1367897.143	361671.75
	Total (Mg CO2)	2191.09		
Transportation		Emission (kg CO2)		
Gasoline Truck		4.248		
Gasoline Vehicles		1.9824		
Diesel Truck		5.687955		
Diesel Vehicles		17.063865		
Diesel Rail		0		
	Subtotal (Mg CO2)	0.2898222		
Total Emission (Mg CO2)		2963.12		

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