Carbon Footprint of Canadian Agriculture

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A more detailed, technical version of this presentation is available from Renaud@lanigangroup.ca for review by scientists

Lanigan Group's Analysis of the Sustainability of Canadian Agriculture

This presentation is the first of a 4-part series of analysis on the Sustainability of Canadian Agriculture:

1. ***Misconceptions About the Sustainability of Canadian Agriculture*** addresses false assumptions and misconceptions about Canadian agriculture's role in global warming due to lack of attention to on-farm sequestration by policymakers.

2. ***Carbon as a Cash Crop*** addresses why Canada's current narrative for agricultural climate action isn't working and why carbon credits are ineffective as a basis for incentivizing agricultural climate action. It proposes a more effective alternative based on the concept of incentives for excess sequestration services.

3. ***Enteric Emissions are Climate Neutral*** presents a detailed analysis of enteric emissions in Canadian dairy which establishes that enteric emissions in Canada are better than non-additive to global warming because they occur in a biogenic carbon cycle that sequesters more carbon than is emitted.

4. ***Carbon Footprint of Canadian Agriculture*** (this report) presents a comprehensive estimate of the net carbon footprint for Canadian agriculture that is otherwise unavailable from official sources. It documents why Canadian agriculture is already sustainable because it is already generating over $3 B in unpaid, excess sequestration services.

Why Look at Agriculture Differently than Other Industry Sectors?

- **The climate crisis is caused by human activity not being in balance with nature**.
  - Since the industrial revolution, emissions have soared past the capacity of natural sequestration
  - Yet emissions from agrarian activity occurred successfully for thousands of years prior to the industrial revolution

- Agriculture is an important part of the Canadian economy, according to Agriculture and AgriFood Canada:
  - Primary agriculture (work done on farms) provides over 2x the jobs compared to the oil & gas sector and directly contributes $32 B to Canadian GDP
  - Plus it literally is the start of the food chain for all Food Retail, Wholesale, Food Service industries as well as Food & Beverage Processing totalling $135 B of Canadian GDP, over 2 million Canadians (1 in 9 jobs in Canada)

- Returning emissions from agrarian activity to a balance with natural sequestration on farms returns agriculture to a sustainable posture – i.e. climate neutral
  - Agriculture is unique because (like forestry) it is the only economic sector that can offset emissions with natural sequestration + plus, we need food to eat
  - If agriculture becomes better than climate neutral, provision of excess sequestration services offsets emissions by other economic sectors

Number of Farms in Canada

Map showing the agricultural extent of Canada *(Source: AAFC, 2013)*.

Atlantic Canada				
	Nova Scotia	2,741		
	New Brunswick	1,851	6,131	3%
	Prince Edward Island	1,195		
	Newfoundland and Labrador	344		
Central Canada				
	Ontario	48,346	77,726	41%
	Quebec	29,380		
Western Canada				
	Alberta	41,505		
	Saskatchewan	34,128	90,176	47%
	Manitoba	14,543		
Pacitic Canada				
	British Columbia	15,841	15,841	8%
Source: Statscan 2021 Census of Agriculture			189,874	

Province	**Number of farms**	
Ontario	48,346	25%
Alberta	41,505	22%
Saskatchewan	34,128	18%
Quebec	29,380	15%
British Columbia	15,841	8.3%
Manitoba	14,543	7.7%
Nova Scotia	2,741	1.4%
New Brunswick	1,851	1.0%
Prince Edward Island	1,195	0.6%
Newfoundland and Labrador	344	0.2%
Source: Statscan 2021 Census of Agriculture	189,874	

Average Size of Farm by Province

Average size of farms in the prairies is 5x the average size in other provinces

Table 1. Average Farm Size (Acres) 1971 and 2021, and Percentage Change, 1971-2021

	Average Farm Size (Acres)		% Change	
Province	**1971**	**2021**	**1971-2016 (avg)**	**2016-2021**
Newfoundland	60	144	23.20	-17.24
PEI	171	422	11.37	-0.71
Nova Scotia	221	263	3.31	0.00
New Brunswick	244	370	6.08	0.00
Quebec	176	264	5.84	-5.71
Ontario	169	243	4.41	-2.41
Manitoba	543	1,177	9.57	-1.26
Saskatchewan	845	1,766	8.92	-1.01
Alberta	790	1,184	5.87	-4.28
British Columbia	316	357	3.31	-2.19
Canada	**463**	**809**	**7.41**	**-1.34**

Data from Statistics Canada, Table 32-10-0153-01 Land Use, Census of Agriculture historical data

Total Agricultural Volume is Highest in The Prairies Where Farms are Larger but Crop Production Leadership Varies Significantly by Province

- The 3 prairie provinces produce the most canola (99%), spring wheat (98%), and barley (96%)
- Ontario produces the largest volume of winter wheat (76%), soybeans (54%), and corn for grain (60%)
- 62% of all greenhouse products are grown in Ontario.
- Quebec produces the most cranberries (58%), and maple syrup (90%) and
- Quebec combined with Ontario, the most dairy (70%) and swine (58%),
- Alberta the most beef and combined with the other prairie provinces (73%),
- Atlantic provinces produce the most blueberries and potato
- British Columbia dominates aquaculture production.

Source: Statistics Canada 2020

Challenges in determining carbon footprint of agriculture

WHY DON'T WE ALREADY KNOW THE ANSWER?

Canada's National Inventory of GHG provides only a partial view of the actual Carbon Footprint of Primary Agriculture in Canada

- Canada's National Inventory of GHG **does not reveal a complete picture** for agriculture
  - Only direct emissions in agriculture are shown in Figures ES-2, ES-7 which comingles biogenic and additive emissions
  - Figure ES-7's total of 69 MT includes agri-food processing as well as agricultural production emissions
    - ES-2 identifies 55 MT in emissions from primary agriculture
  - Sequestration from agricultural activities is comingled with forestry under the section of LULUCF (Land Use, Land-Use Change, Forestry)
  - Sequestration from land use in agriculture includes only crop contribution to soil which is not included in the Executive Summary.
    - Need to locate Fig. 6-6 under LULUCF in Chapter 6.5 of Vol 1 to find it
  - The sequestration contribution from Prairie-farm shelterbelts is rolled up into Forestry land use contribution
  - Emissions due to stationary and off-road fuel use in agriculture are comingled with fishing and forestry
  - There is no accounting for existing sequestration from:
    - **Biomass of farm trees and other perennial biomass beyond large shelterbelts**
    - **Soil input from woody biomass on farms from trees, orchards, vineyards, hedgerows, or shrubs**
      - **Even orchards maintained at a constant biomass still contribute to soil organic carbon**
    - **Managed wetlands areas employed for food production** (e.g. wild rice, cranberries, etc.)
    - **Harvested Crop Yield employed to feed livestock**
      - 24 MT of Enteric emissions and 7.8 MT of manure related emissions (NIR Table 5-1) are non-additive as they are completely offset by the carbon sequestered in the crops grown to feed cattle
      - A review of harvested yield to feed livestock reveals a net 10 Mg carbon sequestration per dairy cow after deducting enteric emissions – hence reversing enteric emissions would be conservative

Source: Canada National Inventory of GHG 2020

Figure ES–7 Breakdown of Canada's GHG Emissions by Economic Sector (2020)

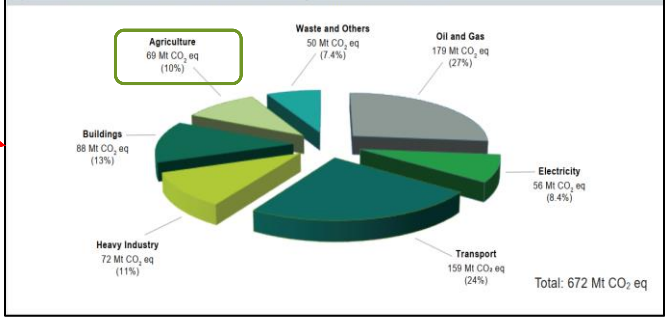


Figure ES–2 Breakdown of Canada's Emissions by Intergovernmental Panel on Climate Change Sector (2020)

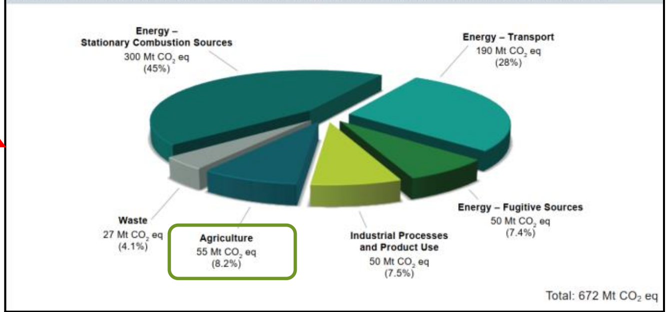
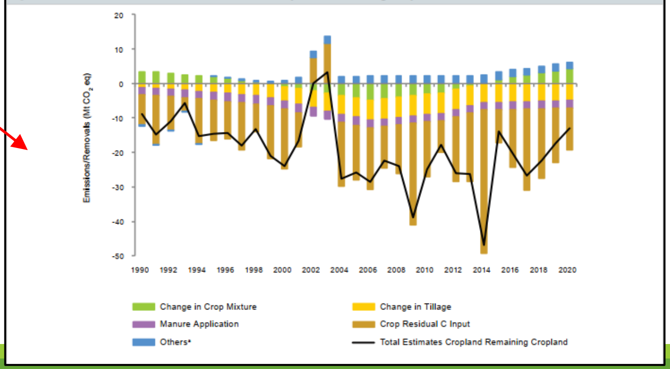


Figure 6–6 Emissions and Removals Related to Cropland Remaining Cropland



Challenges in Discerning Agricultural Carbon Footprint via Canada's National Inventory of GHG

Co-Mingled Emissions

- Stationary& off-road combustion combined with fishing & forestry
- Agrifood processing combined with primary agriculture

Insufficient Emission Detail

- Agrichemical manufacturing not broken out within chemical manufacturing

Missing Sequestration

- Annual biomass growth in perennial vegetation
- Carbon input to soil from woody perennials in woodlots, orchards, vineyards and hedgerows
- Wetland areas used to grow food (wild risk, cranberries)
- Carbon in harvested crops used to feed livestock

Comingled Sequestration

- Shelterbelt sequestration comingled with forestry land use

Missing Sequestration Estimates of Existing Trees on Farms

- The use of carbon credits to offset emissions in other sectors of the economy is based on the necessity of those offsets being "additional" to existing levels of sequestration
  - More accurately, addition or removal of atmospheric carbon is considered additional if it would not have otherwise occurred without offset project funding
  - **Carbon credit accounting devalues the importance of existing trees** in offsetting farm emissions
- *Additionality* **does not apply** to agricultural areas or in managed forests that have direct access to natural sequestration (i.e. trees)
  - These areas are designated by the IPCC and Environment Canada as *Managed Lands* for the purposes of carbon footprint accounting
  - On Managed Lands, ALL sequestration is counted for the purpose of carbon footprint accounting – not just additional sequestration
  - Consequently, sequestration from existing trees is very important when determining net carbon footprint and in many cases results in a farm already being net-zero or better when the carbon footprint of the whole farm is analyzed

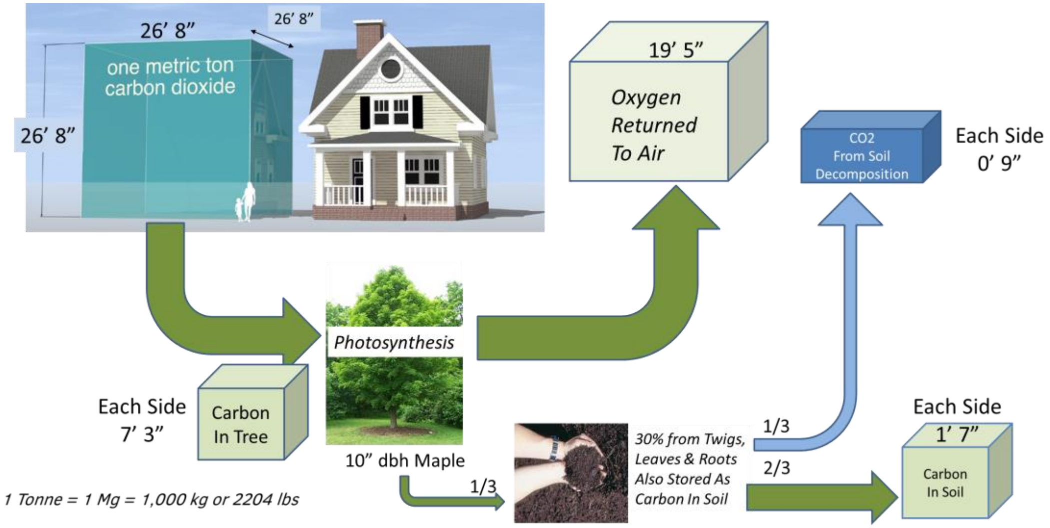
Are There Any Trees on Farms?

- There is a popular misconception that there are no trees on farms (or not enough to matter)
- However, our research (presented later) shows that the sequestration from permanent perennial vegetation on farms is a significant omission from current national estimates of GHG additions and removals
  - A “permanent perennial” is a perennial plant that is not harvested by the farm
  - These plants sequester carbon in their biomass and release it to the soil (net of soil respiration as it decomposes when it dies)
  - Because they are perennial, they also provide “cover crop” style benefits that reduces emissions from soil
  - It also provides better context for understanding the upside for increased sequestration from agroforestry methods which have been under-utilized to-date to increase sequestration in agriculture
  - When the perennial is a tree, significant levels of carbon are reliably stored in the biomass and soil surrounding the tree
    - Trees grow better on farms because farms are generally located (by design) in areas having higher quality soils
    - Farm trees are not prone to early death due to forest fires
    - Use of pesticides on crops has the effect of reducing tree-harming insects on adjacent farm trees

Sequestration Benefits From Farm Trees – 1 of 2

What does a Metric Tonne of Carbon look like?

- Look at a mature maple tree
  - A 10-inch diameter maple tree has sequestered approx. a metric ton of carbon to reach that size
- On an annual basis the increase of the size (radial area) of the tree sequesters a lot of carbon
- 100 mature maples on average sequester 1 Metric Tonne of carbon per year (2204 lbs)
- Sequestration varies by species and increases as trees in the stand grow
  - Especially in 2nd generation woodlots and open farm areas where biomass loss from tree mortality is less than biomass gained from tree growth
  - Only in old-growth forests is total biomass in equilibrium with mortality
- Compared to forests, most farm trees are not harvested for fuel and saw logs so sequestration grows with their biomass as per any perennial crop
  - Sequestration reversals due to fire and disease are far less common on farms than in wild forests



Sequestration Benefits From Farm Trees – 2 of 2

Sequestration from farm trees is 4 – 10x greater than from crops:

- Trees are bigger than crops, so they contribute meaningfully to farm sequestration even with less treed acreage than crops
- Trees also contribute to soil carbon and, as per any perennial cover crop, reduce soil carbon emissions in treed areas, contributing to less average emissions per farm acre
- Trees also significantly enhance soil carbon in adjacent fields as evidenced by extensive research in agroforestry
  - Tree intercropping has been proven to upgrade Class 5 soils to Class 3 quality over time
  - Silvopasture has been proven to increase livestock unit density due to faster regeneration of grasses
  - Riparian buffers have been proven to increase soil carbon by over 50% in adjacent cropland

Agriculture’s Net Carbon Footprint

NATIONAL & PROVINCIAL SCALE

What is the Carbon Footprint of the Agriculture Sector in Canada?

- According to Canada's 2022 National Inventory of GHGs: Agriculture emissions in Canada is currently 59.1 M Tonnes of CO_2e.
  - But to calculate the carbon footprint, we first need to remove biogenic, non-additive, agricultural emissions that are completely offset by the crops grown to feed livestock:

Restating National Inventory Emissions to Determine Carbon Footprint Net Emissions

		MT CO2e/yr	
		69.0	Emitted per National Inventory Rpt (NIR Table A10-3)
	-	23.7	Enteric emissions offset by CO2 in crops grown to feed livestock
	-	7.8	Manure Management emissions offset by crops grown to feed livestock
	-	2.7	Crop Residue Decomposition emissions offset by crops grown
	-	0.2	Manure applied to Pasture, Range & Paddock offset by crops grown
	-	9.6	Sequesterd by Cropland Remaining Cropland (Table 6-1)
		0.0012	Net Emissions on Grassland remaining Grassland (Table 6-1)
Restated Emissions from Farms		**25.00**	**Actual Net Emissions by Cdn Agriculture + Fishing + Forestry**

  - Note that this still includes fuel usage that should be allocated to forestry & fishing (for which no supplementary detail is available).

- But that is only the emissions portion of agriculture's carbon footprint, **what was the total carbon sequestered on Canadian farms** from permanent perennials on farms (trees, shrubs, grasses).
  - Only Prairie shelterbelts are currently included in the national inventory in Chapter 6
  - This missing sequestration can be estimated based on determining the percent of perennial cover in unworkable areas of farms

What is the Distribution of Permanent Perennial Cover by Province?

- As Statistics Canada does not survey the acreage of trees, woody perennials and other permanent perennials on farms, we need to estimate it.
  - These are the plants that grow in the "unworkable" areas of farms (ravines, drainage ditches, rough ground, etc.) that are never (or rarely) harvested
  - In BC and Eastern Canada, the National Inventory Reports cites that perennial coverage is predominately trees in BC and Eastern Canada
  - In the Prairie provinces we estimate the distribution based on an analysis of a worst-case eco-district -- i.e., least likely to have large woody perennials (details in Annex).

Statistics Canada 2021 Census	Average Farm Land Use (Acres)						Province-Wide Total Perennial Acreage			
Province	Cropland	Pasture	Fallow	Perennial	Remainder	% Perennial	Perennial Acres	Grassland	Woody Perennials	Treed
Alberta	775	344	157	356	184	20%	11,795,139	4,529,333	6,546,302	719,503
British Columbia	116	123	21	197	101	35%	2,498,158			2,498,158
Manitoba	945	251	96	275	141	16%	3,067,949	1,178,092	1,702,711	187,145
New Brunswick	219	53	8	147	76	29%	224,604			224,604
Newfoundland	72	48	5	76	39	32%	19,108			19,108
Nova Scotia	116	42	5	132	68	36%	296,401			296,401
Ontario	**126**	**42**	**17**	42	21	17%	1,519,122			1,519,122
Prince Edward Island	351	52	10	84	44	16%	75,362			75,362
Quebec	225	50	13	83	43	20%	1,926,716			1,926,716
Saskatchewan	1353	508	268	399	206	15%	9,468,522	3,635,913	5,255,030	577,580
						24%	**30,891,082**	**9,343,338**	**13,504,044**	**8,043,700**
						Hectares	12,501,188	3,781,118	5,464,897	3,255,173

What is the Sequestration by Uncounted Permanent Perennials?

- Determining the distribution of existing trees on farms in Canada is currently difficult, requiring many assumptions (details in annex)
  - The largest gap is the lack of accurate data from authoritative sources on the sequestration by existing trees on farms
  - Our modeling indicates existing trees on farms conservatively sequester 14 MT CO_2e /yr (mostly in non-prairie provinces)
  - Our modelling also identifies that the net sequestration in crops fed to livestock is greater than the level of enteric emissions
  - Plus approx. 10 MT of sequestration from permanent perennials and shelterbelts in prairie provinces from official sources
- Canadian Agriculture is already operating on a net-zero basis - **generating $3.2B /yr in excess sequestration services**

Restated Emissions from Farms		**25.00**	**Actual Net Emissions by Cdn Agriculture + Fishing + Forestry**
Estimate of Missed Sequestration by Farms			
	-	13.6	Sequestered annually by Farm Trees
	-	23.7	Net sequestration by crops fed to livestock in excess of enteric emissions
	-	0.4	Sequestered in Sask. Shelterbelts [2016 Amichev et al]
	-	10.0	Sequestered annually by woody perennials on farms
	-	1.0	Sequestered annually by perennial permanent grasses
	-	0.25	Contribution to Soil Organic Carbon in Orchards
	-	**48.89**	**Estimated Existing Sequestration Services**
Net Carbon Footprint of Canadian Agriculture	-	23.89	**MT CO_2e/yr net emissions**
	$	65	Price of carbon established by the Federal Carbon Tax
	$	3.2	**B Value of existing sequestration in Canadian Agriculture**

Variation By Province

- Treed acreage varies by Province and by Eco-District and also by farm due to:
  - Different agricultural products
  - Different species of trees dominating the landscape
  - Different growth rates due to soil quality
- The proportion of perennial biomass varies by province:
  - In eastern and coastal regions of Canada, this is almost entirely treed acreage
    - Trees are commonly found in ravines, riparian buffers, “rough areas”, around wetland areas, and the “back 40” of many farms
  - In the Prairie regions this is a mix of trees, grasslands and perennial woody shrubs, depending on Eco-District
    - These permanent perennial grasslands should not be confused with pasture areas (which are also grasslands) as they are generally found in unworkable / unreachable areas of a farm such as drains, ravines, etc. and exist also on farms that produce only crops
    - Species of shrubs, grasses and trees also vary across different prairie soil types
    - Most trees are found in shelterbelts and farm tree windbreaks around houses and barns
    - Ravines and farm drains are commonly populated with wild shrubs that aid in erosion control

Typical Prairie farm with windbreaks around buildings and wild shrubs growing in nearby riparian area

Example Provincial Scale: Net Carbon Footprint of Ontario Agriculture (25% of Canadian farms are in Ontario)

- Ontario does not have the largest ***acreage*** of farms but does have the largest ***number*** of farms
  - So, we would expect it to have lower than average contribution from crop sequestration, while having higher emissions from farm activities operating less efficiently at a lower scale due to smaller farm sizes and greater number of farms

- Emissions, adjusted to show only additive emissions, are only 2 MT CO_2e /Yr which are completely offset by sequestration from farm trees

- The value of excess sequestration from Ontario farms is $155 M /year

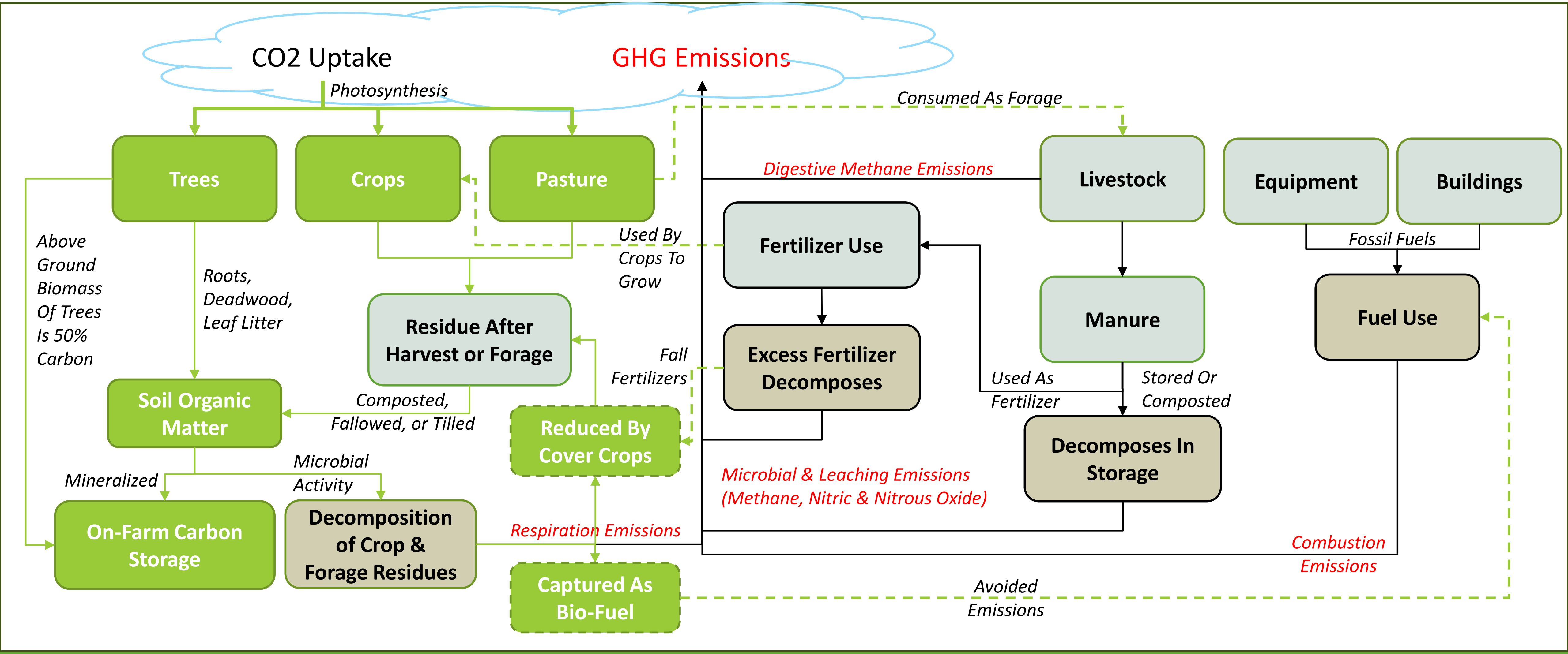
Carbon Footprint

Estimated Sequestration			
		2.6	Sequestered by Farm Trees
		1.9	Cropland sequestration based on 2/3 of cropland use
Total On-Farm Sequestration		4.4	MT
Ontario Farm Emissions Per National Inventory Rpt (NIR Table A11-2)			
		1.54	Attributed to Stationary Combustion on Farms & Forestry
		1.04	Attributed to Offroad Fuel use on Farms & Forestry
		-3.4	Attributed to Enteric Emissions
		-1.9	Attributed to Manure Management
		4.5	Attributed to Soil Respiration
		0.2602	Attributed to Fertilizers & Burning of Residue
Total On-Farm Emissions		2.0	MT
Net Emissions	-	2.39	MT CO2e/yr
Fair Cost of Carbon in 2023	$	65.00	per tonne
Value of Sequestration Services	$	288	M
Value of Excess Sequestration	$	155	M

Farm-Scale
Net Carbon Footprint

HOW MUCH EXCESS SEQUESTRATION (NET OF EMISSIONS) IS AVAILABLE TODAY FROM FARMS?

Visualizing Farm-Level Carbon Footprint Dynamics (excluding changes in land-use and indirect emissions)



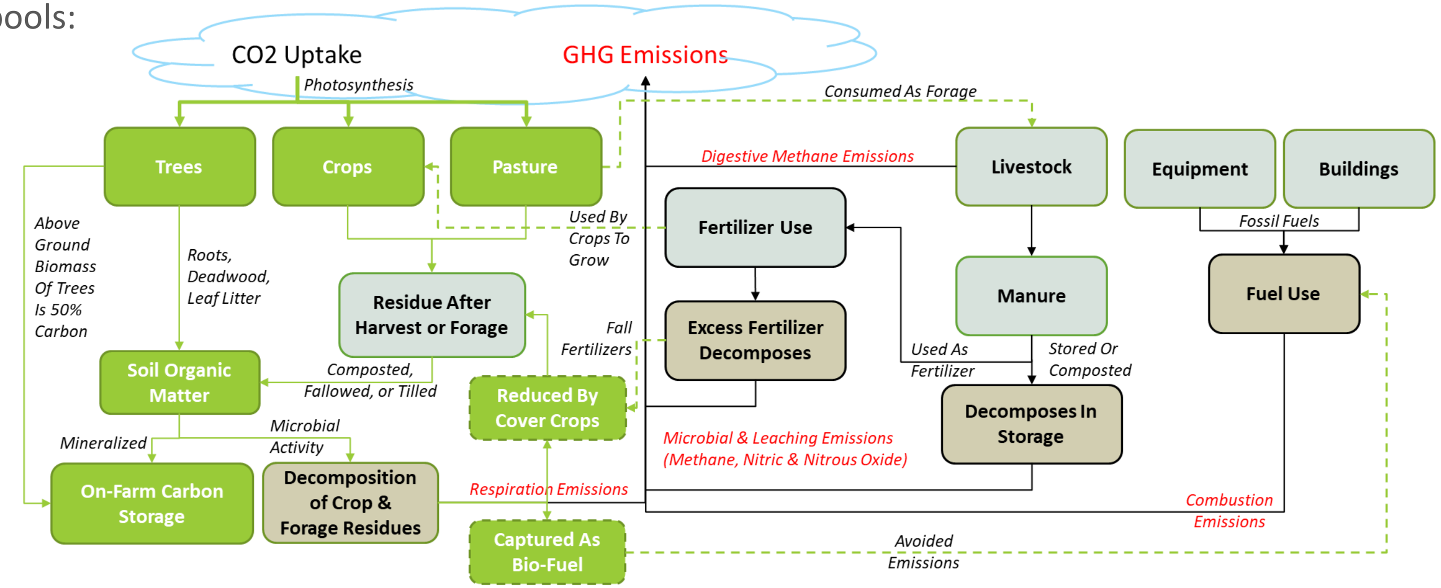
Comprehensive Farm-Level Carbon Footprint Modeling of Those Dynamics

Sequestration

- Gains/losses are modelled In IPCC-defined carbon pools:
  - Above Ground Biomass
  - Below Ground Biomass
  - Soil Organic Carbon
  - Organic Litter & Deadwood
- Includes trees, crop residues, grasses

Emissions

- Models all 3 Scopes (ISO 16047)
- Direct Emissions
  - Crops & Livestock
  - Fuel & Fertilizer use
- Indirect Emissions
  - Electrical use
  - Upstream
    - Fuel extraction & processing
    - Input chemical manufacturing
    - Feed & other input deliveries
  - Downstream
    - Transport Harvest to Market
    - Export of manure and other by-products to other farms



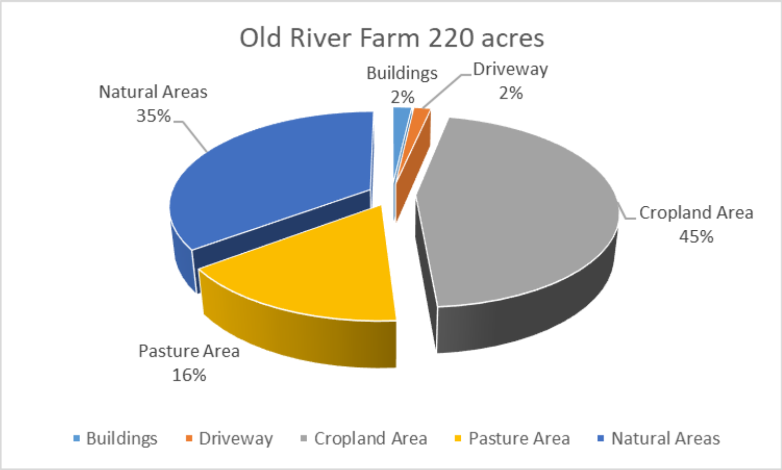
The carbon content in harvested crops is not considered to be a carbon pool because it is believed to be either consumed or wasted, ultimately releasing any stored carbon in the process.

Although this is not true for crops consumed by livestock (see Enteric Emissions are Carbon Neutral) we excluded sequestration of carbon in harvested crops in the whole farm analysis shown on the next slides.

Bottom-up Farm-level Results are Consistent with Sector-level Results

- Case Studies done to-date (details later in this section):
  1. Old River Farm – typical Ontario or Quebec mixed farm with net-zero footprint, located in southern Ontario
     - ~200 acres used for Major Crops / Beef / Poultry
     - Producing > 3.5 Million eggs/yr,
  2. Elm Creft Farm – typical Ontario or Quebec dairy farm with better than net-zero footprint located in southeastern Ontario
     - ~1300 acres used for 200 Dairy Cattle and growing the crops needed to feed them
     - Producing > ¾ Million L milk /yr, & over 4 Tonnes of manure/year
  3. Fortune Farm – typical Ontario or Quebec maple syrup producer operating with excess sequestration, located in eastern Ontario
     - Energy-intensive evaporation of maple sap from 2% input sugar solution to 66% output syrup
     - ~150 acres used for producing > 10,000 L maple syrup/yr

Old River Farm – London, Ont



Farm Activity

Livestock

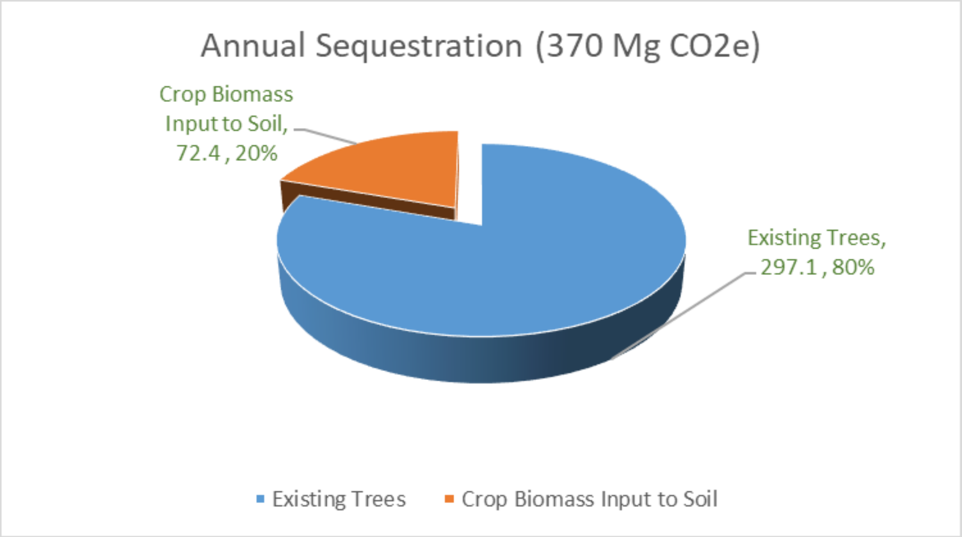
- 12,000 Chickens
- 3.5 M eggs/yr
- 24 Beef Cattle

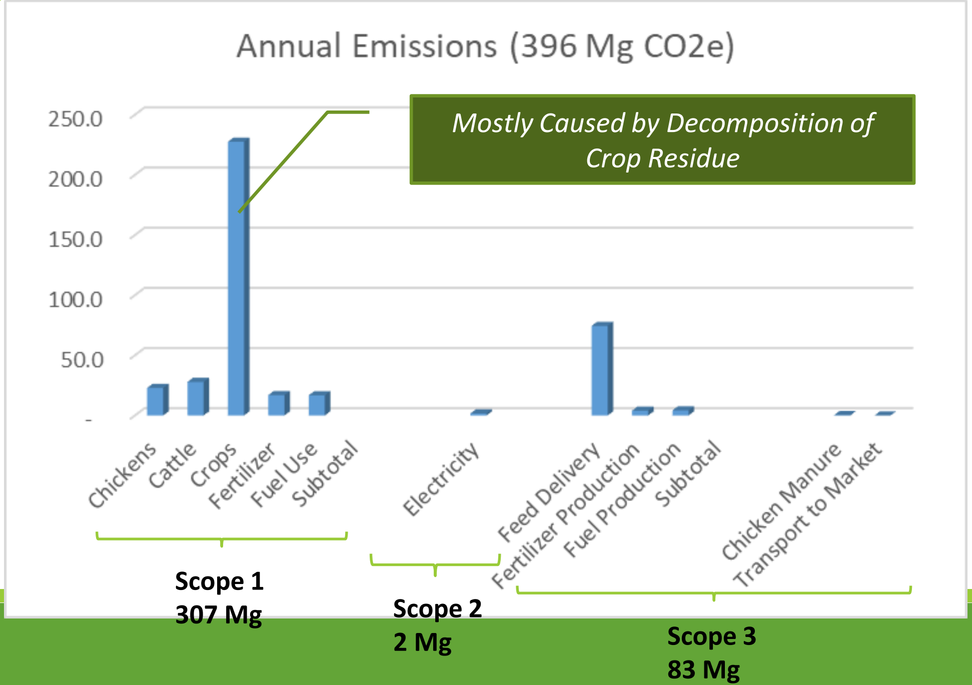
Crop Yields

- 116,182 kg Soybeans
- 168,000 kg Corn
- 6,477 kg Hay/Alfalfa

Net Emissions are Easily Mitigated by Converting <5% of Pasture to Silvopasture

Carbon Footprint = 26.9 Mg Net Emissions is less than 10% of their total emissions





Elm Creft Farm, Perth Ont

Farm Activity

Carbon Negative Dairy Farm

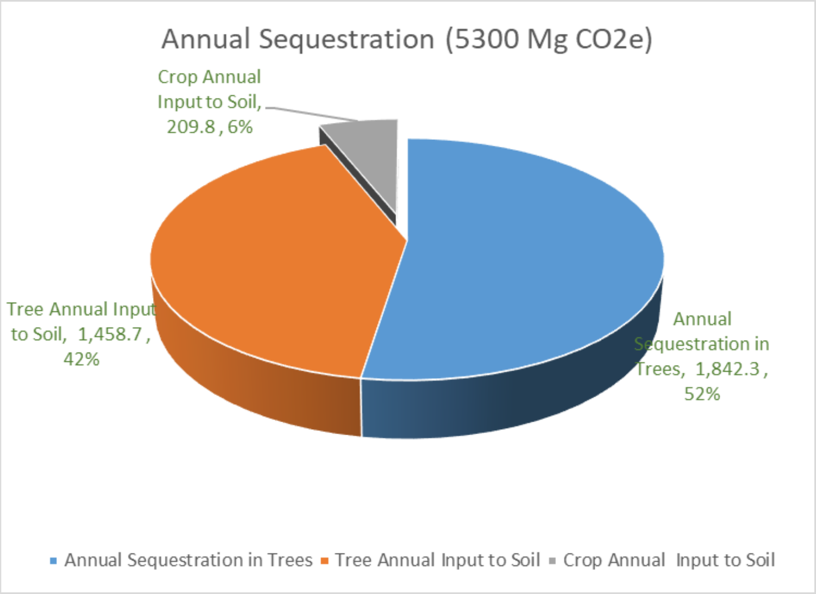
Livestock

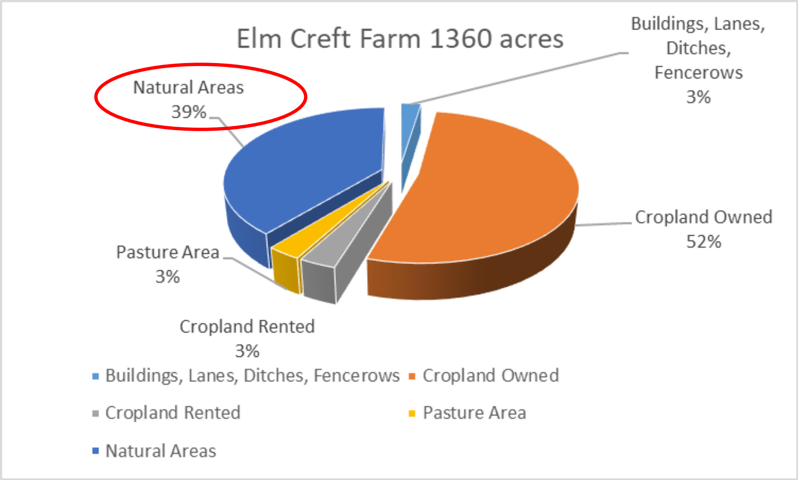
- 190 Dairy Cattle
- 776,728 L Milk Produced
- 5,050 T Manure Nutrients

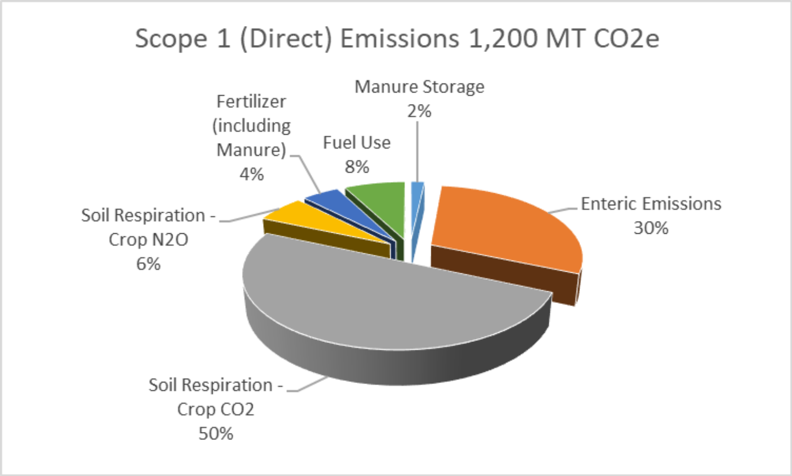
Crop Yields

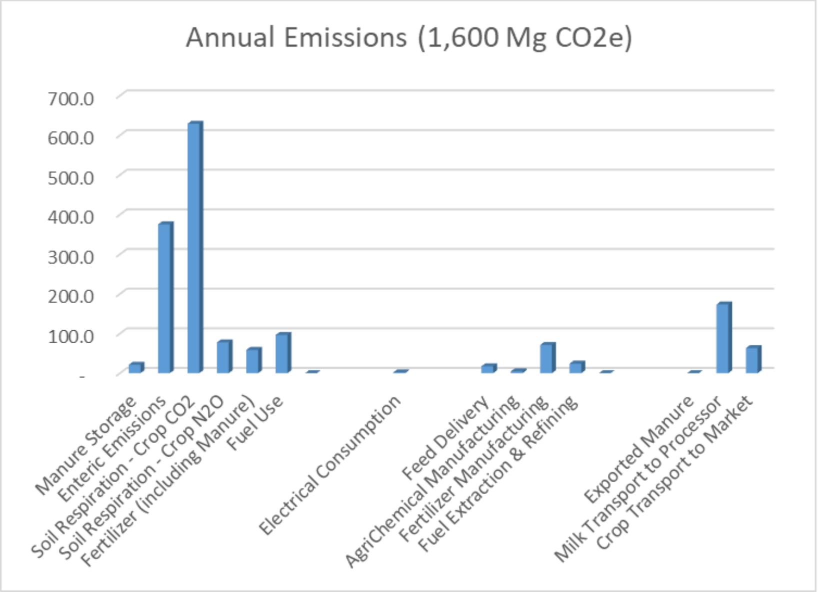
- 1,753 T Hay
- 714 T Corn – Grain
- 322 T Corn - Silage
- 100 T Barley
- 172 T Soybeans

Carbon Footprint is Significantly Carbon-Negative









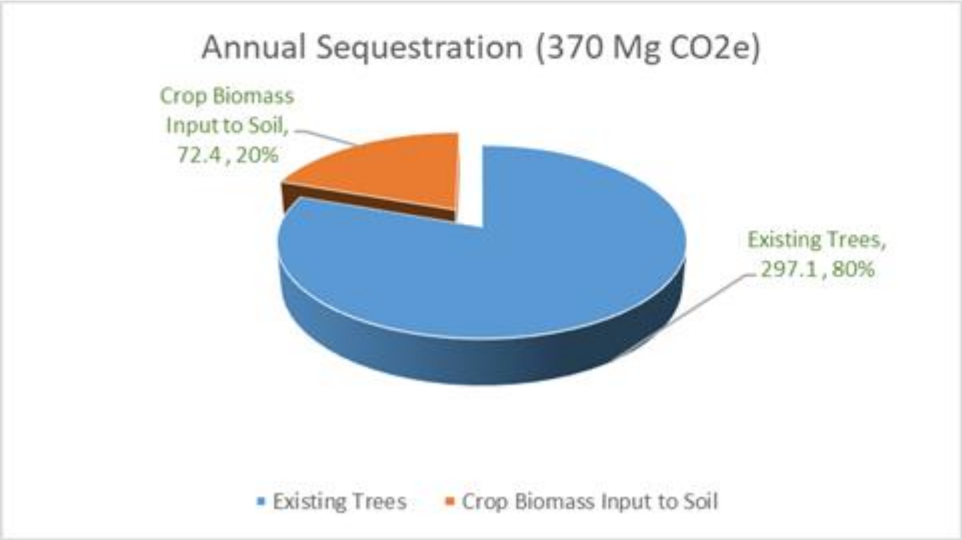
Scope 1
85%

Scope 2
0.2%

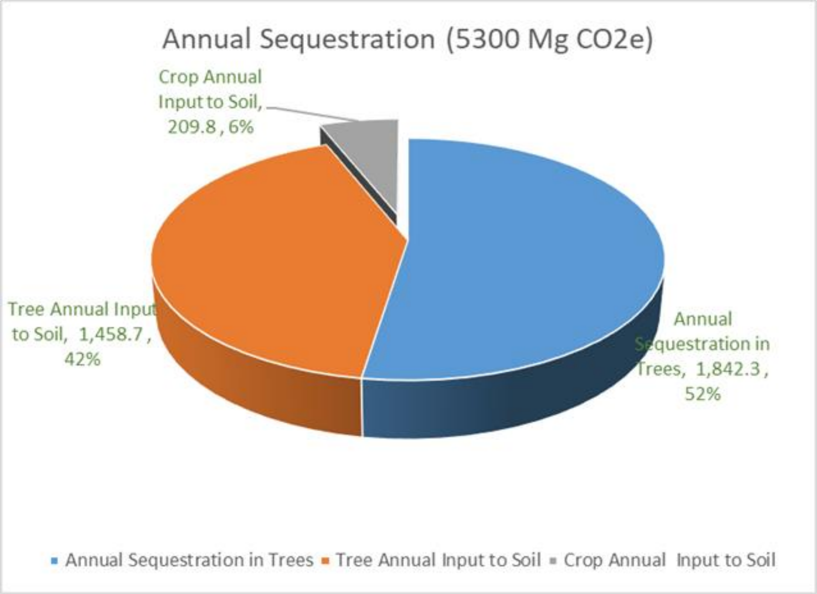
Scope 3
14%

Sequestration by Farm Trees is Significant

200 Acre Farm with 35% Woodlot, 45% Cropland



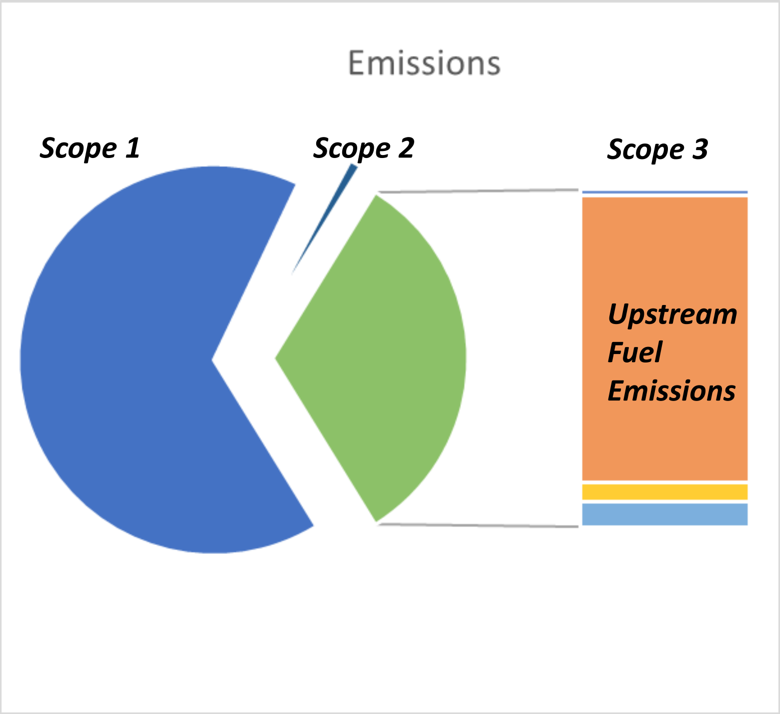
1300 Acre Farm with 39% Woodlot, 52% Cropland



- The sequestration benefit from trees scales faster than from crop residues as farm size increases
- This is because of the larger biomass from trees compared to any harvested crop and we are excluding the carbon sequestered in the harvested yield portion of crops

Fortune Farm (Case Study in Development)

- A maple syrup producing farm, natural areas comprise > 90% of farm area
- Although this case study is still under development preliminary results show:
  - Oil-fueled evaporator-related emissions are 94% of total emissions (99% of Scope 1 and 82% of Scope 3)
  - Net excess sequestration of 30 KT CO_2e/yr after producing maple syrup
- On a unit product basis, Fortune Farms is sequestering 8 kg/CO_2e while emitting less than 3 kg/CO_2e for every Litre of maple syrup produced
  - In other words, even after producing the syrup Fortune Farms sequestered 5x as much CO_2 as the weight of a full bottle of syrup
- Any reduction in upstream fuel emissions in the extraction & refining of oil (beyond the control of the farm) would significantly reduce Scope 3 emissions



Common Findings from Case Studies

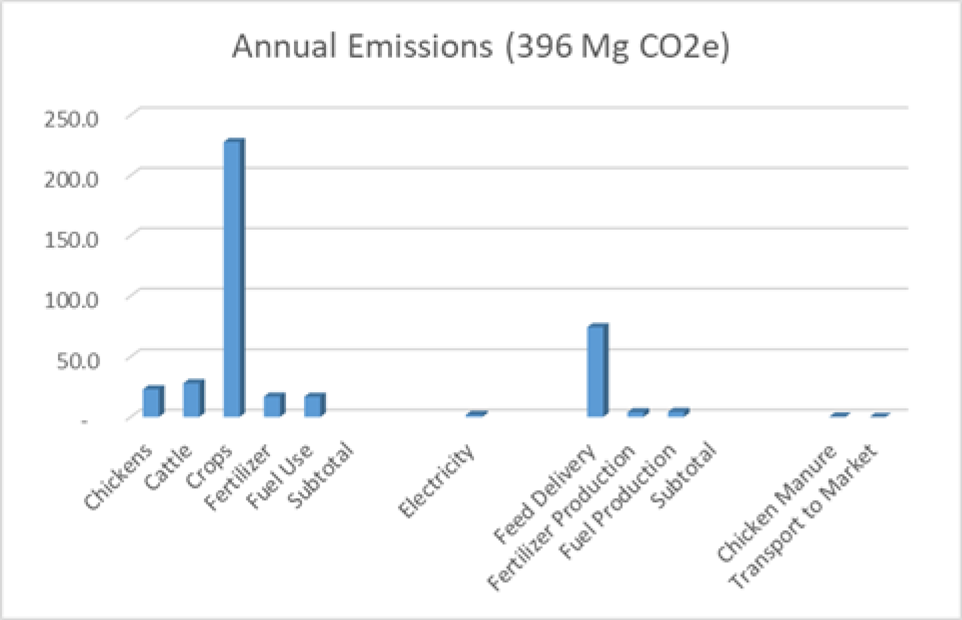
- Even including enteric and manure-related emissions (which are non-additive to climate change) our farm-level modelling to-date has revealed farms that are already operating on a net-zero basis

- There are a lot of existing trees on farms – more than you might expect:

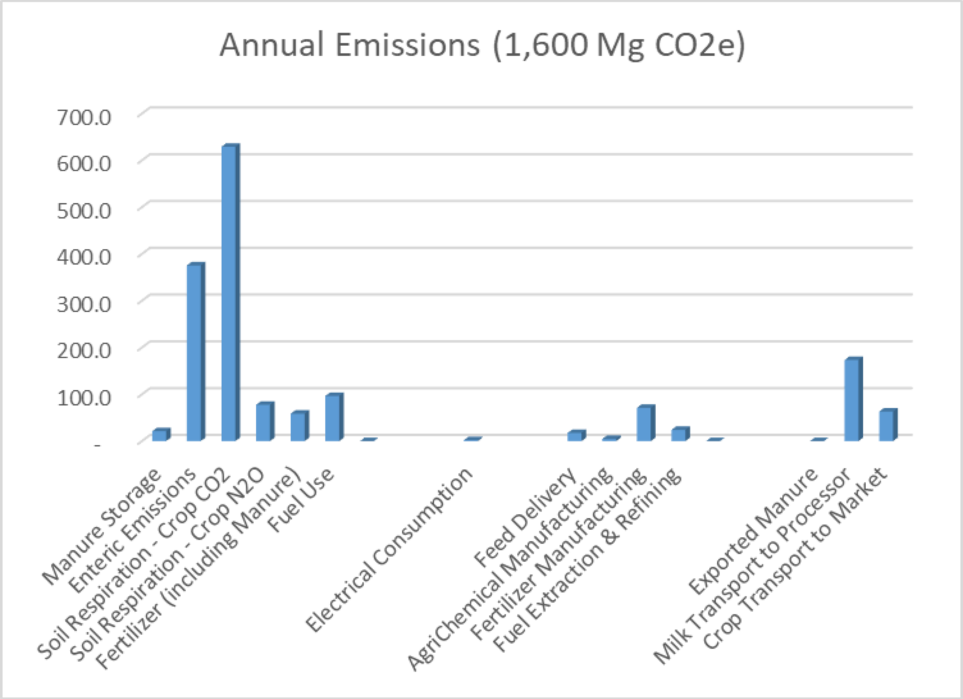
- Over 30% natural areas on both Old River and Elm Creft Farms are treed
- Over 90% at Fortune Farms (as might be expected for a maple syrup producer)
- This is better than our conservative estimate of provincial acreage of trees on farms (17% for Ontario, 20% for Quebec)
- Sequestration from farm trees is 4 – 10x greater than from crops:
  - Trees are 100x bigger, so they contribute meaningfully to sequestration even with less acreage than crops
  - In most cases, trees are not harvested, so sequestration grows with their biomass as per any perennial crop
  - Trees also contribute to soil carbon and, as per any perennial cover crop, reduce soil carbon emissions
  - Trees also enhance soil carbon and quality in adjacent fields

Farm-Level Carbon Modeling is Revealing about Emissions (even if we include biogenic emissions)

Mixed Farm : Crops, Beef, Poultry



Dairy Farm : 190 head, 5,000 T Manure, 1500 T Crop Production



- Major emissions usually dominated by top 2 – 3 sources
  - E.G. for the mixed farm, better to focus on crop emissions than fertilizer
  - But on the dairy farm, crop respiration, enteric and manure related emissions are offset by the sequestration of carbon in crops used to feed cattle, the largest real emissions source is in the transport of milk to the next stage of agri-food production
- Indirect emissions from transportation are always important, as evidenced by feed delivery in the mixed farm example
  - Improving transportation emissions on a sector basis has big payback
  - EV / Renewable Fuel improvement in transportation has significant benefit to agriculture

Summary

- Our top-down analysis suggests that **Canadian Agriculture is already climate neutral**, at the national scale
- Our provincial-scale modelling shows that **Ontario agriculture is already operating on a climate neutral basis:**
  - Although Ontario and Quebec are similar, this is not enough to establish that other provinces are climate neutral without individually modelling them
  - However, the Ontario result does support our findings at the national scale and Ontario has the most farms of any province
  - Although we did not model Quebec, it has more maple syrup producers than Ontario while producing many similar farm products, so it is reasonable to expect that Quebec agriculture will also be proven to be carbon neutral
- Our farm-level analysis discovered that the first two farms that we modeled were already climate neutral
  - While this is too small a sample to suggest a bottom-up trend, it does substantiate our top-down findings
  - Notably, since a dairy farm is generally viewed as having a worse carbon footprint than other farms, this is significant.
  - It also suggests that the commonly held belief that dairy farms are high net carbon emitters may be a myth due to:
    - Misunderstanding the biogenic nature of enteric and manure-related emissions
    - Lack of scientific attention on the fate of stored carbon in harvested crops
    - Most of Canada's diary production is from eastern-Canadian provinces that have significant treed areas on farms.

Key Takeaways

- Our conservative analysis of the actual carbon footprint of Canadian agriculture shows that **agriculture overall is already sustainable** and is currently generating unpaid excess sequestration services valued at $1.6 B

- There is considerable room for improvement in the presentation of agriculture's sustainability by official sources:
  - Agriculture sector emissions due to fossil fuel usage should not be comingled with fishing & forestry in the National Inventory of GHG
  - Upstream emissions from agri-chemical manufacturing should be detailed so that a more accurate understanding of real emissions in agriculture can be determined
  - Enteric and manure related emissions should be noted as biogenic
  - Net sequestration by trees and other biogenic cycles on farms should be more clearly presented
  - Since Canada's climate action plan requires increased sequestration of carbon in agriculture to reach national net-zero goals, the AAFC should provide an annual net carbon footprint of Canadian agriculture overall and by province

- Further research should be funded to obtain better estimates of the contribution of sequestration by:
  - Permanent perennials on farms (esp. farm trees)
  - Better estimates of the net sequestration of carbon in the harvested yield of crops as our research has revealed that
    - It is false to assume that all the carbon sequestered in harvested yield is ultimately released,
    - We need to better account for livestock related emissions as a flux on farm-based biogenic carbon

Annex

Step 1: Land Use in Canadian Agriculture

- Cropland sequesters 9.6 MT, pastures & fallow have no net sequestration [2020 EEEC, National Inventory Report, NIR]
  - Sequestration by existing cropland : 13 MT on 47 M ha in 2020, (0.3 Mg CO2e/ ha) which is offset by 3.4 MT emissions due to cropland conversion from forest land
  - The NIR only tracks treed acreage on farms on large stands only for the purpose of calculating emissions due to changes in land use.
  - Sequestration from this acreage is not included in offsetting emissions on farms.
  - This acreage is not disclosed in the NIR, and conversions are only included under forest land use changes.

Statistics Canada 2021 Census	Average Farm Land Use (Acres)				Province-Wide Other Land (Acres)
Province	Cropland	Pasture	Fallow	"Other" Land	
Alberta	775	344	157	540	17,871,423
British Columbia	116	123	21	298	3,785,088
Manitoba	945	251	96	416	4,648,407
New Brunswick	219	53	8	223	340,309
Newfoundland	72	48	5	115	28,952
Nova Scotia	116	42	5	200	449,093
Ontario	**126**	**42**	**17**	**63**	**2,301,700**
Prince Edward Island	351	52	10	128	114,185
Quebec	225	50	13	125	2,919,267
Saskatchewan	1353	508	268	605	14,346,246
					46,804,670

- Permanent Perennial acreage on farms is captured in the "Other" category by StatsCan
  - Undercounting fenced treelines, and many windbreaks & treed riparian buffers, which are also typically reported under crop, pasture, or fallow categories
  - "Other" in the StatsCan Agricultural Census generally includes:
    - Buildings & roads, Open yards used for farm work
    - Treed & Wetland areas that sequester carbon
    - Open, unworkable areas that are not used for farming or sequestration (bluffs, ditches, pits, rock outcrops, etc.)

Step 1: So How Much of the "Other" Land Category is Permanent Perennial?

- Our approach is to subtract a reasonable allocation (based on our case studies) for non-natural areas:
  - Buildings, yards, drainage ditches, roads & access ways
- Then subtract an allocation for ponds and wetlands:
  - We can use the national average for land that is wetland since wetlands occurs at most as often on farmland as not
  - Actually, land that is predominantly wetlands is less likely to be farmed
  - But applying the national density of wetland to farms produces a conservative result for treed land since more area is ascribed to wetlands
- Then subtract an allocation for land upon which trees and plants cannot grow:
  - Since this is not directly available, we need to use a proxy metric, such as the number and size of canopy gaps in a forest
  - Canopy gaps in unmanaged forests occur wherever trees cannot grow (rocky outcrops, steep cliffs, etc.)
  - It is less likely that land areas with large areas that cannot support trees will be used for crops or pasture
  - Thus, canopy gaps in forests produce a conservative result since there are likely to be less of them on farms as in wild forests
- The remainder must be covered by permanent, perennial biomass by virtue of the process of elimination:
  - The type of permanent biomass cover will vary by Eco-District
  - In Eastern and coastal Eco-Regions of Canada this type of cover will be mostly treed with some grasses and shrubs in rocky coastline areas where tress will not grow as well
  - In Prairie Eco-Regions, this cover will be dominated by a mix of perennial grasses and shrubs with fewer trees
  - Although the sequestration contribution of shrubs and grasses is not as great as trees, this is still a significant omission in current farm cropland calculations because unlike pastures, these grasses are not disturbed by farming activities

Step 1a: What is the Area of Farms that Is Permanent Perennial?

Other Land Usage	**100%**	**Source**	**Citations**
Buildings & Roads	-5%	Case Studies	(Old River, Elm Creft farms)
Open Yards & Ditches	-5%	Estimate assumed equal to built areas above	
Wetland	-14%	Canadian National Average	Environment Canada [ECCC 2016]
Unlikely to support trees	-10%	Based on Canopy Gaps	Based on Canopy Gaps [1994 EOMF Forest Structure], [2007 Neuendorff] cites 5.7 - 6.9% for hardwood forests around the Great Lakes
Net Perennial Biomass	66%		

- Estimated Perennial proportion of "Other" Land is approx. 2/3
- Hence, the average Canadian farm has 24% of acreage not being counted as existing sequestration
  - Consisting primarily of tree lines used for fence lines, windbreaks & riparian buffers as well as larger on-farm bush areas/woodlots on which pasture or crop use is infeasible
  - National Inventory does not currently capture any private woodlots on farms due to relatively small disturbances compared to forestry occurring on managed Crown lands

Statistics Canada 2021 Census	**Average Farm Land Use (Acres)**					
Province	**Cropland**	**Pasture**	**Fallow**	**Perennial**	**Remainder**	**% Perennial**
Alberta	775	344	157	356	184	20%
British Columbia	116	123	21	197	101	35%
Manitoba	945	251	96	275	141	16%
New Brunswick	219	53	8	147	76	29%
Newfoundland	72	48	5	76	39	32%
Nova Scotia	116	42	5	132	68	36%
Ontario	**126**	**42**	**17**	42	21	17%
Prince Edward Island	351	52	10	84	44	16%
Quebec	225	50	13	83	43	20%
Saskatchewan	1353	508	268	399	206	15%
						24%

Step 1b: What is the acreage by type of Permanent Perennial?

- According to the National Inventory Report, in most provinces trees are the dominant perennial, so our model allocates perennial coverage to trees in BC, Ontario, Quebec and Atlantic Provinces
- In the Prairie provinces, we need to account for
  - Shelterbelts (established via prior published research)
  - Woody Perennials (e.g. Caragana, Manitoba Maple, etc.) that are woody shrubs using an assumed density that is 50%what is found in shelterbelts
  - Natural grassland areas (e.g. wheatgrass, speargrass, etc.) that grow naturally in areas where trees and woody perennials do not
- To obtain a distribution of perennial acreage for the Prairies we used Google maps to analyze 1000 ha in EcoDistrict 794 near Weyburn, SK

Example Feature	Ha	%Shrubs	%Grass	%Trees	Ha Shrubs	Ha Grass	Ha Trees
Mound	0.25		100%		-	0.25	-
Farm Drains	125	38%	60%	2%	47.50	75.00	2.50
Ravine	0.66	67%	33%		0.44	0.22	-
Farm Windbreak1	2.2			100%	-	-	2.20
Riparian Area	13.75	50%	40%	10%	6.88	5.50	1.38
Farm Windbreak2	0.75			100%	-	-	0.75
Riparian Zone	4.84	50%	40%	10%	2.42	1.94	0.48
Farm Windbreak3	1.78			100%	-	-	1.78
	149.23				57.24	82.90	9.09
	14.9%				5.7%	8.3%	0.9%

Step 1c: Summarizing Permanent Perennial Coverage by Province

Statistics Canada 2021 Census	Average Farm Land Use (Acres)						Province-Wide Total Perennial Acreage			
Province	**Cropland**	**Pasture**	**Fallow**	**Perennial**	**Remainder**	**% Perennial**	**Perennial Acres**	**Grassland**	**Woody Perennials**	**Treed**
Alberta	775	344	157	356	184	20%	11,795,139	4,529,333	6,546,302	719,503
British Columbia	116	123	21	197	101	35%	2,498,158			2,498,158
Manitoba	945	251	96	275	141	16%	3,067,949	1,178,092	1,702,711	187,145
New Brunswick	219	53	8	147	76	29%	224,604			224,604
Newfoundland	72	48	5	76	39	32%	19,108			19,108
Nova Scotia	116	42	5	132	68	36%	296,401			296,401
Ontario	**126**	**42**	**17**	42	21	17%	1,519,122			1,519,122
Prince Edward Island	351	52	10	84	44	16%	75,362			75,362
Quebec	225	50	13	83	43	20%	1,926,716			1,926,716
Saskatchewan	1353	508	268	399	206	15%	9,468,522	3,635,913	5,255,030	577,580
						24%	**30,891,082**	**9,343,338**	**13,504,044**	**8,043,700**
						Hectares	12,501,188	3,781,118	5,464,897	3,255,173

Step 2: How Many Trees Are On Treed Acreage?

- Farm trees occur in a variety of contexts:
  - Isolated tree standing alone in a field
  - Linear plantations such as alone a fence line (single row) or windbreak (multi-row) or riparian buffer (multi-row)
  - Even-age Woodlot plantations
  - Even-age orchards
  - Uneven-age Woodlots of irregular size
- Since we have no data regarding this contribution from different contexts, we model the most general format, an uneven-age woodlot as a truncated stand
  - The number of trees in an uneven-aged stand resembles an inverse-J shape
  - In other words, there are more smaller trees than larger trees and there are always fewer larger trees than a tree of any given diameter
  - By truncating the stand, we do not count any trees larger than a maximum size measured as a diameter at breast height (DBH)
  - By choosing a small maximum DBH, we better approximate other contexts and we better reflect the likelihood that larger trees may have already been cut down as fuel wood or saw logs
- We also have no data on the species of trees, however the bulk of Canadian agriculture occurs in either lands that were originally grasslands or mixed deciduous forests
  - So, we use deciduous trees as the baseline for the modeling of treed areas
  - Deciduous trees also tend to have lower densities and grow slower in a woodlot than coniferous trees, which results in a more conservative assumption on the number of trees on a given acreage and their growth rate

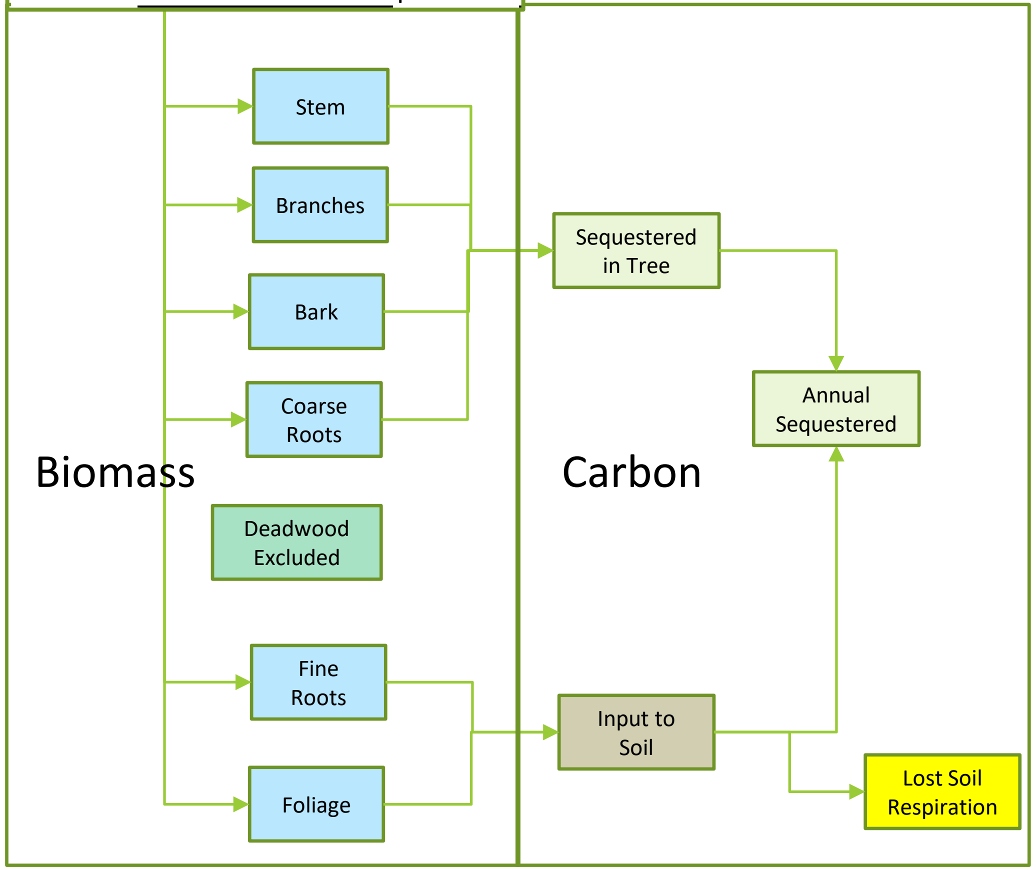
Step 2: Modelling Tree Size Distribution for Farms

DBH (in)	Trees	
4	300	
10	150	
20	75	
	525	per ha

- We used a Tree Density that is ½ of typical natural forest densities per Eastern Ontario Model Forest benchmark study of eastern North American Forest Structure
  - In the absence of national data, we benchmark off of eastern Canadian info since Ontario has the largest number of farms of any province
  - Forest structure is not profoundly different in other provinces and tree density actually tends to be higher in coniferous stands in western Canada
  - We reduce the tree density by half to reflect that farm woodlots are second growth managed stands
- We calibrated our model by using South Central Ontario Study to compare it to the most stressed forests in Ontario, i.e. a reasonable minimum compared to other forest-based studies, and more likely to be similar to farm woodlands that are also fractured and stressed by adjacent agricultural usage
  - Treed areas constitute 20 – 30% of total landcover in Southern Ontario (where most of Ontario farms are), our model assumes a more conservative 17%
  - Our model uses a tree density of 525 trees / ha which is less than the 662/ha tree density reported
  - Our cut-off in tree size at 20”dbh is highly conservative, the Ontario study found tree diameter ranges up to 90” with only 1 location having no trees > 30”
  - It is possible that our model is too conservative for Ontario, but a more conservative model is helpful for use in western provinces where tree density may be lower in agricultural regions (for example, the tree density in shelterbelt studies reveals approx. 525 trees / ha

Step 3: What is the Sequestration From Those Trees?

DBH (in)	Trees	
4	300	
10	150	
20	75	
	525	per ha



- We modelled all trees using national allometric equations to estimate above ground carbon pool
- We used IPCC recommended Root-to-Shoot modeling to estimate blow ground biomass, and Tier 3 below ground carbon pool estimation methods published by agroforestry research at Guelph University which include both root biomass plus the annual input to soil carbon stocks (from fine root turnover and prior year foliage decomposition) less the loss due to soil respiration.
- We excluded the effect of carbon leaching from soil (which is relatively low and very site specific)
- We also excluded soil carbon input from deadwood, as well as above ground deadwood carbon pool, since
  - It can only be measured on a site-specific basis onsite and excluding it helps produce a conservative result
  - Farm tree woodlots are not at steady state because they are often managed for fuel wood which removes dead and dying trees
  - We do model the Litter Carbon Pool
- Using species-specific allometric parameters and % carbon input to soil would result in a slightly more accurate estimate for provinces where agricultural land is dominated by specific species
- However, agricultural land in Eastern Canada and the southern portion of Western Canada (where most agricultural activity occurs) is dominated by hardwoods whose dominance can best be determined when performing this analysis at an eco-district level.

Step 4: Annual Sequestration is Modelled by Tree Growth

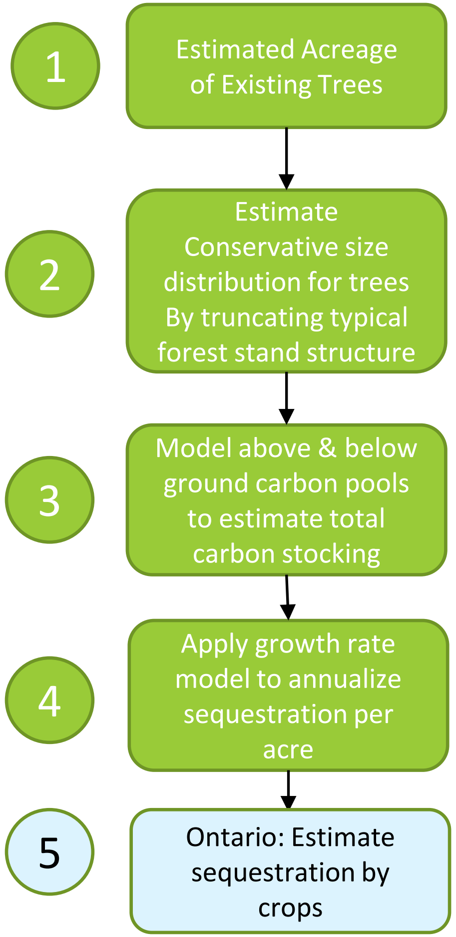
- Once we know the size of the carbon pools we need to estimate annual gains and losses

- We use the average growth rate based on all hardwood trees since the majority of agricultural land by province is dominated by hardwoods:
  - Actual growth rates will vary by eco-district but no published data exists
  - This might be obtained efficiently via successive LIDAR measurements over time

- Using tree age to predict annual sequestration results in an average over the age of the tree, not the current level of sequestration with is generally higher as it increases with tree age under 100 years (for most species):
  - Also, not all trees grow at the same rate if they are repressed by competition
  - Generally, repression is less in a small stand than in a larger forest since there are fewer larger trees
  - We compensate for uneven annual growth by using an arbitrary adjustment assuming that 1/3 of the trees will grow at ½ the average rate
  - Again, this results in a more conservative result

- Tree growth is widely accepted to be sigmoidal over the life of the tree (initially growing quickly than slowing down as the tree ages)
  - Sensitivity analysis based on using USDA sigmoidal tree growth model was used to calibrate our findings
  - Repressed tree growth is incorporated in this sensitivity analysis since the USDA tree growth models use cumulative basal area of trees larger than the subject tree to model competition effect
  - The difference found was approx. 10% higher, suggesting that our compensation was sufficiently conservative

Summary of Modelling Estimated Sequestration of Trees in Agriculture



- Our modelling assumptions are conservative:
  - Not including biomass of any trees < 4” diameter
  - Assuming no trees > 20” diameter on farm bush acreage (many farms do have larger trees & sequestration)
  - Assumes that 1/3 of trees grow at ½ the average growth rate, since not all trees will grow at same rate
  - Not including carbon stored in biomass in understory & deadwood which require on-site measurement to do accurately
  - Not including higher sequestration of treed fence lines, windbreaks & riparian buffers that typically have larger representative growth rates due to no competition for sunlight
  - Not including faster growth rates due to higher soil quality on farms
  - Not including cover crop or perennial grass input to soil in pastures
  - Not including fallow land sequestration (which varies by type of fallow land cover)
  - Not including sequestration in wetlands (which are known to be net carbon sinks when they are undisturbed)
  - Not including benefit of less albedo effect on treed-land compared to cropland or pasture in winter

- Opportunities to improve the analysis:
  - Factor in varying sequestration, carbon %, growth rates by tree species
  - Obtain farm tree coverage data by eco-district by using satellite imagery overlaid on property boundaries (Landsat already provides a sufficient level of resolution to support this approach)

Step 5: Land Use of Ontario Agriculture

- Although possibly net-zero at a national scale, we need to consider variation by province and ultimately by farm
- Type of tree cover, crop mix, productivity, and extent of existing trees vary by province, ecoregion, and farm
- For Ontario:

Statistics Canada 2021 Census		Average Farm Land Use (Acres)				Province-Wide						
Ontario	Avg Total Size	Cropland	Pasture	Fallow	"Other" Land	Total Farm	Cropland	Pasture	Fallow	Other Land	Treed	Remainder
Acres	243	216	42	17	63	11,766,071	9,051,011	400,480	13,964	2,301,700	1,519,122	782,578
Hectares						4,761,559	3,662,814	162,048	5,651	931,465	614,767	316,698

- Cropland input to soil is not disclosed for Ontario in the National Inventory Report, so we estimates a lower bound based on 2/3 of the total crop acreage in Ontario being employed by the production of the top 5 crops grown in Ontario via step 5 (next slide)
  - This produces a highly conservative estimate for crop sequestration since we are excluding 33% of crop inputs in this analysis
  - Hence it is possible that crop input is up to 0.5 MT higher than in our calculation (shown on next slide)

Step 6: Ontario Crop Input to Soil

2020 OMAFRA

Crops	Hectares Harvested[a]	% Hectares	Yield (tonnes per hectare)[a]	Production ('000 tonnes)[a]	
Soybeans	1,146,600	24%	3.4	3,909	
Grain Corn	866,000	18%	10.3	8,909	
Hay	580,900	12%	4.4	2,565	65%
Winter Wheat	418,900	8.8%	5.6	2,338	
Fodder Corn	100,800	2.1%	39.1	3,946	
Spring Wheat	46,200	1.0%	3.2	147	
Oats	37,500	0.8%	2.8	104	
Coloured Beans	35,500	0.7%	2.7	97	
Barley	34,000	0.7%	3.3	113	
Dry White Beans	32,900	0.7%	2.9	97	
Fall Rye	28,400	0.6%	2.9	83	
Mixed Grain	23,400	0.5%	3.1	73	
Canola	13,000	0.3%	2.6	33	

	Harvested Yield (T)	Harvested (Ha)	Input to Soil (T Carbon)	T CO2e Sequestered
Soybeans	3,908,700	1,146,600	129,419	474,200
Corn - Grain	8,908,800	866,000	200,664	735,243
Hay	2,565,100	580,900	78,672	288,259
Winter Wheat	2,338,400	418,900	96,479	353,505
Corn - Silage	3,945,600	100,800	3,655	13,391
				1,864,598

	Harvested Yield (T)	Harvested (Ha)	Dry Matter of Harvest	Dry Harvest Yield (T)	Above Ground Dry Residue ratio to HY	Below Ground Dry Residue Ratio to HY	Above Ground Residue (T)	Below Ground Residue (T)	Total Residue (T)	AB Biomass (T)	Total Biomass (T)	Residue Carbon (T)	Input to Soil (T Carbon)	T CO2e Sequestered
Soybeans	3,908,700	1,146,600	0.86	3,361,482	15.4%	17.4%	517,809	583,632	1,101,440	3,879,291	4,462,922	517,677	129,419	474,200
Corn - Grain	8,908,800	866,000	0.82	7,305,216	14.0%	9.4%	1,024,666	683,111	1,707,776	8,329,882	9,012,992	802,655	200,664	735,243
Hay	2,565,100	580,900	0.86	2,205,986	0.6%	29.8%	13,226	656,323	669,549	2,219,212	2,875,535	314,688	78,672	288,259
Winter Wheat	2,338,400	418,900	0.86	2,011,024	25.5%	15.3%	513,006	308,094	821,100	2,524,030	2,832,124	385,917	96,479	353,505
Corn - Silage	3,945,600	100,800	0.35	1,380,960	0.1%	2.2%	1,012	30,092	31,104	1,381,972	1,412,064	14,619	3,655	13,391
														1,864,598

Step 7: Determine Ontario Treed Acreage & Sequestration

- Now that we know the crop input to soil, we can determine tree input by applying the national model at a provincial level
- From Step 5 we know the treed acreage in Ontario
- From Steps 2 – 4 we know the tree size distribution and sequestration per hectare

Carbon Footprint

Estimated Sequestration			
		2.6	Sequestered by Farm Trees
		1.9	Cropland sequestration based on 2/3 of cropland use
Total On-Farm Sequestration		4.4	MT
Ontario Farm Emissions Per National Inventory Rpt (NIR Table A11-2)			
		1.54	Attributed to Stationary Combustion on Farms & Forestry
		1.04	Attributed to Offroad Fuel use on Farms & Forestry
		-3.4	Attributed to Enteric Emissions
		-1.9	Attributed to Manure Management
		4.5	Attributed to Soil Respiration
		0.2602	Attributed to Fertilizers & Burning of Residue
Total On-Farm Emissions		2.0	MT
Net Emissions	-	2.39	MT CO_2e/yr
Fair Cost of Carbon in 2023	$	65.00	per tonne
Value of Sequestration Services	$	288	M
Value of Excess Sequestration	$	155	M

Related Research

- [Liu, S., Proudman, J., Mitloehner F.M. 2021] Rethinking methane from animal agriculture, CABI Agriculture & Bioscience, (2021) 2:22 https://doi.org/10.1186/s43170-021-00041-y
  - Concurs that enteric emissions are biogenic and non-additive. Further observes that enteric emissions have fallen in the USA over the past 5 years due to improvements in livestock productivity.
- [Allen MR. 2021] Short-lived promise? The science and policy of cumulative and short-lived climate pollutants. Oxford Martin Policy Paper; 2015. http://www.oxfordmartin.ox.ac.uk/downloads/briefings/Short_Lived_Promise.pdf.
  - Argues that it is better to prioritize early reductions in peak CO_2 & N_2O over short lived climate pollutants (SLCP) such as CH_4, black carbon aerosols & HFCs because early SLCP mitigation will have very little impact on eventual peak warming due primarily to CO_2
- [Badr, O., Probert, S.D., O'Callaghan, P.W., 1992] Sinks for atmospheric methane, Applied Energy, Vol 41, Issue 2, 1992, pp 137-147 https://doi.org/10.1016/0306-2619(92)90041-9
  - Identifies several natural sinks in the methane to CO_2 cycle
- [EPA, 1995] Greenhouse gas biogenic sources. In: Fifth edition compilation of air pollutant emissions factors, vol. 1. Raleigh: EPA; 1995. https://www3.epa.gov/ttn/chief/ap42/ch14/index.html.
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