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Cropland Carbon Monitoring in Canada, Current Estimates, Future Directions

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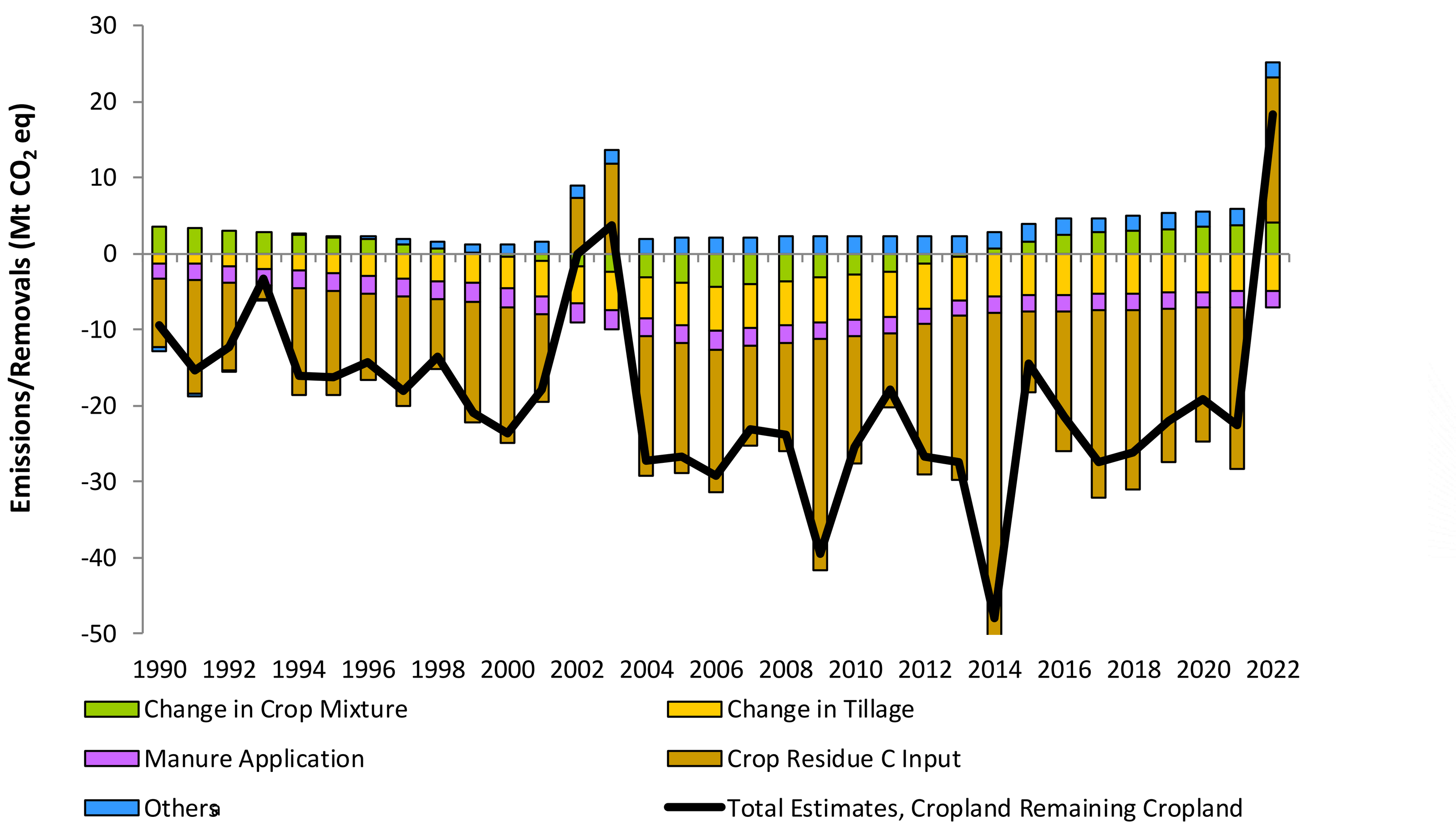
Introduction and Current Status

Cultivated agricultural land (≈ 50Mha), occurs in southern regions of Canada, about 83% in the dry interior plains of Western Canada, and another 12% is in the sub-humid Mixedwood Plains reporting zone of Eastern Canada.

Agricultural land management practices have changed in Canada. Producers have largely adopted conservation tillage practices, reduced summer fallow and increased crop yields — in turn, increasing C input to soils. It is estimated that these changes have resulted in an increase in net removals of CO_2 during the 1990–2006 period. Interannual variability occurs throughout the time series, reflecting weather-related impacts to crop production. in particular severe drought on the prairies, or high yields resulting in periodic peaks in emissions and removals.

Canada currently uses a combination of empirical factors and the data driven IPCC Tier 2 method published in the *2019 Refinement of the 2006 IPCC Guidelines* to produce estimates. Emission estimate methodologies are moving to an integrated modelling approach parameterized from country-specific data.



Note:
a. "Others" include emissions/removals associated with perennial woody crops and cultivation of histosols, and residual emissions from land conversion.

Figure 1– Emissions and Removals Related to Cropland Remaining Cropland Reported in Canada`s 2024 National Inventory Report

Compiling Canadian Studies

Comprehensive compilation of national data provides a total of 417 studies ranging in length from 4 to 72 years, with periodic measurements, provides a rich source of information to understand the bounds of change and drivers of change in Canadian agricultural soils.

Table 1. Compilation of Canadian Studies in Soil C Storage Impacted by Land Use and Management

Land Use/Management Change	Publication	Region	Drivers	Site	Duration	Soil C Gain/Loss		
					yr	Mg C ha^{-1}	%	kg C ha^{-1}yr^{-1}
Land Use Change[1]	**36**							
Deforestation	18	Eastern Canada	Coarse	11	44	-18.2 (±4.4)^{c}	-22 (±5.8)^{a}	
			Medium	22	61	-43.1 (±7.4)^{ab}	-30 (±5.0)^{a}	
			Fine	5	67	64.8 (±28.5)	-32 (±16.2)^{a}	
	18	Western Canada	Coarse	6	67	0.4 (±5.4)^{b}	1.3 (±10.0)^{b}	
			Medium	23	63	-26.8 (±4.9)^{a}	-25 (±4.3)^{a}	
Grassland		Western Canada	Coarse	12	72	-15.4 (±7.9)^{ab}	-21 (±8.4)^{a}	
			Medium	40	40	-26.2 (±4.7)^{a}	-26 (±3.2)^{a}	
			Fine	7	70	-4.7 (±10.7)^{b}	-14 (±7.4)^{a}	
Land Management Practice								
Conservation Tillage[2]	**37**							
No-Till vs Conventional Tillage	16	Eastern Canada		13	3-10	-2.6^{NS} (±2.1)^{a}		-470 (±410)^{a}
				15	11-20	1.7^{NS} (±1.5)^{a}		130 (±120)^{a}
				4	>20	1.4^{NS} (±2.2)^{a}		40 (±80)^{a}
	21	Western Canada		11	3-10	4.6** (±1.4)^{a}		740 (±220)^{a}
				14	11-20	3.2** (±0.5)^{a}		260 (±50)^{b}
				9	>20	2.5* (±1.0)^{a}		95 (±40)^{b}
		Eastern Canada	Coarse	9	9.6	-3.3^{NS} (±1.2)^{b}		-490 (±180)^{a}
			Medium	19	16	2.3^{NS} (±1.3)^{a}		160 (±160)^{a}
			Fine	4	4	4.1^{NS} (±6.0)^{bc}		-660 (±1180)^{a}
		Western Canada	Coarse	5	10	4.4** (±1.5)^{a}		580 (±310)^{a}
			Medium	21	18	3.2** (±0.8)^{a}		300 (±110)^{a}
			Fine	8	10	3.6** (±0.6)^{a}		430 (±90)^{a}
Summerfallow Reduction[3]	**28**							
	10	Canadian Prairies	Black Chernozem	24	31	6.7 (±1.6)		620 (±135)
	5		Dark Brown Chernozem	61	34	3.0 (±0.3)		390 (±120)
	22		Brown Chernozem	12	17	2.3 (±0.9)		410 (±50)
Green Manure	**8**	Canadian Prairies	Green Manure vs Fallow	15	22	2.1 (±0.6)		450 (±140)
Perennial/Annual Crop	**22**							
	10	Eastern Canada	Annual vs Cont Perennial	7	31	26^{NS} (±1.0)		736^{NS} (±169)
			Annual vs Discrete Perennial	11	31	12^{NS} (±3.7)		708^{NS} (±248)
	12	Western Canada	Annual vs Cont Perennial	8	30	7.7^{b} (±1.6)		734^{b} (±172)
			Annual vs Discrete Perennial	21	30	4.3^{b} (±1.4)		195^{a} (±111)

[1]Liang, B.C., A.J. VandenBygaart, J.D. MacDonald, Kiu Liu, and Darrel Cerkowniak. 2023. Change in soil organic carbon storage as influenced by forestland and grassland conversion to cropland in Canada. Geoderma Regional 33. E00648.
[2]Liang, B.C., A.J. VandenBygaart, D. Cerkowniak, D.J. MacDonald, B.G. McConkey, R.L. Desjardins, and D.A. Angers. 2020. Revisiting no-till's impact on soil organic carbon storage in Canada. Soil Till. Research 198, 104529
[3]Liang, B.C., MacDonald, D.J., Ogle, S., VandenBygaart, A.J., Dias Ferreira, G. 2024. Global importance of soil carbon sequestration through Intensification of cropping systems (In preparation).
[4]Liang, B.C., MacDonald, D.J., VandenBygaart, A.J., Hung, C.Y., Pelletier, N., Thiagarajan, A., Krobel, R. 2024. Perennial crop in annual crop-based rotation enhances soil organic carbon storage. Soil & Tillage Research (under review).

Modelling Infrastructure

The development of a data management system for agricultural data in Canada provides critical infrastructure for carrying out increasing complex, integrated spatially relevant analysis. Harmonized Units of Production (HUP) framework, standardizes data sources, defines investigation units, enforces data structure standards, and manages spatial and temporal differences.

Individual modelling units are built on unique combinations of spatial and temporal data – not spatially explicit but differentiates where and when there is a likelihood of differences based on unique model input.

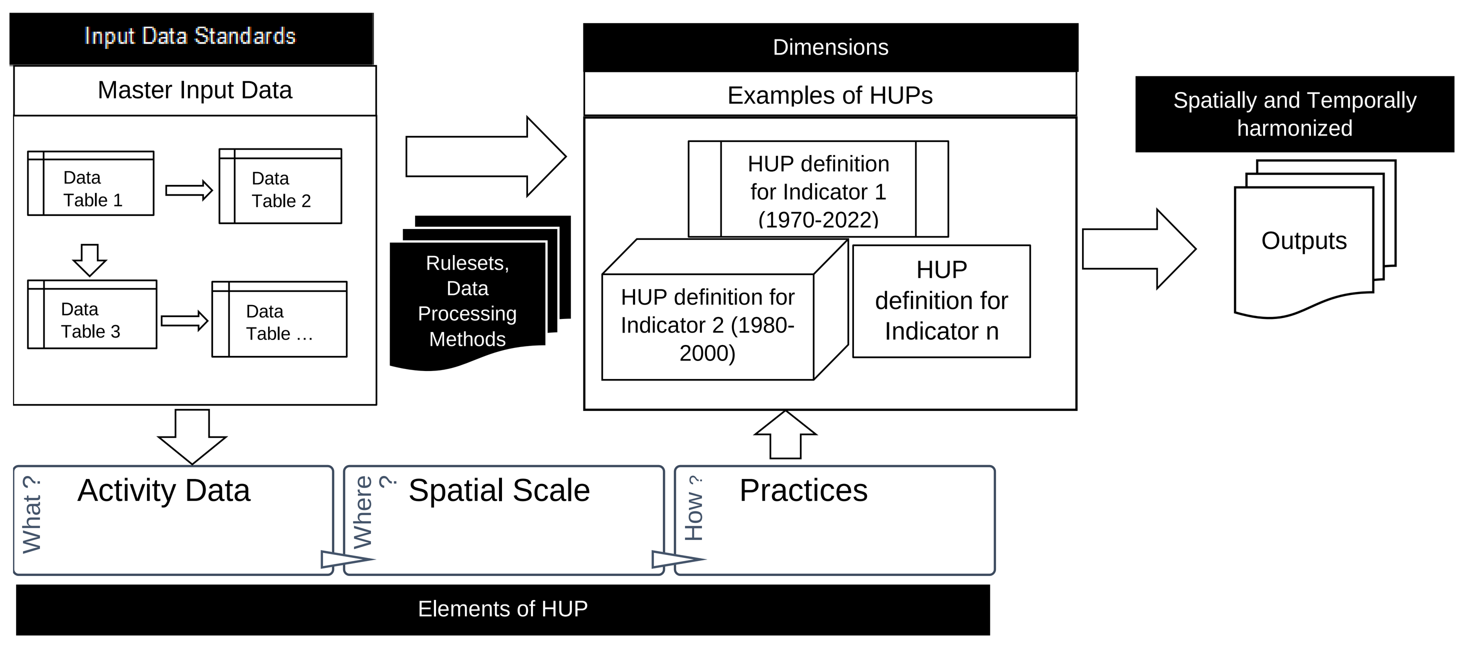


Figure 2– Abstract Illustration of HUP framework for AgriEnvironmental Indicators

Model Testing – Multiple model analyses

A number of models had been used to simulate Soil Organic Carbon (SOC) in Canada. We simulated changes in SOC with four models using default parameterization. The IPCC Tier 2 approach provided similar estimates to other models. However, in general, models did not effectively simulate SOC change. The results indicated the need for regional calibration and validation to reduce uncertainties in quantification of SOC changes.

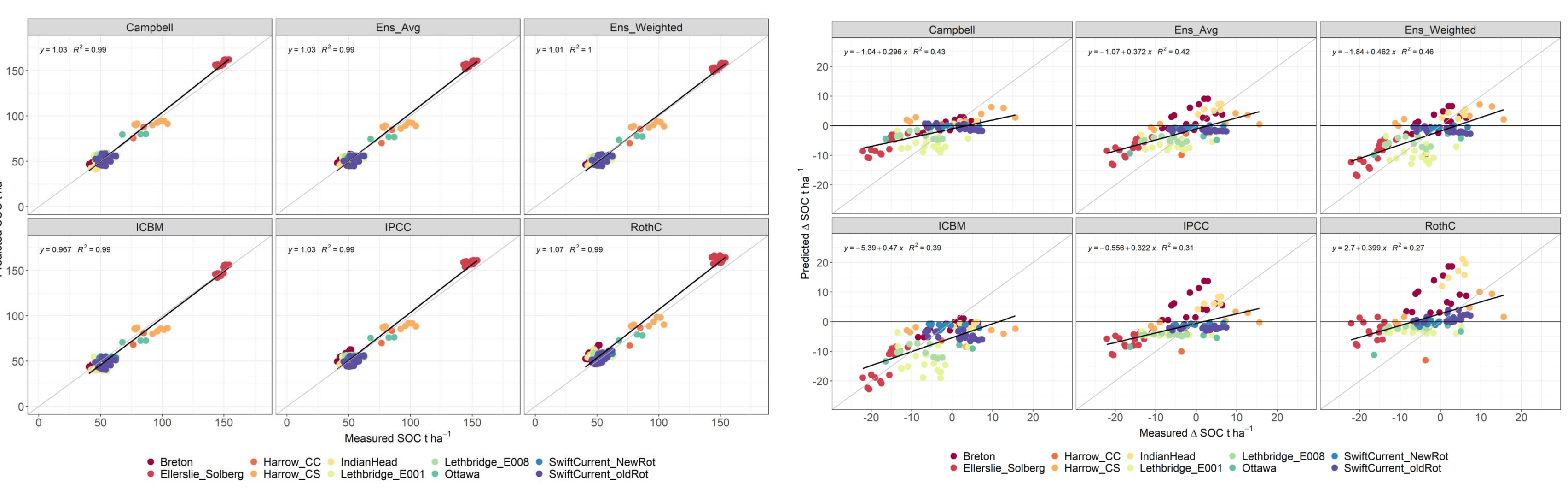


Figure 3– Comparison between measured and predicted SOC stocks and ΔSOC by Campbell, Ensemble Average (Ens_Avg). Ensemble Weighted average (Ens_Weighted), ICBM, IPCC and RothC in the ten experimental sites. The Measured stock represents the actual SOC stocks measured in certain years. The ΔSOC (t ha−1) represents the stock difference from initial SOC and the measured stocks (n = 113).

Bayesian calibration of IPCC Tier 2 steady state soil organic carbon model was performed with experimental data (83 SOC time series data) representative of varied crop production, regions and crop rotations. Calibration of Model parameters reduced RMSE, bias and uncertainty of the predictions in validation datasets (See Figure 4). Regionally based Bayesian optimization and the use of multi-model ensemble techniques appears to be the most effective approach to reduce uncertainty and bias in agricultural SOC modelling for national inventories. Further analysis and comparison against daily time step process models is pending.

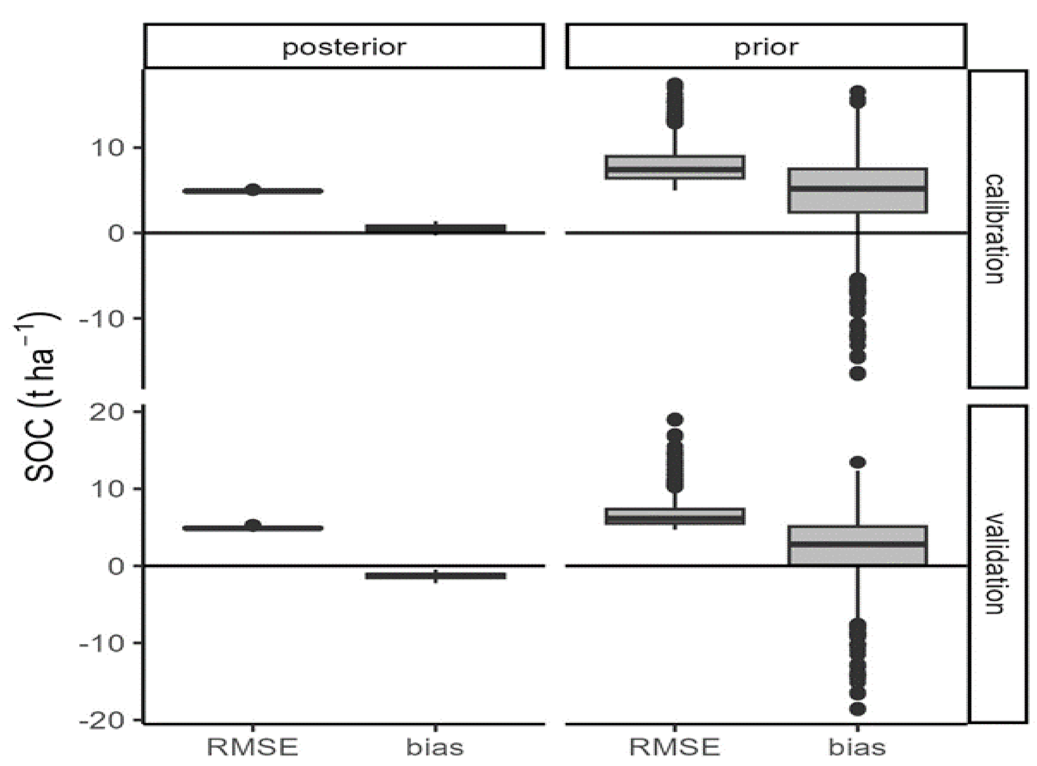


Figure 4– Boxplot showing the distribution of RMSE and bias between measured and modelled SOC using the prior parameter distribution and the posterior parameter distribution. The calibration and validation sets are shown separately.