Assessing Soil Organic Carbon on BC Farmlands as a Climate Change Mitigation Tool: An Overview

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Acknowledgements

This report was written and researched on the unceded traditional territory and homelands of the xʷməθkʷəy̓əm (Musqueam), sḵwx̱wú7mesh (Squamish), and sel̓íl̓witulh (Tsleil-Waututh) First Nations, upon which I am an uninvited guest. This report refers to the agricultural sector in BC, which originated through the settlement of European colonizers and led to the historic and continued displacement and loss of Indigenous Peoples, food systems and food resources (Turner & Turner, 2008). It is my hope that this report will help to further climate actions in British Columbia, particularly through the restoration of degraded soils on farmland.

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Executive Summary

In British Columbia, climate change is expected to impact life significantly, disrupting natural environments, economies, and the social fabric of communities (BC Ministry of Environment and Climate Change Strategy, 2019; *Introduction - British Columbia | Natural Resources Canada*, 2014), and BC is not on track to meet targets for 2030 or 2050 (BC Auditor General, 2018). Drastic reductions in anthropogenic GHG emissions in the near-term will not be enough to prevent dangerous climate change (IPCC, 2018). A growing body of evidence suggests that agricultural soils could play an essential role in climate change mitigation through their capacity to serve as C sinks (Bossio et al., 2020; Kane, 2015; Minasny et al., 2017; Paustian et al., 2016; Powlson et al., 2011; Smith P., M. Bustamante, H. Ahammad, H. Clark, H. Dong, E. A. Elsiddig, H. Haberl, R. Harper, J. House, M. Jafari, O. Masera, C. Mbow, N. H. Ravindranath, C. W. Rice, C. Robledo Abad, A. Romanovskaya, F. Sperling, 2014; Smukler, 2019; Wood-Bohm, 2018). This report uses existing data and literature to estimate the potential for BC farmland to serve as a C sink and contribute to the provincial climate change mitigation strategy. We estimate that BC farmland holds an estimated 194 Mt to a depth of 30 cm, and 259 Mt to a depth of 100 cm: and, that the implementation of targeted agricultural practices (VandenBygaart et al. 2003, 2008; as cited by Minasny et al., 2017) may result in estimated SOC gains ranging from of 0.26 to 1.3 Mt C per year. At the high range, this is equivalent to taking 47% of BC's passenger vehicle fleet (Statistics Canada, 2021b) off the road for one year[9]. We also estimate that BC farmlands need to sequester 0.78 Mt C per year to a depth of 30 cm and 1.04 Mt C per year to a depth of 100 cm to achieve the 4 Per 1000 target (4 Per 1000, 2018).

The literature review reveals the significance of land conservation, afforestation and conversion of agricultural lands to pasture in maximizing SOC on farmlands (Minasny et al., 2017; Paul et al., 2020; Powlson et al., 2011; VandenBygaart et al., 2003). Future research should focus on identifying and restoring severely to moderately degraded soils (Minasny et al., 2017) on BC farmlands, to prioritize the implementation of incentives and policies. Due to the province's diverse geography and agriculture sector, it is recommended that incentive programs be piloted by Regional Districts or in collaboration with producer associations and piggyback on existing programs.

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Terms

Carbon sink:

A natural or artificial reservoir that absorbs more carbon than it releases as carbon dioxide (Auditors General of Canada, 2018).

Cropland:

All land in annual crops, summer fallow, or perennial crops (mostly forage, but also including berries, grapes, nursery crops, vegetables, and fruit trees) and non-forest pasture or rangeland used for grazing domestic livestock that does not meet the definition of grassland. This definition of cropland is broader than some definitions in common use in BC due to the inclusion of non-forest land used for pasture and grazing (BC Ministry of Environment and Climate Change Strategy, 2020, p. 23).

Farmland:

According to the BC Ministry of Agriculture farmland area includes both workable and non-workable land on farm operations in B.C.(2016). This includes crops, summer fallow, tame or seeded pasture, natural land for pasture, and other farmland ("woodland, wetlands, Christmas tree land, land on which farm building, barnyards, lanes, home gardens, greenhouses and mushroom houses are located and idle land") (BC Ministry of Agriculture, 2016, p. 2).

Mitigation:

A human intervention to reduce the sources of greenhouse gases or enhance carbon sinks (Auditors General of Canada, 2018).

Soil organic carbon (SOC):

The carbon portion of soil organic matter (SOM) (roughly 58%) (Pribyl, 2010 as referenced in Food and Agriculture Organization of the United Nations, 2017).

Abbreviations and Acronyms

BC – British Columbia

C – carbon

cm – centimetre

CO_2 – carbon dioxide

CO_2e – carbon dioxide equivalent

GHG – greenhouse gas

Ha – hectare

IPCC – Intergovernmental Panel on Climate Change

kt – kilotonne

Mt – megatonne

SOC – soil organic carbon

T – tonne

Introduction

Problem Statement

There is now a significant body of evidence highlighting the urgent need for climate action across sectors and regions to prevent global warming beyond 1.5 °C above pre-industrial times. The Intergovernmental Panel on Climate Change (IPCC) states an increase beyond this poses serious risks to ecological and human health, food security, infrastructure, and economic stability (IPCC, 2019).

In British Columbia (BC), climate change is expected to disrupt life significantly, including changes to natural environments, economic development, and the social fabric of communities (BC Ministry of Environment and Climate Change Strategy, 2019; *Introduction - British Columbia | Natural Resources Canada*, 2014). Such impacts are already occurring and are expected to increase in frequency and severity in the coming decades (BC Ministry of Environment and Climate Change Strategy, 2019; Bush et al., 2019). Most climate change related risk events are expected to have catastrophic economic impacts (BC Ministry of Environment and Climate Change Strategy, 2019). For example, climate change related riverine flooding is projected to result in $22.9 billion in losses to various economic sectors, including agriculture, transportation and energy (BC Ministry of Environment and Climate Change Strategy, 2019).

In light of the imminent risks to BC's food system, population, natural environment and economy, climate action is needed across all sectors of the province. According to the IPCC, trajectories leading to a 1.5 °C pathway require drastic reductions in greenhouse gas (GHG) emissions, including major adjustments to the status quo in many sectors, including agriculture (IPCC, 2019). Furthermore, global climate models suggest that even drastic reductions in anthropogenic GHG emissions in the near-term will not be sufficient to achieve safe levels of atmospheric carbon (C) and prevent climate change (IPCC, 2018). This means that climate change mitigation efforts must also include actions to bring down atmospheric levels of CO_2 in the near term by sequestering previously generated anthropogenic emissions in global C sinks (Kane, 2015). While global cooperation and action is certainly required to ensure a safe pathway (not exceeding 1.5 °C above pre-industrial times), initiatives at the provincial and regional level towards mitigation and adaptation are also needed to provide timely, politically feasible actions, that are within the provincial and regional government's realm of control. Additionally, while the Government of BC has stated its commitment to climate action and resiliency, adaptation and transitions to low-C economies (Government of British Columbia, n.d.), BC is not on track to meet its climate targets (Auditors General of Canada, 2018). After reducing emissions to 61.92 Megatonnes (Mt) CO_2e in 2015, provincial emissions have increased again to 64.46 Mt CO_2e in 2017 (Ministry of Environmentand Climate Change Strategy, 2017).

Soil Organic Carbon as a Climate Change Mitigation Strategy

There is a growing body of evidence suggesting that farmlands and agricultural soils could play an essential role in climate change mitigation through its capacity to serve as a C sink (Bossio et al., 2020; Kane, 2015; Minasny et al., 2017; Paustian et al., 2016; Powlson et al., 2011; Smith P., M. Bustamante, H. Ahammad, H. Clark, H. Dong, E. A. Elsiddig, H. Haberl, R. Harper, J. House, M. Jafari, O. Masera, C. Mbow, N. H. Ravindranath, C. W. Rice, C. Robledo Abad, A. Romanovskaya, F. Sperling, 2014; Smukler, 2019; Wood-Bohm, 2018). The 4 Per 1000 Initiative was launched at COP 21 in 2015 to bring global partners together with the goal of achieving annual 0.4% increases in global soil organic carbon (SOC) as a means to sequester a portion of anthropogenic emissions and ensure global food security (4 Per 1000, 2018). There have been a number of studies that have evaluated the 4 Per 1000 approach illustrating the sizeable potential, globally and nationally, for agricultural soils to sequester C (Minasny et al. 2017; Smukler 2019). As a result, some scientists and organizations have called for further exploration of agricultural mitigation planning in Canada (Smukler, 2019) and BC (Moreau et al., 2012), specifically initiatives that will compensate farmers for the climate change mitigation and other ecosystems goods and services they provide (Farm Folk City Folk, 2019; Qualman & desLibris - Documents, 2020; Smukler, 2019).

Objectives

This report provides an overview of SOC as a climate change mitigation tool across BC's farmlands. It uses existing data from studies by Minasny et al. (2017), Tarnocai (1998) and VandenBygaart et al. (2003, 2008) to estimate the potential for BC farmland to serve as a C sink and contribute to the provincial climate change mitigation strategy. A scan of pertinent literature is conducted to assess available evidence related to SOC on practices that may increase SOC in BC agricultural soils. Potential co-benefits and common challenges with implementing SOC sequestration strategies as a climate change mitigation strategy are also identified. Finally, several recommendations are provided to inform next steps and further research.

Objectives:

1. Estimate SOC in BC farmland and capacity to achieve the 4 Per 1000 initiative target
2. Identify practices that increase SOC in BC and Canadian farmlands
3. Identify challenges and co-benefits associated with implementing C sequestration on farmlands as a GHG mitigation strategy

Scope, Limitations and Assumptions

This study focuses on utilizing SOC on BC farmlands as a C sink and climate change mitigation tool. The report provides an overview of this complex and variable topic in the context of BC. Due to limitations of time and resources, the author does not suggest that this report covers all aspects of SOC in BC farmlands in their entirety.

In addition to CO_2, other important GHGs include nitrous oxide (N_2O) and methane (CH_4), perfluorocarbons (PFCs), hydrofluorocarbons (HFCs), sulphur hexafluoride (SF_6) and nitrogen trifluoride (NF_3) (Government of Canada, 2018). Every GHG differs in their global warming potential (GWP), which considers how long they persist in the atmosphere and how much energy they are able to absorb (United States Environmental Protection Agency, 2020). Compared to other GHGs, CO_2 absorbs little energy but remains in the atmosphere for thousands of years; it has a GWP of 1 (United States Environmental Protection Agency, 2020). CH_4 has a GWP of 28-36; it absorbs more energy than CO_2 but only remains in the atmosphere for a decade on average. N_2O has a GWP of 265-298 and remains in the atmosphere for over a century (United States Environmental Protection Agency, 2020). This report focuses on increasing C sinks as a means to draw down atmospheric CO_2. It touches on sources of agricultural GHG emissions in BC and Canada but does not address the topic in depth.

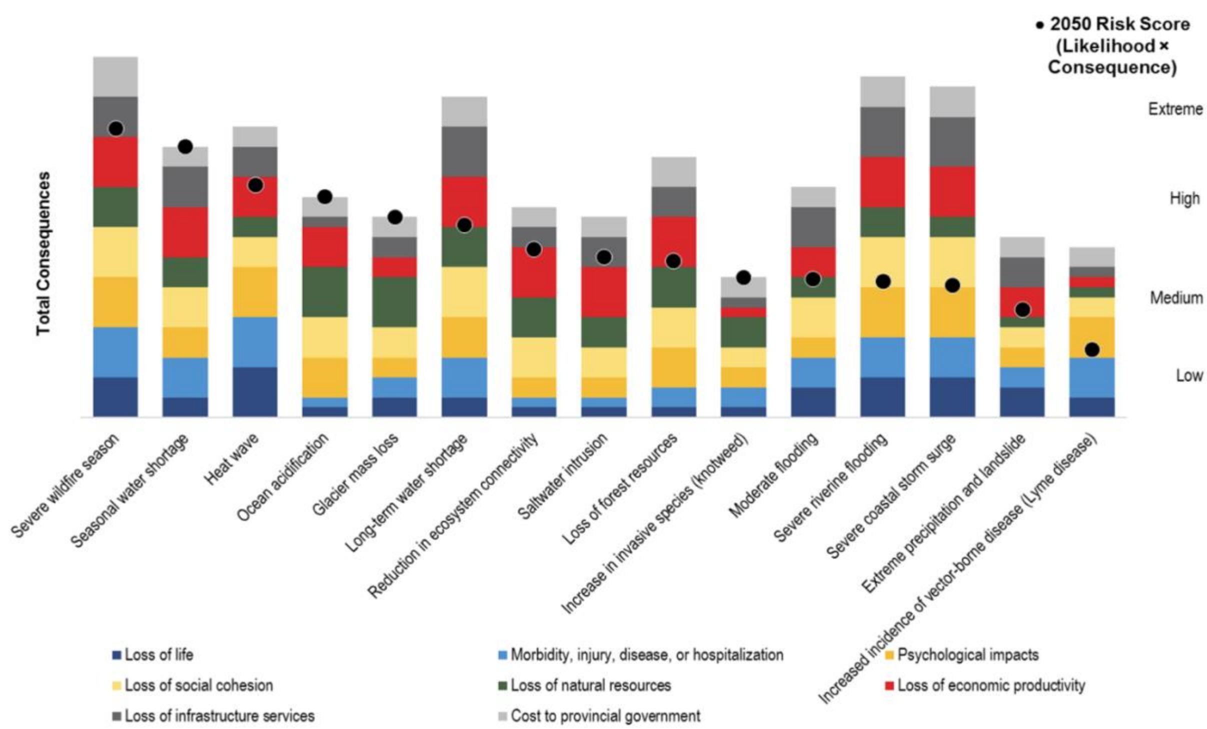
According to VandenBygaart et al. (2003, 2008) as cited in Minasny et al (2017), some agricultural management practices may provide SOC gains on Canadian land used for agriculture ranging from 0.1 to 0.5 t C ha per year. For the purposes of this study, it is assumed that these practices could be applied to the total farmland area of BC, which is defined as both workable and non-workable lands on farm operations, including crops, summer fallow, tame or seeded pasture, natural land for pasture, and other farmland area (including forests, wetlands, Christmas trees, idle lands, home gardens, farm structures, barnyards and lanes) (BC Ministry of Agriculture, 2016). As a result, the estimated gains in SOC on BC farmland resulting from the implementation of selected management practices calculated for this report are likely higher that they would be in reality. This is due to the fact that the aforementioned agricultural management practices cannot realistically be applied to all farmlands or croplands in BC.

Furthermore, in *Soil carbon 4 per mille*, Minasny et al. refer to the amount of C in Canadian "land currently used for agriculture" (2017, p. 76). Minasny et al. do not define this phrase and the terminology differs from that used by Statistics Canada for the 2016 Census of Agriculture. The area of land currently used for agriculture noted by Minasny et al. (55.2 MHa) (2017) differs from standard categories used by Statistics Canada in the Census of Agriculture, such as "total farmland area" (64.2MHa) (2016) and "land in crops" (37.8MHa) (2017). In this study, tonnes of C in BC farmland was calculated using data available from Statistics Canada for total farmland area in BC. For the purposes of this study, the terms “land currently used for agriculture” (Minasny et al., 2017, p. 76) and total farmland area in BC are used interchangeably. The impacts of this assumption on study results are unknown.

Background

Impacts of Climate Change in British Columbia

Climate change is projected to have far-reaching consequences on many aspects of life in BC, including permanent loss of employment and way of life, degradation of natural resources, and up to $1 billion in added costs (BCMECCS, 2019). Figure 1 illustrates the array of consequences associated with particular climate risk events projected in BC. According to the 2019 report for the BC Ministry of Environment and Climate Change Strategy (BCMECCS) composed of input from a 20-person advisory committee representing eight BC ministries and 70 experts, by the 2050’s BC is at highest risk[1,2]of seasonal water shortages, heat waves, and severe wildfire seasons followed by lasting water shortages, ocean acidification and glacier loss.



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[1] Risk is assessed using “2050 Risk Score (Likelihood x Consequence)” (BCMECCS, 2019, p.4).

[2] The risk assessment model used by the BC Ministry of Environment and Climate Change Strategy presumes high global emissions increases until 2050 based on the IPCC’s Representative Concentration Pathway (RCP) 8.5(2019.)

Figure 1: Consequences Associated with Climate Risk Events in BC

Many such consequences will directly impact BC's agricultural sector, including moderate to severe flooding, saltwater intrusion and seasonal water shortages. The cumulative impacts of these will range from billions in economic losses, to wide-ranging loss of ecosystem health and services, and contamination of soil and drinking water (BCMECCS, 2019). These severe risks and consequences highlight the need for immediate climate change mitigation in BC and beyond.

BC's Agricultural Emissions, Sources and Sinks

The most recent BC GHG inventory at the time of writing reported BC's 2018 emissions at 67.92 Mt CO_2e, marking the highest total emissions since 2001 (67.99 Mt CO_2e). Table 1 shows trends and percentage shifts in BC's total and agricultural emissions and sinks between 1990 and 2018.

Table 1: BC's Total and Agricultural GHG Emissions and Sinks (kt CO_2e)

	1990	1997	2007	2017	2018	% Change (1990 - 2018)	% Change (2007-2018)	% Change (2017-2018)
Total	**55,853**	**63,246**	**63,401**	**65,757**	**67,924**	**21.61%**	**7.13%**	**3.30%**
Agriculture	2,200	2,515	2,464	2,372	2,473	12.41%	0.38%	4.29%
Enteric Fermentation	1,358	1,577	1,563	1,426	1,470	8.31%	-5.90%	3.11%
Manure Management	311	381	402	407	417	34.21%	3.77%	2.55%
Agricultural Soils	506	528	484	510	552	9.06%	14.10%	8.29%
Direct Sources	406	417	377	405	439	8.25%	16.51%	8.53%
Indirect Sources	101	111	107	105	113	12%	5.63%	7.36%
Field Burning of Agricultural Residues	-	-	-	-	-	-	-	-
Liming, Urea Application, and Other Carbon-Containing Fertilizers	25	28	16	28	33	31.93%	113.64%	16.62%
Afforestation and Deforestation								
Grassland Converted to Cropland	2	4	6	2	2	0.00%	-66.67%	0.00%
Emissions not included in inventory total:								
Other Land Use								
Cropland Management	-9	49	62	136	137	1610.86%	120.97%	0.74%

(Adapted from *Provincial Greenhouse Gas Emissions Inventory 2018*, 2020)

In 2018, agriculture accounted for 3.6% of BC's total GHG emissions (*Provincial Greenhouse Gas Emissions Inventory 2018*, 2020). Total agricultural emissions have increased by approximately 12% since tracking started in 1990, and with some fluctuations in between, have returned to 2007 levels in 2018, despite the provincial targets to reduce emissions by 30% below 2007 levels (Province of British Columbia, 2020). The largest source of agricultural emissions in the province is methane (CH_4) from enteric fermentation from cattle. This accounted for over 50% of the sector's emissions in 2018 (*Provincial Greenhouse Gas Emissions Inventory 2018*, 2020). The next largest source of emissions is from agricultural soils in the form of N_2O, which accounted for over 20% in 2018 (*Provincial Greenhouse Gas Emissions Inventory 2018*, 2020). The BC Ministry of Environment and Climate Change Strategy describes emissions from agricultural soils as "N_2O emissions from the application of fertilizers to agricultural land and management practices such as crop rotations, tillage, summer fallow, and irrigation"(2020, p.11). This category includes both direct[3] and indirect[4] sources of agricultural soils emissions, of which the former accounted for nearly 80% of emissions in this category in 2018.

The emissions line item, cropland management, is not included in the Provincial Inventory, but is documented in the other land use category. It refers to emissions from cropland that has remained as cropland (as opposed to being transitioned to a different land use). This includes, "carbon sequestration by crops, transfer and storage of carbon in soils, and emissions through soils and crop composition,"(BC Ministry of Environment and Climate Change Strategy, 2020, p.16). This emissions category demonstrates how changes to cropland management over time have resulted in BC croplands[5] shifting from a C sink to a growing C source (-9 kt CO_2e in 1990 to 137 kt CO_2e in 2018). This is in contrast to the National Inventory Report, which documented Canada's croplands as a C sink since 2005, although the amount of C sequestered has steadily decreased from -10 Mt CO_2e in 2013 to -6.2 Mt CO_2e in 2018 (Environment and Climate Change Canada, 2020).

BC's Emissions Targets and Policies

The Government of BC has committed to taking climate action and developing low-C economies across all sectors that will be resilient to shifts in climate (Government of British Columbia, n.d.). According to the province's Climate Change Accountability Act, BC legislated emissions reduction targets of:

- 33% below 2007 emissions by 2020

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[3] The BC Ministry of Environment and Climate Change Strategy describes direct sources of emissions from agricultural soils as, "application of synthetic and manure-based fertilizers, decomposition of crop residue, irrigation, losses of soil organic matter through mineralization, cultivation of organic soils, and changes to tillage practices, summer fallow, and irrigation" (2020, p. 11).

[4] The BC Ministry of Environment and Climate Change Strategy describes indirect sources of emissions from agricultural soils as, "volatilization and subsequent re-deposition, leaching and erosion, or run-off of nitrogen from crop residue, animal manure, and synthetic fertilizer" (2020, p. 11).

[5] The BC Ministry of Environment and Climate Change Strategy describes cropland, "All land in annual crops, summer fallow, or perennial crops (mostly forage, but also including berries, grapes, nursery crops, vegetables, and fruit trees) and non-forest pasture or rangeland used for grazing domestic livestock that does not meet the definition of grassland. This definition of cropland is broader than some definitions in common use in BC due to the inclusion of non-forest land used for pasture and grazing." (2020, p. 23)

- 40% below 2007 emissions by 2030
- 60% below 2007 emissions by 2040
- 80% below 2007 emissions by 2050

According to the province's own 2019 Climate Change Accountability Report, "early progress to meet our commitments was slow, making the 2020 target out of reach" (Province of British Columbia, 2020). By the same report, the province acknowledges that its current climate action plan (CleanBC) is only capable of reaching 75% of 2030 emissions targets; this leaves 6.1 Mt unaccounted for in BC's plan (2020). Additionally, in an independent audit by the Auditors General of Canada, models suggest that BC will not meet its 2050 emissions targets under the current trajectory (BC Auditor General, 2018). Table 2 summarizes BC's progress and track record in meeting GHG emissions targets.

Table 2: British Columbia Climate Targets and Progress

2018 BC GHG Emissions	**Target Year**	**Target % below 2007 Levels (63,401 kt CO_2e)**	**Total Emissions At Target**	**On Track to Target**
67,924 kt CO_2e	2020	33% reduction	42,478.67 kt CO_2e	Not Met
	2030	40% reduction	38,040.60 kt CO_2e	Not on Track*
	2040	60% reduction	25,360.40 kt CO_2e	Unknown
	2050	80% reduction	12,680.2 kt CO_2e	Unknown

*(Auditors General of Canada, 2018)

The province's CleanBC strategy includes the formation of an appointed Food Security Task Force to "examine new ways to use technology and innovation to strengthen our agricultural sector and grow our economy" (Province of British Columbia, 2020, p. 51). According to CleanBC, this task force will provide recommendations to the government in the following areas in 2020:

- supporting the objectives of CleanBC through the adoption of technologies and practices that will help reduce GHG emissions
- increasing access to fresh, healthy food and supporting local economies
  (Province of British Columbia, 2020, p. 51).

CleanBC also mentions the partnership between the Ministry of Agriculture and the BC Agriculture and Food Climate Action Initiative, which focuses on understanding and preparing farmers for climate change adaptation to ensure future food supplies. The CleanBC strategy does not mention utilizing agricultural soil or farmlands as C sinks, pointing to an opportunity for the province to broaden its climate change mitigation and adaptation strategy further.

Soil Organic Carbon: An Introduction

Globally, soils play an important role in regulating C pools; alone they store approximately 75 per cent of terrestrial C (as cited by Dignac et al., 2017 in Jobba´gy et al., 2000). The process by which atmospheric C comes to be stored as organic C within soil organic matter (SOM) is called biological C sequestration or bio-sequestration (Wood-Bohm, 2018). Through the process of photosynthesis, plants take C from the atmosphere (as CO_2) and use it to support their metabolic processes and form C based molecules which make up plant tissues (Wood-Bohm, 2018). The amount of organic C stored in the soil is directly linked to the addition and conservation of SOM (Alexander et al., 2015). Hence, SOM is increased in two ways: by the addition of C rich materials, like organic matter, and by the reduction in loss of SOC from decomposition (e.g. preventing soil disturbance) (Alexander et al., 2015; Paustian et al., 2016). Based on this, agricultural soils can become C sinks once the amount of C sequestered is greater than the amount of C lost over the same time period.

SOC dynamics are complex, and impacted by numerous biotic and abiotic mechanisms including flora, microorganisms, macrofauna, physical structure, porosity and mineral fraction (Dignac et al., 2017). Furthermore, not all SOC is created equal. Three categories of soil C pools exist and are distinguished by their decomposition rates (Von Lützow et al., 2008 as cited by Dignac et al., 2017). Decomposition or turnover rates, refer to the amount of time (mean residence time or half-life) that C remains in the soil in an unchanged state (Lal et al., 2005). When soil C turns over, it returns to the atmosphere in the form of CO_2. The labile soil C pool has a turnover time of one day to one year and is mostly comprised of plant litter and roots (Dignac et al., 2017). The intermediate pool has a turnover time of several years to one decade; it is comprised of plant litter and roots and the organic matter degradation products from labile pool (Dignac et al., 2017). The stable pool has a turnover time of decades to centuries and is located in soil aggregates that are resistant to decomposition (Dignac et al., 2017). Soil C stocks are constantly shifting as a result of land management practices and changes to temperature, precipitation and other factors, resulting in fluctuations in global C pools and atmospheric CO_2 concentrations (Alexander et al., 2015). Hence, from a climate change mitigation perspective, the objective of initiatives, such as 4 Per 1000, is to maximize the amount and duration of soil C in the intermediate and stable pools, where it is less prone to mineralization and transformation to atmospheric CO_2 (Dignac et al., 2017). As such if SOC is to be used as a climate change mitigation strategy, efforts need to be focused on both increasing SOC, but also conserving it.

British Columbia Soil and Agriculture

Of all Canadian provinces, BC is the most physically and biologically diverse, with fourteen distinct biogeoclimatic zones (*Introduction - British Columbia | Natural Resources Canada*, 2015). Along with the diversity of landscapes comes a diversity of soil types, resulting from differing parent material, climate, biology, and topography (Valentine et al., 1978). A map of BC soils from the Soil Landscapes of BC, by Valentine et al. is included below (see Figure 2). Resultingly, BC has one of the most diverse agricultural sectors in the country, producing over 200 commodities (Government of British Columbia, 2019). With such mountainous topography, only a small proportion of BC's land is suitable for agriculture, and even less possesses the soil and climate to support a wide variety of food and farm products (Ministry of Environment Lands and Parks British Columbia and the Minister of State (Environment) Ottawa, 1993). Such diverse landscapes and land use types lead to further complexity in attempting to develop province wide SOC managements strategies. Additionally, some reports have suggested that BC may experience higher levels of soil loss than other provinces, due to minimal freezing (Coote et al., 1981).

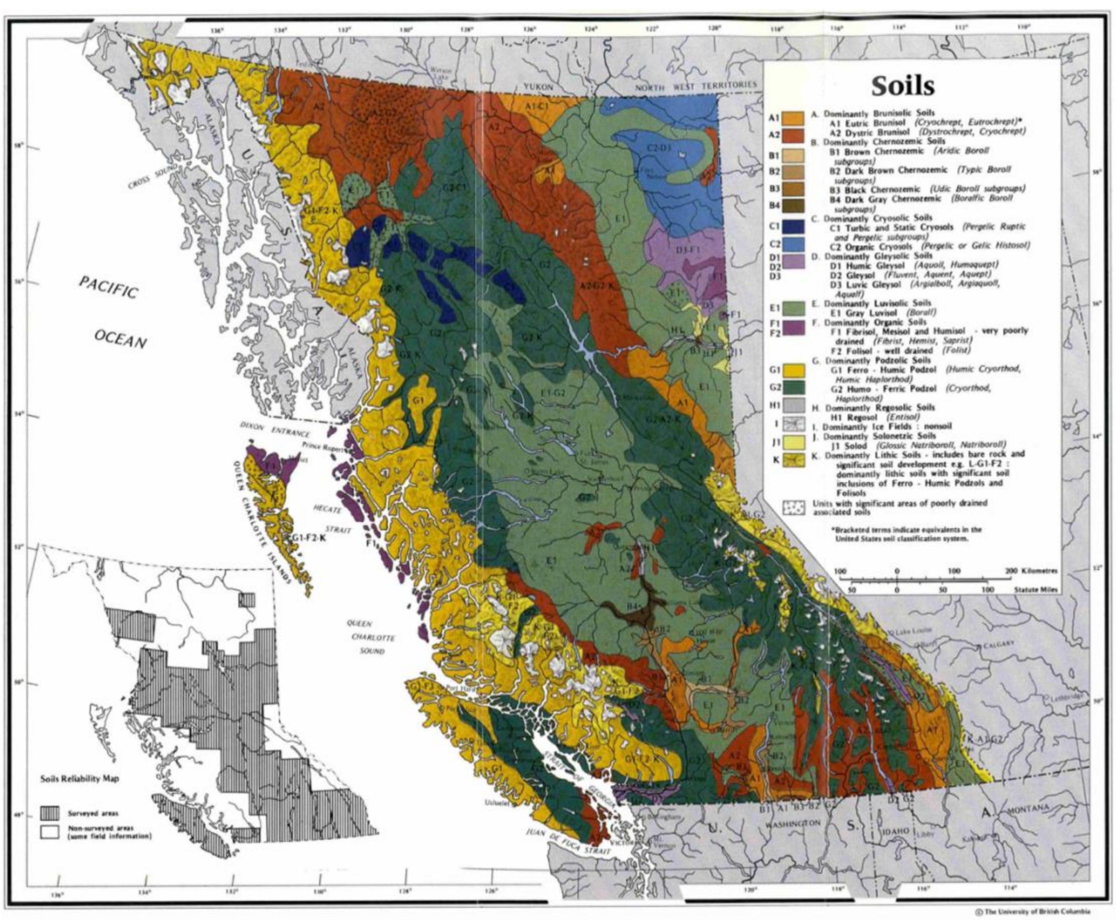

Figure 2: Map of BC soils from *Soil Landscapes of BC* by Valentine et al.(1978)

Methods

Literature Review

A review of pertinent academic and grey literature including government publications was conducted to gather current information on utilizing SOC in agriculture as a climate change mitigation strategy in BC. Journal articles were identified using database searches of UBC Library, PUBAG, Web of Science and Google for grey literature. Several journal articles and reports were recommended by academics in the field, and reports by the IPCC provided insight to the particular role and dynamics of soils in climate change mitigation and adaptation. Database search terms included: soil organic carbon, SOC, agricultural soil, climate change mitigation, policy/policies, incentives, Canada, British Columbia. Articles that focused on undeveloped countries or regions were excluded from the search criteria because this report focuses on implementing SOC practices in the context of the developed region of BC.

Literature was reviewed to gather information on common practices used to build SOC on farmland in BC and Canada, potential co-benefits and trade-offs associated with practices and general implementation of C sequestration in agriculture as a climate mitigation.

Grey literature, including reports, policies and data released by the Canadian and BC Governments and provincial and federal non-governmental organizations were also key sources of information for this report. Government publications provided data on BC's GHG emissions, climate change impacts, emissions targets, climate action plans as well as geography and agriculture in BC. Recent reports and presentations by non-governmental organizations on the topic of Canadian agriculture and climate change also provided important context and perspective on this topic, including *Tackling the Farm and the Climate Crisis* by the National Farmers Union (2019) and Climate Change Mitigation Opportunities in Canadian Agriculture and Food Systems by FarmFolk CityFolk Society (2019).

Data Analysis

Existing data on C stored in Canadian soils (Tarnocai, 1998) and Canadian land used for agriculture (Minasny et al., 2017) was used to estimate tonnes of SOC stored in 2,590,210 Ha of BC farmland (BC Ministry of Agriculture, 2016). Data collected by VandenBygaart et al. on potential SOC gains achieved by various agricultural management practices implemented on Canadian farmland was used to estimate how much SOC can be sequestered annually if such management practices are applied to all BC farmlands (2003, 2008 as cited in Minasny et al., 2017).

Calculations

The following calculations use existing data to estimate current SOC in BC farmlands, and potential gains in SOC based on the adoption of agricultural management practices.

1. Average tonnes of C per Ha of "land used for agriculture"[6] in Canada
   a. To a soil depth of 30 cm:

      4,140,000,000 t C ÷ 55,200,000 Ha ***= 75 t C/Ha***

   b. To a soil depth of 100 cm

      5,500,000,000 t C ÷ 55,200,000 Ha = ***100 t C/Ha***

2. Tonnes of C in BC farmland[7]
   a. To a soil depth of 30 cm

      75 t C/Ha x 2,590,210 Ha = ***194,265,750 t C***

   b. To a soil depth of 100 cm

      100 t C/Ha x 2,590,210 Ha = ***259,021,000 t C***

3. How much SOC does BC farmland need to sequester per year to meet the 4 Per 1000 Initiative target (0.4%)?
   a. To a soil depth of 30 cm:

      194,265,750 t C x 0.004 t C/ year = **777,063 t C** $\boldsymbol{year^{-1}}$

   b. To a soil depth of 100 cm:

      259,021,000 t C x 0.004 t C/ year = **1,036,084 t C** $\boldsymbol{year^{-1}}$

[6] Note, Minasny et al. do not provide a definition or source for 55.2 Mha of "Canadian land used for agriculture" (Minasny et al., 2017, p. 76).

[7] According to the BC Ministry of Agriculture farmland area includes both workable and non-workable land on farm operations in B.C.(2016).

4. Estimated gains in SOC (0.1 to 0.5 t C Ha per year) on BC farmland with the implementation of selected management practices[8].
    a. Assuming that management practices result in a gain of 0.1 (low range) t C/Ha per year, how much SOC can be sequestered in BC farmlands?

       2,590,210 Ha x 0.1 t C Ha year $^{-1}$ = ***259,021 t C year*** $^{-1}$
    b. Assuming that management practices result in a gain of 0.5 (high range) t C/Ha per year, how much SOC can be sequestered in BC farmlands?

       2,590,210 Ha x 0.5 t C Ha year $^{-1}$ = ***1,295,105 t C year*** $^{-1}$

Greenhouse Gas Equivalencies

GHG equivalencies for equations 3 and 4 (above) are presented in the Results and Discussion section; they were calculated using Natural Resources Canada's Greenhouse Gas Equivalencies Calculator[9]. Using this tool, we enter the results (t C per year) from equations 3 and 4 and receive estimated equivalencies for energy consumed (t CO_2e per year). For this report, equivalencies of energy consumed by passenger vehicles is used. Passenger vehicles are defined as having a total weight less than 3,856 kg (US EPA, 2017 as cited by Natural Resources Canada, 2018). Natural Resources Canada uses the following formula to estimate emissions for passenger vehicles per year; this is based on the total CO_2e emissions from passenger vehicles in 2016 and the estimated vehicle stock (2018):

72.1 Mt CO_2e / 22,088,845 vehicles × 1,000,000 t/Mt =

3.26 t CO_2e emissions vehicle^{-1} year^{-1}

Personal Communications

Personal communications with academics and professionals working at UBC, the BC Ministry of Agriculture and several non-governmental organizations running relevant programming took place via telephone between January and October 2020. Conversations helped to form project objectives and provided input on provincial context, potential areas of focus, resources, and existing policies and initiatives.

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[8] VandenBygaart et al. provide evidence that some management practices (e.g., no-till, decreasing summer fallow, increasing perennial crops into rotations, restoring degraded lands) may provide gains in SOC in Canadian land used for agriculture ranging from 0.1 to 0.5 t C ha per year (2003, 2008 as cited by Minasny et al., 2017).

[9] Estimates generated by Natural Resources Canada's Greenhouse Gas Calculator are approximate and are not suitable for use in formal emissions inventories. The calculator can be found at: https://oee.nrcan.gc.ca/corporate/statistics/neud/dpa/calculator/ghg-calculator.cfm#results.

Results and Discussion

Estimate SOC in BC Farmlands and Capacity for 4 Per 1000 Initiative

Based on analysis and calculations using existing data from the BC Ministry of Agriculture (2016) and Minasny et al. (2017) BC farmland holds an estimated 194 Mt to a depth of 30 cm, and 259 Mt to a depth of 100 cm. Using data from Minasny et al. (2017), the calculations for this report were made to soil depths of 30 and 100 cm. However, in their 2008 study VandenBygaart et al. limit their soil sampling depth for Western Canada to 15 cm since tillage in this region does not usually exceed that, thus limiting "the zone of influence on soil C dynamics to shallower depths than the mouldboard ploughed soils of Eastern Canada (Campbell et al., 1995)" (p.674).

According to VandenBygaart et al. (2003, 2008; as cited by Minasny et al., 2017) some management practices such as no-till, decreasing summer fallow, increasing perennial crops into rotations and restoring degraded lands may provide gains in SOC in Canadian land used for agriculture ranging from 0.1 to 0.5 t C ha per year. As Minasny et al. state, these values are in the range of the 4 Per 1000 target (2017). In order to achieve the 4 Per 1000 target of a 0.4% annual increase in global SOC (4 Per 1000, 2018), BC farmlands need to sequester 0.78 Mt C per year to a depth of 30 cm and 1.04 Mt C per year to a depth of 100 cm. Based on this data, the implementation of aforementioned management practices on BC farmland may result in estimated SOC gains ranging from of 0.26 to 1.3 Mt C per year. At the high range, this is equivalent to taking 1.45 million passenger vehicles off the road for one year[9], which is equal to 47% of BC's passenger vehicle fleet (Statistics Canada, 2021b). At the low range this is equivalent to taking 290 thousand passenger vehicles off the road for one year[9], which is equal to 9% of BC's passenger vehicle fleet (Statistics Canada, 2021b). Estimates and associated GHG equivalencies are included below in Table

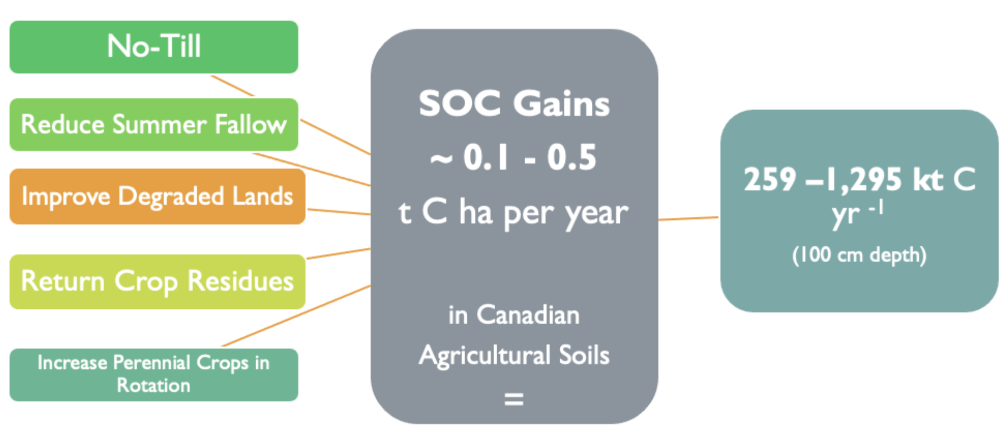

Figure 3: Practices known to increase SOC in agricultural soils in Canada

These results suggest that the 4 Per 1000 initiative target can be achieved on BC farmland soils, and that the implementation of targeted management practices (restoring degraded lands, increasing perennial crops into rotations, no-till, decreasing fallow) can support the BC Government in closing the 6.1 Mt emissions gap in its current climate policy and meeting its 2030 and 2050 emissions targets. If the high range of SOC gains were achieved on BC farmlands, this would reduce the province's 6.1 Mt emissions gap to 4.8 Mt while improving agricultural productivity and food security. In considering the application of the beneficial management practices (BMP) identified by VandenBygaart et al. (2003, 2008) in BC, it is important to note that not all of them are applicable to all cropland and farmland in BC.

Table 3: Summary of Findings and GHG Equivalencies

Description		GHG Equivalency[10]
Annual SOC gains needed for BC farmland to meet the 4 Per 1000 Initiative target (0.4%) to a depth of 30cm	777 kt C $year^{-1}$	Taking 872,902 passenger vehicles off the road for one year[11]. This is equivalent to 28% of BC's passenger vehicles (Statistics Canada, 2021b).
Annual SOC gains needed for BC farmland to meet the 4 Per 1000 Initiative target (0.4%) to a depth of 100cm	1,036 kt C $year^{-1}$	Taking 1.16 million passenger vehicles off the road for one year[10]. This is equivalent to 37% of BC's passenger vehicles (Statistics Canada, 2021b).
Annual estimated gains in SOC on BC farmland with the implementation of selected management practices (low range = 0.1 t C /Ha/ year)	259 kt C $year^{-1}$	Taking 290,967 passenger vehicles off the road for one year[10]. This is equivalent to 9% of BC's passenger vehicles (Statistics Canada, 2021b).
Annual estimated gains in SOC on BC farmland with the implementation of	1,295 kt C $year^{-1}$	Taking 1.45 million passenger vehicles

[10] All greenhouse gas equivalencies were calculated using Natural Resources Canada's Greenhouse Gas Equivalencies Calculator: https://oee.nrcan.gc.ca/corporate/statistics/neud/dpa/calculator/ghg-calculator.cfm#results

[11] Passenger vehicles in Canada are those weighing less than 3,856 kilograms. The information used to make these calculations is available on Natural Resources Canada's Greenhouse Gas Equivalencies Calculator – Calculations and References webpage: https://oee.nrcan.gc.ca/corporate/statistics/neud/dpa/calculator/refs.cfm

selected management practices (high range = 0.5 t C /Ha/ year)		off the road for one year[10]. This is equivalent to 47% of BC's passenger vehicles (Statistics Canada, 2021b).

Practices to Increase SOC in Agricultural Soils in BC and Canada

Some agricultural management practices have become known for their capacity to influence SOC in Canadian agricultural land. These include: reduced or no till practices, reducing summer fallow, switching from annual to perennial crops, the addition of organic material and improving degraded lands (Minasny et al., 2017). Long-term studies have examined the relationship between SOC storage and agricultural practices across Canada. These have demonstrated that management of agricultural soils in Canada has a significant impact on SOC stocks, though the effects vary by location and management practice (VandenBygaart et al., 2003). As mentioned in previous sections, VandenBygaart et al. (2003, 2008) found that the implementation of these practices may provide gains in SOC in Canadian agricultural lands ranging from 0.1 to 0.5 t C ha per year (Minasny et al., 2017). From the other side of the coin, Paul et al. observed spatiotemporal fluctuations in SOC in the Lower Fraser Valley in BC over a 34-year period and found that most SOC losses were attributable to unchanged agricultural uses (2020). They found that some of the largest decreases in SOC over the study period took place in annual cropping systems that did not undergo changes to land use land cover for 34 years (with a mean change of −32.27%)(Paul et al., 2020). This suggests that consistent agricultural use, without targeted efforts to replenish SOC results in net losses of SOC.

In their review of 62 studies on the long-term impacts of agricultural management practices on SOC across Canada, VandenBygaart et al. noted broad findings relating to tillage practices, crop rotation and fertilizer management (2003). Regarding fertilizer management, VandenBygaart et al. found that across the reviewed studies, both inorganic and organic fertilizers typically lead to increases in SOC (2003). One of the reviewed studies was located in Summerland, BC, and assessed the effect of organic fertilizer treatments on SOC storage. Studies were conducted on brown chernozem soils to a depth of 15 cm (Zebarth et al., 1999). All three experiments found net C gains, ranging from 3.1 to 54.8 Mg ha $^{-1}$, and increased C storage rates ranging from 0.79 to 13.69 Mg C ha per year (Zebarth et al., 1999 as cited by VandenBygaart et al., 2003)). The organic wastes applied included municipal biosolids; biowastes from commercial poultry, food waste and composted hog manure solids; locally mined peat moss, and a control that received no organic amendment (Zebarth et al., 1999). While this evidence suggests that the addition of both inorganic and organic fertilizers to agricultural soils tend to result in SOC increases, the inefficient use of inorganic fertilizers and nitrogen inputs in particular, are also a significant source of nitrous oxide, a GHG that is 265 times (Myhre et al., 2013) as powerful as CO_2 (Paustian et al., 2016). This can be observed in BC too, where agricultural soils accounted for over 20% of BC's agricultural emissions in 2018 (*Provincial Greenhouse Gas Emissions Inventory 2018*, 2020). Regarding organic inputs that are sourced from off the farm site (exogenous), Paustian et al. recommend adopting an approach which considers life-cycle GHG emissions (2016). For example, taking in consideration different end uses of organic inputs, such as burning or being disposed of in landfills (Paustian et al., 2016).

VandenBygaart et al.'s review also found that the impacts of tillage practices on SOC storage varies by soil type and climate (2003). For example, shifting from conventional tillage to no-till was most successful in increasing C storage in the Canadian Prairies where Chernozic soils are dominant (VandenBygaart et al., 2003), in contrast to BC, which has few regions dominated by Chernozic soils (Valentine et al., 1978). No-till did not increase C storage as effectively in Eastern Canada (east of Ontario), which typically has a cooler climate and more precipitation (VandenBygaart et al., 2003). None of the studies on tillage reviewed by VandenBygaart et al. (2003) were conducted in BC.

In 87 comparison studies (mostly located in Western Canada), VandenBygaart et al. found that repeatedly leaving fields fallow lead to reduced potential for SOC increases (2003). A variety of crops were found to potentially increase SOC storage when replacing fallow fields, including wheat grass (Agropyron crista- tum L. or A. trichophorum), hay, legumes (such as lentils, Lens culinaris M.) and red clover (Trifolium pratense L.) (VandenBygaart et al., 2003). Using legumes in crop rotations has the added benefit of providing green manures that can be plowed into the soil, providing accessible sources of soil nitrogen, and retaining higher levels of C (McGill & Bailey, 1999 as cited in VandenBygaart et al., 2003). Rotating hay with wheat was also found to result in higher SOC storage (VandenBygaart et al., 2003). None of the studies on fallowing reviewed by VandenBygaart et al. (2003) were conducted in BC. However, Paul et al. found that the conversion of annual crops to perennial crops and grasslands, lead to some of the highest SOC gains observed over the 34 year study period (51% gains from annual to perennial crops and 38% gains from annual crops to grasslands) (2020).

Recent Census of Agriculture data shows that the adoption of conservation tillage and cover cropping has been on the rise in BC since 2006 (see Figure 3)(Agriculture and Agri-Food Canada, 2021). Hectares under no-till and zero-till seeding increased by 146% between 2006 and 2016, (from 37,892 Ha in 2006 to 93,070 Ha in 2016) (Statistics Canada, 2021a). Hectares in summer fallow in BC decreased by 79% between 2006 and 2016 (from 25,581 Ha in 2006 to 5,337 Ha in 2016) (Statistics Canada, 2021a). Similar trends have been documented across Canada, and in the Canadian Prairies in particular (Minasny et al., 2017).

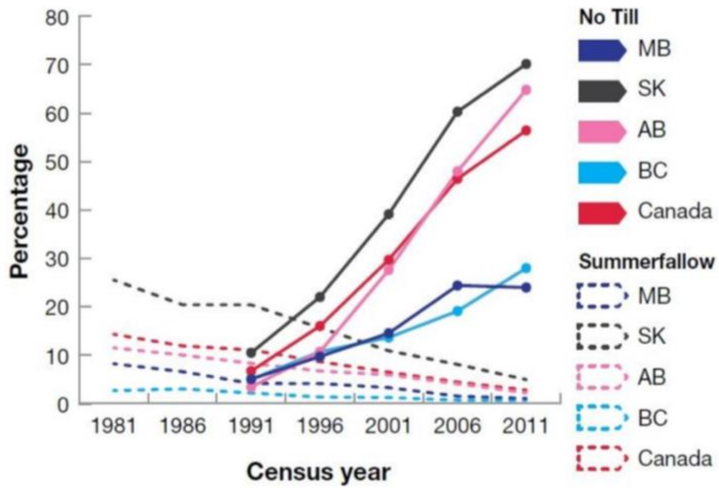

Figure 4: Change in Percentage of Farmland Area Under Summer fallow and No-Till in Western Canada 1981-2011 (Agriculture and Agri-Food Canada, 2021)

Furthermore, SOC gains in Canada's agricultural lands have diminished in recent years, dropping from 13 Mt of CO_2 in 2005 to 11 Mt in 2013 (Minasny et al., 2017). According to Environment and Climate Change Canada, emissions removals by croplands in Canada reached their maximum between 2006 and 2011, after which point they decreased due to the diminishing impacts of conservation tillage adoption and the shift from annual to perennial crops on the Prairies (2020).

In light of this, in their 2017 study surveying the potential of SOC sequestration in 20 regions of the world, including Canada, Minasny et al. conclude that the greatest potential for increasing SOC and preventing its further loss in Canada, lies in focusing initiatives and policies on restoring severely degraded and moderately degraded agricultural soils. As such, Minasny et al. recommend that SOC policies be implemented on the most degraded lands to reap maximum benefits of improved soil health and climate change mitigation (2017). Applying this recommendation to BC would require targeted efforts to locate and monitor highly and moderately degraded soils across the province. Currently, the availability of this information at the provincial and regional level is limited.

The review of pertinent literature also uncovered the significance of land conservation, afforestation and conversion of agricultural lands to pasture in maximizing SOC (Minasny et al., 2017; Paul et al., 2020; Powlson et al., 2011; VandenBygaart et al., 2003). In their review of 50 comparisons across Canada, VandenBygaart et al. noted that when native ecosystems were replaced by croplands, an average of 24 ± 6% of SOC was lost (2003). Paul et al. also found sizable differences in SOC values between agricultural and wild lands, suggesting that types of LULC are an important determining factor of SOC values across regions (2020). Within the 34-year study period, wetlands, forest/forest patches and lands under perennial cropping (especially under cranberry cultivation in organic peat soil) were found to have the highest SOC values. The lowest SOC values were present in croplands (Paul et al., 2020). As such, Paul et al. suggest that the protection and careful management of forest/forest patches are highly important to preserving SOC stocks in BC's Lower Fraser Valley region (2020). In the same study, they also observed that annual crops with higher SOC values were mostly found in fields lined with woody vegetation, however, it is suggested that some of these high SOC values may also be attributed to the use of cover crops and large amounts of organic inputs (Paul et al., 2020).

These observations have been made by other authors as well. Powlson et al. suggest that afforestation or converting agricultural land to pasture is a true form of SOC sequestration, since soil C stocks tend to be much lower under cropland management when compared to stocks before their conversion (2011). However, when considering land use changes, it is important to consider the possible trade-offs associated with removing agricultural land from production (Minasny et al., 2017). For example, could this place additional pressure on remaining lands to produce more foods. As a result, Powlson et al. suggest that converting agricultural lands to pasture or forest, be reserved for degraded or unproductive agricultural lands (2011).

Despite the many detailed findings on the impacts of agricultural practices on SOC stocks in Canada, very limited spatial data exists on the country's expansive agricultural lands (VandenBygaart, 2008). This is also true in the case of BC, where limited empirical data is available on SOC stocks and degraded lands in the province.

Challenges and Co-benefits of SOC as Climate Change Mitigation Strategy

Efforts to operationalize soil C sequestration in agricultural soils are accompanied by both challenges and co-benefits. Associated co-benefits of implementing C sequestration policies in agricultural soils include increasing soil fertility and agricultural productivity, building soil biodiversity, diminishing soil erosion and water pollution, and helping shield agro-ecosystems from impacts of climate change (Paustian et al., 2016). Additionally, SOC management and sustainable food production have been identified by the IPCC as two of "a select set of options [that] have the unique capacity to deliver across all of the following challenges: climate change adaptation, mitigation, desertification and land degradation, food security and sustainable development" (2019, p. 20).

There are also a number of unique challenges associated with using soil C sequestration as a climate change mitigation strategy. These include saturation (Smith, 2005), impermanence (Smith, 2008), leakage (IPCC, 2000), verification (Alexander et al., 2015) and eco-system service trade-offs (Smukler, 2019). Even under climate friendly farming practices, soils cannot sequester C indefinitely. Soil C stocks eventually reach a saturation point, before which the rate of sequestration will diminish

(Intergovernmental Panel on Climate Change, 2015). For this reason, it is argued that SOC policies should be implemented on the most degraded lands to reap maximum benefits of improved soil health and climate change mitigation as these lands hold the most potential for increased SOC (Minasny et al., 2017) .

Another major challenge related to using C sequestration on farmland soils as a GHG mitigation strategy is the fact that it is impermanent and can be undone by farmers and other land managers, resulting in the release of emissions that were previously sequestered (Smith P., M. Bustamante, H. Ahammad, H. Clark, H. Dong, E.A. Elsiddig, H. Haberl, R. Harper, J. House, M. Jafari, O. Masera, C. Mbow, N.H. Ravindranath, C.W. Rice, C. Robledo Abad, A. Romanovskaya, F. Sperling, 2014). As noted by Smith et al. weather and natural events like climate change, shifts in hydrological cycles or fires can also change soils' capacity to act as C sinks (2014). Such possibilities add to the complexity of verifying and monitoring SOC stocks on farmlands.

A broader challenge also exists within the current economic system, in that it does not assign a value to C sequestration. As such, C sequestration on farmland soils for the purpose of climate change mitigation is a positive externality that farmers are not compensated for. This provides multiple benefits to farmers and the public, such as improved food security and agricultural productivity, and the prevention of land degradation (IPCC, 2019). Recent reports have called for further research into initiatives that will compensate farmers for the climate change mitigation and other ecosystems goods and services they provide (Farm Folk City Folk, 2019; Qualman & desLibris - Documents, 2020; Smukler, 2019). Regarding BC farmers' adoption of BMPs, in their 2018 thesis exploring the differing views of BC government officials and farmers on BMP's, Semmelink found that a majority of farmers surveyed, "do not view BMP adoption as a complex task with many barriers" (p. 38). Rather, their findings suggest that insufficient time and money are the main factors preventing farmers from adopting the additional BMP's they would like to (Semmelink, 2018). As such, Semmelink recommends that financial incentive programs for farmers be designed with the aim of reducing barriers to adopting BMP's, such as limited money and time (2018).

Recommendations

More Information is Needed

The literature review revealed that there is limited data on shifting SOC stocks and degraded soils (topsoil containing less than or equal to 30 t C ha^{-1}) (Minasny et al., 2017) on BC farmlands. This poses a barrier to implementing recommendations by Minasny et al., to focus initiatives and policies on restoring severely and moderately degraded agricultural soils. As such, resources devoted to increasing the availability of information should be focused on identifying and monitoring degraded soils on BC farmlands. The following steps could be taken to increase awareness of fluctuations in SOC stock on BC farmlands:

- The 'scorpan' static-empirical model developed by Paul et al. provides a "simple and cost-effective methodology to monitor SOC changes at landscape scales that can easily be updated by incorporating new data," and could be used to support the implementation of programs incentivizing soil C sequestration on farmlands (2020, p. 12).
- Data on tillage practices and summer fallow is currently collected by Statistics Canada. This allows the tracking of adoption of some of the agricultural practices associated with increasing SOC stocks. We recommend that Statistics Canada additionally track winter fallow, application of fertilizer by type (inorganic and organic, origin: on-site or off-site) and shifts in annual and perennial crops by hectare.
- Explore the development of soil monitoring networks, supported by government, non-profits or citizen science networks. Existing examples include:
    - Citizen Science Soil Health Project (https://projects.sare.org/sare_project/fw19-341/)
    - Swiss Soil Monitoring Network (https://www.agroscope.admin.ch/agroscope/en/home/topics/environment-resources/soil-bodies-water-nutrients/nabo.html)
    - Prairie Soil Carbon Balance Project, by the Saskatchewan Soil Conversation Association (https://ssca.ca/projects/pscb-project)

Provide Financial Incentives for the Increase and Maintenance of SOC on BC Farmland

Policies should incentivize the adoption of practices identified in the literature review, including restoring degraded lands, decreasing summer fallow, increasing perennial crops into rotations and no-till, based on regional geography and crops (Minasny et al., 2017; VandenBygaart et al., 2003, 2008) and conservation of wild lands (Minasny et al., 2017; Paul et al., 2020; Powlson et al., 2011; VandenBygaart et al., 2003). Focusing initiatives and policies on restoring severely degraded and moderately degraded agricultural soils with low SOC stocks (topsoil containing less than or equal to 30 t C ha^{-1}) will result in maximum benefits of climate change mitigation and improved soil health (Minasny et al., 2017). The following should be considered in the development of incentive programs:

- Due to the diverse geography and agricultural sector in BC, it is recommended that incentive programs be piloted in one to several Regional Districts or in collaboration with one to several producer associations. Identify Regional Districts with severely to moderately degraded soils, frequent instances of fallowing, consistent unchanged annual crop production (as opposed to perennial production or crop rotations) and/or relatively low rates of no-till.

- Reduce the risk of impermanence or undoing C sequestration by refraining from operating incentive programs on land plots that are highly susceptible to weather or natural events such as fires. Furthermore, consider that prescribed burning and averting fires can be included in strategies to increase C sequestration (Paustian et al., 2016).
- Explore potential benefits of operating incentive programs on ALR land, such as utilizing existing monitoring and regulatory capacities, which may reduce risk of impermanence or undoing C sequestration.
- Examples of programs that provide financial incentives to farmers to increase SOC:
  - Environmental Farm Plan and Beneficial Management Practices Programs (http://ardcorp.ca/programs/environmental-farm-plan/efp-program-resources/
  - ALUS, now operating in six Canadian provinces (https://alus.ca/)
  - Delta Farmland and Wildlife Trust Stewardship Programs (https://deltafarmland.ca/our-programs/)
  - California's Healthy Soils Initiative (https://www.cdfa.ca.gov/healthysoils/)
    - Marin Carbon Project (https://www.marincarbonproject.org/home)
    - Compost Additions to Grazed Grasslands (https://americancarbonregistry.org/carbon-accounting/standards-methodologies/methodology-for-greenhouse-gas-emission-reductions-from-compost-additions-to-grazed-grasslands/compost-additions-to-grazed-grasslands-v1-0_final-1.pdf/view)
  - Soil and Water Outcomes Fund (https://www.theoutcomesfund.com/impact)

Utilize Existing Programs and Resources

- Increase capacity of the BC Environmental Farm Plan (EFP) and Beneficial Management Practices (BMPs) Programs. These government funded Programs provide BC farmers with free environmental assessments and incentives to adopt BMP's in the form of cost sharing (Semmelink, 2018). They are existing mechanisms which may be adjusted to reduce financial barriers (Semmelink, 2018) to increasing and maintaining SOC on BC farmland. In their 2019 report, FarmFolk CityFolk writes that the Programs currently lack sufficient resources to meet demand from farmers in the province (2019).
- There is an abundance of literature on the topic of SOC as a GHG mitigation strategy on agricultural lands. Among these, Paustian et al. have developed a practical and simple

resource in the form of a decision tree for cropland GHG mitigating practices, including associated challenges, co-benefits, and relative (2016, p. 51). These resources may support government officials, planners or land managers in decision making and the development of incentive programs.

Conclusion

Climate change is expected to disrupt life in the province significantly, including changes to natural environments, economic development, and resultantly social fabric and communities (BC Ministry of Environment and Climate Change Strategy, 2019; *Introduction - British Columbia | Natural Resources Canada*, 2014). BC did not meet its 2020 GHG emissions targets and is not on track to meet targets for 2030 or 2050 (BC Auditor General, 2018). Furthermore, emissions from cropland management in 2018 were the highest they have been since 1990. Changes to cropland management over time have resulted in BC croplands shifting from a C sink to a growing C source (-9 kt CO_2e in 1990 to 137 kt CO_2e in 2018).

Increasing C stocks on BC farmlands is an additional tool that the provincial government can utilize to mitigate climate change and facilitate co-benefits such as improved agricultural productivity and food security, and the prevention of land degradation (IPCC, 2019). With data from VandenBygaart et al. (2003, 2008), Minasny et al. find that the implementation of targeted management practices may provide gains in SOC in Canadian land used for agriculture ranging from 0.1 to 0.5 t C ha per year (2017). Furthermore, analysis of existing data suggests that the implementation of targeted management practices on BC farmland may result in estimated SOC gains ranging from of 0.26 to 1.3 Mt C per year. At the high range, this is equivalent to taking 47% of BC's passenger vehicle fleet off the road for one year[9] (Statistics Canada, 2021b). At the low range this is equivalent to taking 9% of BC's passenger vehicle fleet off the road for one year[9] (Statistics Canada, 2021b). These results suggest that the 4 Per 1000 initiative target can be achieved on BC farmland soils, and that the implementation of targeted management practices (restoring degraded lands, increasing perennial crops into rotations, no-till, decreasing fallow) can support the BC Government in closing the 6.1 Mt gap in its current climate policy, and meeting its 2030 and 2050 emissions targets while improving agricultural productivity and food security.

The development of incentives and strengthening of existing programs in the province (EFP and BMP Programs) should be focused on identifying and restoring severely to moderately degraded soils. Due to the province's diverse geography and agriculture sector, it is recommended that incentive programs be piloted by Regional Districts or in collaboration with one to several producer associations, prioritizing regions with severely to moderately degraded soils, and practices that are known to deplete

SOC. Programs may be more successful if focused on removing barriers to the adoption of practices such as finances and time (Semmelink, 2018). Future research should focus on identifying severely to moderately degraded soils (Minasny et al., 2017) on BC farmlands, to prioritize the implementation of incentives and policies.

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