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Opportunity Assessment of British Columbia's Agricultural Greenhouse Gas Reductions and Carbon Sinks

Project Summary and Recommendations

Opportunity Assessment of British Columbia's Agricultural Greenhouse Gas Reductions and Carbon Sinks

This report summarizes the findings of three detailed reports published separately:

- Report 1: BC Agriculture GHG Emission Profile Analysis
- Report 2: Multi-Criteria Framework for GHG Emissions and Co-benefits
- Report 3: Agroecosystem Models for GHG Emissions and Co-benefits

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CANADIAN AGRICULTURAL PARTNERSHIP

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UBC Sustainable Agricultural Landscapes Lab

The Sustainable Agricultural Landscapes Lab contributes to understanding the ecology of and management for an agricultural system that meets current needs without compromising the needs of future generations. A major focus is to evaluate the multiple environmental impacts and ecological interactions for various management options, and to provide a better understanding across a diversity of agroecosystems and social and economic contexts.

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Cover photograph

Automatic chambers for measuring soil greenhouse gas emissions set up in a vegetable field at the UBC farm. Photo credit: Carson Li, UBC Sustainable Agricultural Landscapes Lab

Highlights

1. **Detailed assessment of the greenhouse gas (GHG) emission estimates in British Columbia's Provincial Inventory revealed that several of the highest emissions sources/sinks associated with agricultural production are not typically captured in the inventory's 'Agriculture' sector.** While enteric fermentation is the largest emissions source in the 'Agriculture' sector, its relative contribution changes substantially, as do the next highest emissions sources, when agricultural emissions from the 'Land Use and Land Use Change and Forestry' (LULUCF) and 'Energy' sectors are included. Including all agricultural emissions from across sectors, agriculture contributed 5.4% of BC's total emissions in 2018.

2. **There are a number of beneficial management practices (BMPs) that could be adopted by agricultural producers to help BC meet legislated emissions reduction targets announced in March 2021**. Many of these BMPs would reduce emissions or serve as carbon sinks and would have important co-benefits for producers and/or the environment. We built a multi-criteria framework tool in Excel that can be used for evidence-based, stakeholder-involved decision making in evaluating BMPs. The multi-criteria framework systematically assesses GHG benefit, adoptability (cost, regulatory barriers), and environmental co-benefits. The tool is integrated with a pilot database of BMP performance metrics, which we developed for a preliminary set of BMPs targeting a range of agricultural emission categories.

3. **Our coarse-level estimates of GHG benefits indicate that an adoption level of 25% for the preliminary set of BMPs could reduce emissions by -359 (± 66) kt CO_2e per year, which would nearly offset emission increases observed since 2007**. Expanding the preliminary set of BMPs and refining the datasets used to estimate GHG benefits are important next steps to identify ways to increase agriculture's contribution to GHG reduction targets and reduce uncertainties in predicting real-world BMP performance. With enhanced datasets, the multi-criteria framework tool can be used to identify BMPs most likely to optimize GHG benefits while providing environmental and economic co-benefits.

4. **We provide recommendations for both immediate and long-term consideration. Including stakeholders early on in the evaluation of BMPs would likely improve their success and help identify additional BMPs for investigation.** Expansion of the BMP database and further analysis of BMPs are important next steps. Our analysis highlights the need for piloting a wide range of BMPs and incentive options in order to develop the data required for evidence-based decision making. These data are essential for the modelling, and measurement, reporting, and verification approach needed to establish accurate bottom-up emissions quantification and the long-term analyses required to identify actions for pathways to meet future targets.

Project Overview

After more than a decade of programming, British Columbia (BC) has become a national leader in agricultural climate adaptation, but the role of agriculture in meeting provincial greenhouse gas (GHG) emission reduction targets remains unclear. Until now agriculture's potential for mitigation in the province has been largely overlooked given the sector's small contribution to BC's total GHG emissions, which are typically reported to be less than four percent (BC Ministry of Environment and Climate Change Strategy, 2020). However, reductions will be required across all sectors to achieve the BC government's commitment to reduce GHG emissions to 40% below 2007 levels by 2030, and to net-zero emissions by 2050 (Climate Change Accountability Act, 2007). For the agricultural sector this can be through reducing emissions of carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O) gases emitted from soils, livestock production, and farm equipment, and by enhancing carbon sinks through increased sequestration of CO_2 in soil and woody vegetation.

While there are well-established practices and promising new technologies on the horizon that agricultural producers could adopt to help mitigate emissions, there are important knowledge gaps that need to be addressed to develop a successful provincial mitigation strategy for the agricultural sector. The availability of accurate emissions data for BC's diverse agricultural production practices is limited, making calculations for potential mitigation strategies challenging, with large uncertainties. There are also co-benefits for producers and the environment, as the management practices that reduce GHG emissions may also improve a farm's ability to adapt to climate change and/or improve the quality of air, soil, and water. However, there is currently no framework for evaluating alternative practices for their GHG benefits (emission reductions and CO_2 sinks) together with their relative cost of adoption or the potential economic and environmental co-benefits.

Project Objectives

Our team was contracted to help provide data, tools, and guidance for how agriculture could contribute to reaching provincial emission reduction targets. In this project we worked closely with the Ministry of Agriculture, Food and Fisheries (AFF) Climate Action Team (CAT) to develop the following objectives and outputs:

1. Analyze the emissions profile of the BC agricultural sector, identifying key sources of GHG emissions and sinks, and evaluate data sources, quantification approaches, and associated uncertainties.
2. Develop and apply a multi-criteria framework to systematically assess and identify agricultural practices, processes, and technologies with the greatest potential to contribute to net GHG emissions reductions and co-benefits.
3. Inform future modelling of GHG emission reductions for BC agriculture
4. Provide a set of recommendations for developing agricultural beneficial management practices (BMPs) to help meet provincial emissions reduction targets.

In meeting these objectives we have produced four reports including this one, as well as a database of BMPs, a BMP literature review in Excel, and an Excel-based multi-criteria framework tool for assessing BMPs.

British Columbia's Agricultural Emissions Profile

The BC Ministry of Environment and Climate Change Strategy – Climate Action Secretariat has prepared and published an annual Provincial Inventory (PI) since 2009. The BC PI is based on GHG emission data for BC from Canada's National Inventory, which is generated by Environment and Climate Change Canada (ECCC) and submitted each year to the United Nations Framework Convention on Climate Change (UNFCCC). ECCC provides emission estimates in a common reporting format (CRF) for five sectors: (1) Energy, (2) Industrial Processes and Product Use (IPPU), (3) Agriculture, (4) Land Use, Land-Use Change, and Forestry (LULUCF), and (5) Waste. The 'Agriculture' sector accounts for GHG emissions from the production of crops and livestock but does not include emissions from on-farm fuel use or gains/losses from carbon stored in soils and vegetation in agricultural lands; these emissions are instead reported in 'Energy' and 'LULUCF', respectively. In addition to reporting by CRF sector, the BC PI reports agricultural emission estimates by economic sector, which effectively includes emissions reported in the 'Agriculture' sector plus on-farm fuel use counted in the 'Energy' and 'IPPU' sectors. Neither of the current reporting approaches, therefore, account for changes in agricultural practices that could potentially sequester large amounts of CO_2 in agricultural soils and woody vegetation. Additionally, current provincial reporting of BC's emissions is at an aggregated level, whereby agricultural sub-sectors are grouped to sum net emissions. Having disaggregated emission data allows for more detailed understanding of emission sources and sinks attributed to agricultural practices in the province. In our accompanying *Report 1: BC Agriculture GHG Emission Profile Analysis,* we address this gap by:

- compiling available inventory, activity, and emission factor data from ECCC sources
- analyzing GHG profiles by sub-sector
- comparing emission data and methodologies from different data sources, and
- evaluating uncertainty in emission data by sub-sector and activity.

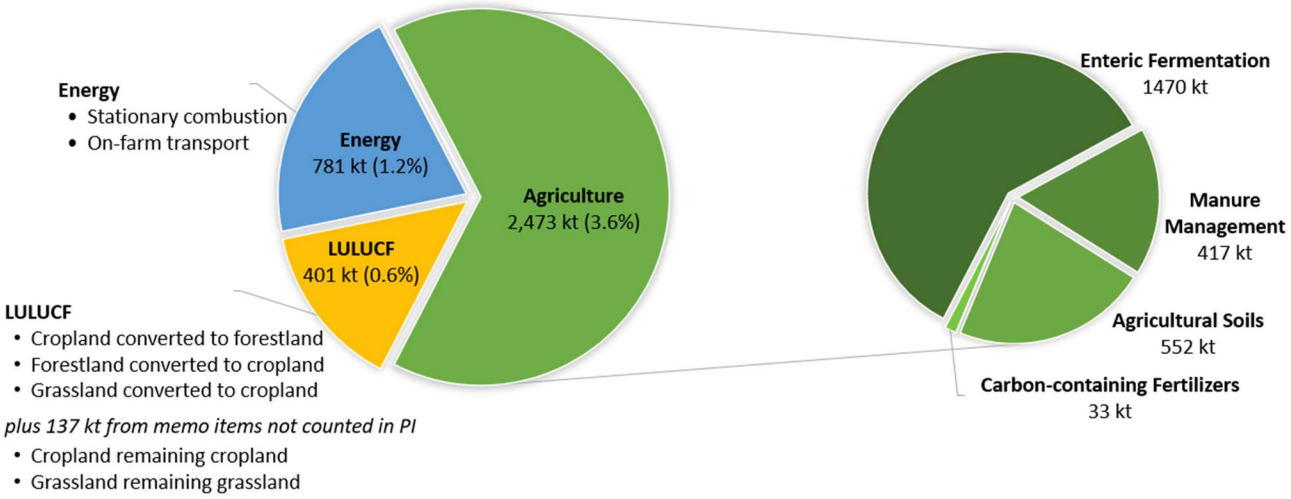

FIGURE 1. COMBINING AGRICULTURAL EMISSIONS FROM THE 'AGRICULTURE', 'ENERGY', AND 'LAND-USE, LAND-USE CHANGE, AND FORESTRY' (LULUCF) SECTORS RESULTS IN A TOTAL OF 3,655 KT CO_2E OR 5.4% OF BC'S 67,924 KT CO_2E EMISSIONS IN 2018. AN ADDITIONAL 137 KT CO_2E FROM CROPLAND AND GRASSLAND MANAGEMENT ARE REPORTED AS INVENTORY MEMO ITEMS BUT NOT COUNTED TOWARDS THE PROVINCIAL INVENTORY (PI).

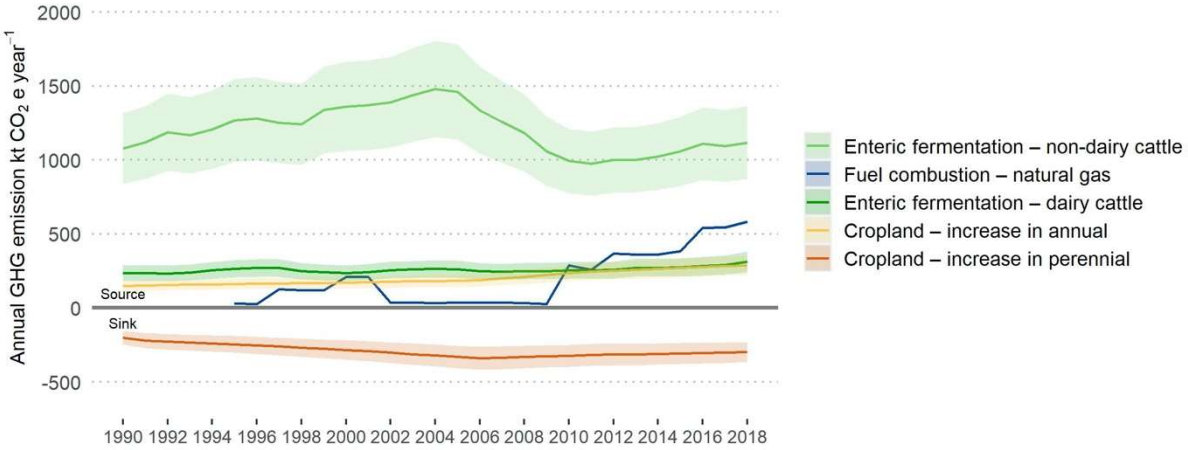

FIGURE 2. GHG EMISSIONS IN THE TOP FIVE KEY SUBCATEGORIES FROM THE AGRICULTURE, ENERGY AND LAND-USE, LAND-USE CHANGE, AND FORESTRY (LULUCF) SECTORS. SHADED AREAS INDICATE THE RELATIVE UNCERTAINTY CALCULATED FROM 2018 AND PROPAGATED FOR ALL YEARS.

The percent contribution of agricultural emissions by CRF sector to BC's total emissions in 2018 are shown in Figure 1. Following international reporting methodology for "level" and "trend" assessments we ranked disaggregated subcategories by how strongly they contributed to total agricultural emissions, and by the extent to which their historical trend differed from the total trend. We compared results based on inclusions of agricultural emissions counted in the different CRF sectors.

When the analysis is performed with only emissions from the 'Agriculture' sector, five subcategories produce 77% of emissions. The first and second largest subcategories are enteric fermentation from non-dairy cattle and dairy cattle, respectively, which together comprise 58% of emissions from 'Agriculture'. The next three top-contributing subcategories, each contributing at least 5% of emissions, are i) manure management in solid storage and drylot, ii) synthetic fertilizers, and iii) organic fertilizers.

When agricultural emissions across the 'Agriculture', 'Energy', and 'LULUCF' sectors are included, five subcategories produce 54.5% of agricultural emissions. The two subcategories of enteric fermentation (non-dairy cattle and dairy cattle) remain in the top three, but the natural gas stationary fuel combustion subcategory from 'Energy' (for heating greenhouses) contributes 12.2% as the second largest emission source overall. The next two subcategories, each contributing at least 5%, are within the 'LULUCF' sector and are due to changes in crop type: either to perennial or to annual. We applied the uncertainty ECCC calculated for 2018 to illustrate our confidence in emission estimates in the top five key subcategories (Figure 2). Notably, following these top five subcategories are three subcategories (comprising 13.6% together) related to emissions from deforestation attributed to agriculture.

Data for emission estimates for each sector are calculated primarily from activity data from Statistics Canada and emission factors compiled by ECCC from either empirical data or emission models. Given the unique and diverse agricultural production, soils, and climates in BC, we identified data and method updates that could lead to more accurate emission estimates for BC (>20 in total). Developing better BC-specific emission factors and activity data with higher spatial resolution would help improve the accuracy of emissions. Some key management options or production types that are important in BC are not reflected in the GHG inventory, such as cover crops, aquaculture, and perennial fruit production.

Multi-criteria framework to systematically assess and identify beneficial management practices for GHG benefits and co-benefits

Effective GHG reduction in the agricultural sector in BC requires an accurate understanding of the GHG benefit (GHG emission reduction + carbon sink) potential from BMPs while also considering costs and co-benefits. In our accompanying *Report 2: Multi-Criteria Framework for GHG Emissions and Co-benefits* we contribute to the development of an approach for evaluating BMPs by:

- creating a multi-criteria framework (MCF) and an associated tool based in Microsoft Excel to assess and compare BMPs across a diverse set of outcomes
- compiling a preliminary database of BMPs, starting with BMPs applicable to the largest emission subcategories from agriculture in BC identified in the work described above, and
- estimating the GHG benefit potential and co-benefits of a preliminary set of BMPs for use in the tool.

BMPs were evaluated for performance and uncertainty in 11 criteria in three criteria groups (Box 1). Through an initial review of primary and secondary literature we developed a library of BMP data focused on GHG benefit potential, while also considering costs and co-benefits. From this review we identified a preliminary set of BMPs that could address a broad range of agricultural emission sources (Box 2).

Using this preliminary set of BMPs we built a database that quantifies emission benefits at various scales, including by specific commodities (e.g. potato production or dairy cattle), emission category (i.e. Agriculture, Energy or LULUCF), greenhouse gas (i.e. CO_2, CH_4 or N_2O), or an aggregated overall GHG benefit potential (e.g. cover crops for all cropping systems). This database feeds directly into the MCF Excel tool for quantitative (GHG and cost) criteria calculations, and a comprehensive evaluation across all criteria. The methods and assumptions for calculating GHG benefits and costs are detailed in our *Report 2: MCF for BMP GHG Benefits*.

BOX 1. EVALUATION CRITERIA FOR AGRICULTURAL BENEFICIAL MANAGEMENT PRACTICES

GHG benefit criteria:

1. short-term GHG benefit potential (to meet reduction targets by 2030)
2. long-term GHG benefit potential (beyond 2030)
3. feasibility of monitoring, reporting, and verification (MRV)

Environmental co-benefit criteria:

4. soil quality
5. water quality
6. air quality
7. biodiversity / pest management

Adoptability criteria:

8. cost of adoption
9. economic risks / benefits
10. adaptation to climate change
11. regulatory barriers

BOX 2. PRELIMINARY LIST OF AGRICULTURAL MANAGEMENT PRACTICES WITH GHG BENEFIT POTENTIAL BY SECTOR

'Agriculture' – reduced CH_4 and N_2O emissions

- 4R nutrient management
- Cattle feed additive: 3-nitrooxypropanol (3NOP)
- Manure composting
- Nitrification inhibitor: dicyandiamide (DCD)

'Energy' – reduced CO_2 emissions

- Anaerobic digestion
- Best-in-class greenhouse retrofits
- Replace diesel tractors with electric

'LULUCF' – reduced CO_2 emissions and increased carbon sequestration

- Plant woody perennials – riparian and vegetative buffers on Crown and private pasture and ALR land
- Preserve forest from conversion to cropland

Combined ('Agriculture' and 'LULUCF') - reduced CH_4 or N_2O emissions and increased carbon sequestration

- Cover crops
- Rotational grazing – basic and intensive

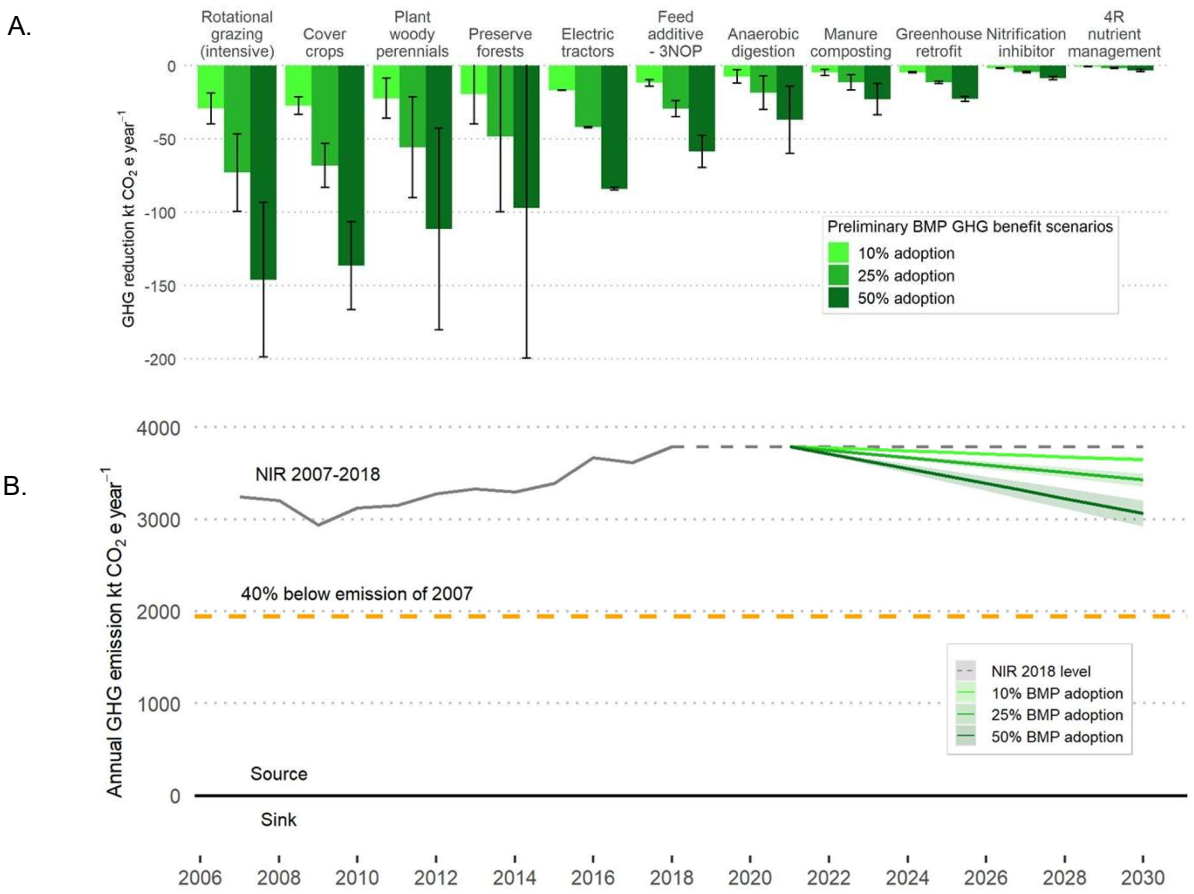

FIGURE 3. GREENHOUSE GAS BENEFIT POTENTIAL OF THE PRELIMINARY SET OF BENEFICIAL MANAGEMENT PRACTICES (A) BY INDIVIDUAL BMP AND ADOPTION RATE AND (B) BY COMBINED PROJECTED EMISSION REDUCTIONS BASED ON THREE ADOPTION LEVELS ACHIEVED BY 2030 RELATIVE TO EMISSIONS IN 2018.

Figure 3 shows our estimates of the GHG benefit of implementing our preliminary set of BMPs at different levels of adoption by 2030 (10%, 25%, and 50%) to evaluate their potential contribution to BC's target of a 40% overall reduction by 2030 from a 2007 baseline. Compared to 2018 emissions this would require a reduction of -1,849 kt CO_2e per year. Assuming a "high" adoption level of 50% for all the BMPs included in this analysis (Figure 3A), we estimate this would result in an annual GHG reduction of -718 (± 132) kt CO_2e per year, which is only a 5% reduction in emissions relative to 2007 (Figure 3B). In comparison, a more achievable adoption level of 25% results in GHG benefits are estimated as -359 (± 66) kt CO_2e per year which would nearly offset the increase in emissions since 2007. In these coarse-level preliminary estimates, most GHG benefit potential is driven by potentially large carbon sinks in soils and vegetation from rotational grazing, cover crops, and tree-planting near riparian waterways, all of which have important co-benefits.

As additional BMPs are identified, the MCF tool can be used to engage stakeholders, prioritize BMPs to develop, and provide an improved picture of agriculture's potential contribution to emission reductions. In *our Report 2: Multi-Criteria Framework for GHG Emissions and Co-benefits,* we present example results and ranking of BMP performance under different stakeholder scenarios to demonstrate the value of this approach. We provide a brief review of the MCF literature, our approach for developing the framework, and instructions to use the MCF Excel tool. We also provide a sensitivity analysis, as well as the equations and data sources used to calculate BMP GHG benefit potentials and determine criteria scores.

Modelling of GHG emission reductions for BC agriculture

Modelling agricultural GHGs in BC can be used to improve understanding GHG benefits of BMP options and inform long-term mitigation plans. Modelling can also help with the measurement, reporting, and verification (MRV) of emission benefits from BMP implementation. Various agroecosystem models have been used at a national scale for a number of emission categories, but there has been little work in BC to use them locally. Modelling is inherently complex, and particularly for BC agriculture given the diversity of production types, soils, and climates across the province. In our accompanying *Report 3: Agroecosystem Models for Greenhouse Gas Emissions and Co-benefits,* we provide guidance on developing provincial modelling by:

- compiling a comprehensive list of potential models
- evaluating these models for suitability and effectiveness for modelling agricultural GHG emission reductions based on key criteria co-developed with AFF
- providing a detailed assessment of the most suitable models, including model assumptions, required parameters, and limitations, and
- recommending a workflow for developing a database that would enhance the integration of empirical data for modelling across the province.

BOX 3. CRITERIA FOR REVIEW OF GHG MODELS

1. Capable of simulating a wide variety of cropping systems found in BC
2. Can be calibrated for BC's climate and soil properties and to accommodate project level simulations for ground truthing
3. Can be used to meet the provincial and national reporting requirements
4. Can be integrated with other models to simulate environmental co-benefits and/or economic performance
5. Provides a user-friendly interface suited to non-scientific users

We reviewed models mainly designed to capture biogeochemical processes related to field production and thus primarily applicable to emissions from 'Agriculture' and 'LULUCF', and not 'Energy'. Our review started with a broad overview of ecosystem models which we narrowed to 40 models applicable to agriculture. We evaluated 16 of these options for their capacity to model agroecosystem processes beyond GHG emissions, including nitrogen and phosphorus dynamics, hydrology, and crop yield. We identified five models that are most likely to meet the criteria outlined by AFF: HOLOS, COMET-FARM, CFT-GHGs, DNDC v.CAN and DayCent/ Century.

Photo credit: Sustainable Agricultural Landscapes Lab

All of the models considered have features and components that are applicable to simulating conditions of the agroecosystems located in the province. Despite this broad applicability, all models have limitations. The result of our review suggests that no single model is ideal, and further comparison and actual testing of our shortlisted models for BC should be a priority next step. It is probable that multiple models will be needed to effectively simulate the GHG benefits and co-benefits for various BMPs that could be deployed across BC's diverse agricultural production.

Conclusions, recommendations, and roadmap for agriculture's role in meeting BC emissions targets

In the six months of this project, we were able to start some of the detailed review and analysis required for developing an effective strategy for BC agriculture to reduce GHG emissions.

While the sector's emissions are small compared to other industries (e.g. oil and gas), reductions can certainly be achieved in the near-term. Our analysis of a preliminary set of BMPs shows that at an ambitious level of adoption (i.e. 50%) agriculture will only achieve modest reductions. This will inevitably be a challenging adoption target for some of these BMPs without substantial incentives, given added costs for producers. Other BMPs, however, may result in improved farm efficiencies and will be easier to promote and achieve higher rates of adoption.

Our analysis of these BMPs was based on limited data, and many calculations have extremely high uncertainties. In the absence of rigorous data for these BMPs, we have used a conservative approach to estimate GHG benefits; a more detailed analysis would likely result in larger estimates. Clearly, additional BMPs need to be identified and/or developed.

Targeting well-established BMPs and larger agricultural operations for adoption may result, initially, in larger GHG benefits; however it is also likely that targeting a diversity of BMPs and a combination of operation sizes will be important given the diverse nature of agriculture in BC.

Developing incentives appropriate for different BMPs, and operation sizes and types could help to reach the greatest number of innovators or early adopters while also addressing issues of equity and diversity in the agricultural sector. Given that many BMPs are likely to have important additional co-benefits for society and the environment, bundling incentives to address benefits beyond reducing GHGs could help maximize their adoption.

Immediate next steps

1. Increase expert and stakeholder involvement: Including experts from various stakeholder groups could help identify additional BMPs or refine our preliminary GHG estimates and associated performance data. Including stakeholders early in the process of BMP development and assessment is likely to increase their successful adoption.

2. Explore additional practices that could contribute to climate benefits: An expanded literature review and query of provincial scientists working on GHG emissions will improve the resolution of the BMP database and help include a wider range of locally-appropriate BMPs. It is likely that additional empirical or modelled data will be required to establish an effective BMP database. Priority should be placed on reducing the uncertainty on "high-risk but high-return" BMPs, such as planting and conserving woody perennials (trees and shrubs) on agricultural land.

Through expert and stakeholder involvement and further literature review, co-benefits could be evaluated with improved site- and industry-specific resolution. Developing cost abatement curves for BMPs would substantially enhance the trade-off analysis capabilities of the MCF and help guide consideration of possible incentives. We recommend further collaboration and integration with groups like Farmers for Climate Solutions to capitalize on important synergies with national BMP development and accounting efforts, and development of a more robust BMP database and the appropriate online infrastructure to house it.

3. Incorporate spatially-explicit analysis: This would enable a comparison of BMP performance within a region to determine which BMPs are best suited for local conditions and commodities, and lead to more accurate GHG benefit estimates. Alternatively, spatially-explicit data could be used to prioritize regions across the province for BMP investment. Incorporating this type of data could be done simply by

expanding the BMP database using activity data from Statistics Canada and climate- and soil-specific emission factors by eco-region and allocating these by region in the BMP database. This approach could be enhanced substantially by integrating the MCF with a geographical information service and by making the tool available online, although this could limit future updates to the MCF tool to more expert programmers and modellers. Further refinement could include the integration of biophysical models.

4. Develop a GHG emissions database: Researchers across the province have been collecting GHG emission and related data for decades, yet only a limited amount of these data are available in the published literature. Developing a database to house and securely share empirical data would substantially improve a provincial BMP database and enhance the utility of future modelling efforts. These data would include production outcomes for crop or livestock systems (e.g. yield), management information (e.g. inputs), economics (e.g. costs of inputs), soil properties, GHG emissions, and other environmental impact data (e.g. leaching). Required input variables for the database could be selected once the models have been identified. The BC Agricultural Climate Adaptation Research Network (ACARN) has developed a database infrastructure that would be suitable for housing this type of data immediately.

Considerations for BC's Roadmap to 2030

1. Pilot BMPs and incentive options: One of the primary limitations for providing effective scientific guidance on how to meet emissions reduction targets is a lack of data. Piloting BMPs and various incentive options under field conditions as demonstration and research will likely be a key source of needed data for evidence-based decision making. Piloted BMPs and incentives will need to be chosen and deployed strategically as BMPs have a wide range of performance outcomes that depend on production type, soil, management, and climate, and the effectiveness of an incentive will vary by BMP. Given that much of the research will take years, and the process of increasing adoption rates is likely to be slow, large-scale promotion of appropriate practices is needed immediately to develop the data required for accurate quantification and provide real-world examples for producers to see and evaluate.

2. Develop a measurement, reporting, and verification approach: It is critical that any GHG reduction initiative includes a robust measurement, reporting, and verification (MRV) approach. Given our lack of empirical data on BMP performance specific to BC, MRV will ensure that anticipated GHG benefits are actually being achieved and can be counted towards any emission reduction targets. As more region-specific empirical data become available, BMPs can be re-assessed and re-prioritized using the MCF. Additionally, an effective MRV approach can leverage field demonstration and research trials to establish quantification methods and parameterize and validate models that can project GHG benefits and co-benefits across regions and over time.

3. Build capacity to transition to a "bottom-up" accounting of emissions: In order to include many of the potential agricultural BMPs in emission reduction strategies, quantification of their emission reductions needs to be aligned with international reporting requirements. Given that provincial and national emission reporting is based largely on activity data acquired through a "top-down" national census, an alternative approach would be necessary to develop a robust incentive and reporting system that is adaptable to local data as it becomes available. Options for collecting these data, for example through the Environmental Farm Plan or the Agricultural Land Use Inventory, need to be investigated, developed, and tested.