Advancing Soil and Crop Management Practices to Achieve Net-Zero Emissions from Agricultural Landscapes Across Canada

Background

This project proposal is being submitted to the Natural Sciences and Engineering Research Council (NSERC) and the Social Sciences and Humanities Research Council (SSHRC) under the Sustainable Agricultural Research Initiative (SARI) program. This program supports university-led research to “initiate or accelerate the development of solutions that will be required for a sustainable, resilient and profitable agriculture sector in a net-zero economy”. In doing so, this program will assist the federal government meet its goal of achieving Net-Zero Emissions of Greenhouse Gases by 2050. This is a $72M research program, and it offers up to $8M over 4 years to teams of researchers to facilitate their work with collaborators and partner organizations.

Proposal

The rationale for the proposed research

Historical soil and crop management practices have resulted in the degradation of agricultural land across Canada. In particular, intensive cultivation has caused severe soil erosion on hilly land, resulting in massive losses of organic-rich topsoil on hilltops and the accumulation of this eroded soil at the bottom of hills. Consequently, soil erosion and how it is managed impacts the production and sequestration of organic carbon (OC) and the production and emission of greenhouse gases (GHGs: CO_2, CH_4, N_2O).

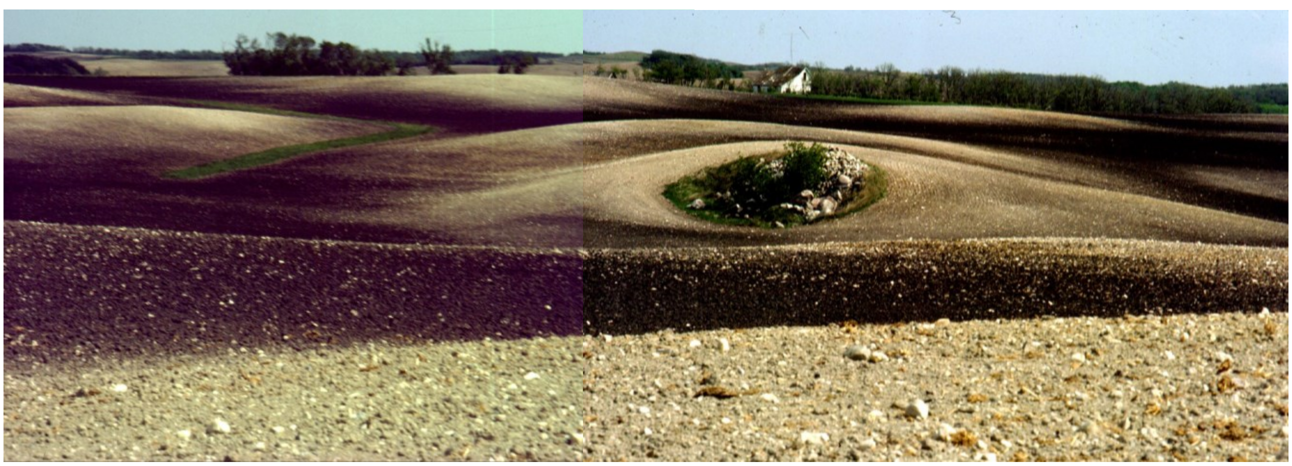

Figure 1. Severely eroded cultivated cropland in Saskatchewan in the 1980s. This figure illustrates the nature of the situation described. It shows the distribution and severity of soil losses and accumulations within hilly land used for crop production in the 1960s through the 1980s when, so-called conventional tillage practices dominated nearly all forms of crop production on nearly all cultivated land across Canada.

Severity of soil loss

Areas of fields that are moderately to severely eroded have experienced rates of soil loss greater than 11 t ha^{-1} yr^{-1} (Moderate = 11-22 t ha^{-1} yr^{-1}, High = 22-33 t ha^{-1} yr^{-1}, Very High = >33 t ha^{-1} yr^{-1}) over many years (Lobb et al. 2010, 2016, 2023). Sustainable rates of soil loss in Canada are considered to be below 6 t ha^{-1} yr^{-1}, less than 3 t ha^{-1} yr^{-1} on sensitive soil-landscapes. The long-term consequence of such high rates of soil loss is the complete removal of the original topsoil and the exposure of subsoil (cumulative losses and gains of 30-60 cm, and sometimes in excess of 100 cm), dramatically altering the nature of the soil; reducing the soil’s ability to produce crops. Tillage erosion, the progressive downslope movement of soil during tillage, is recognized as the primary cause of this soil erosion in cultivated, topographically complex (hilly) landscapes, with annual rates of soil loss on hill tops typically exceeding 50 t ha^{-1} yr^{-1}, often exceeding 100 t ha^{-1} yr^{-1} (Lobb 2011). Wind and water erosion degrade the soil as it is transported within a field and they can remove the soil from a field as sediment. In contrast, the soil eroded by tillage is removed from convex areas (hill tops) and accumulates on concave areas (hill bottoms): there is no net loss at the field scale. In general, the natural variability of soil properties within a field becomes dramatically amplified over time (Lobb 2011). At such high rates of soil loss, the soil can become moderately to severely degraded in a few decades, as has been the case across much of Canada.

Extent of soil loss

The cropland area in Canada that is currently being moderately to severely eroded is estimated to be 10% (3.7 M ha of 35.2 M ha in 2016), even with widespread adoption on soil erosion control practices (Lobb et al. 2023). In the past, as much as 40% (14.7 M ha of 39.8 M ha in 1981) of the cropland area was being moderately to severely eroded during the peak use of conventional (intensive) tillage practices in the 1970s and 1980s. Importantly, the cumulative losses from the past largely persist and continue to be expressed as very low soil organic matter levels, crop growth and grain yields (typically 30% lower than non-eroded areas). Equally important, most of the eroded material is simply moved within the landscape and much of it will have accumulated in concave areas (lower slopes), which are estimated to be 10 to 20% of the cropland area.

Cost of soil loss to farmers

This loss of topsoil is estimated to result in about a 10% loss in Canada's total crop production, about $3B per year (2016 $) (Lobb 2017, Badreldin and Lobb 2023). Even with the widespread adoption of soil conservation practices over the past 40 years, this 10% loss of crop production has remained roughly the same (less area, but more severely eroded), and with increasing levels of crop production and market values over this period, the cost of lost topsoil has increased three-fold from about $1B per year since the 1980s (2016 $). This loss is a serious threat to Canada's food security and to the wellbeing of individual farms, farm communities and the agriculture industry. Similar observations and conclusions have been made in the northern United States (Thaler et al. 2021), and in both cases soil loss by tillage erosion was identified as the major cause of the economic loss.

Impacts on OC sequestration and GHG emissions

The soil moved by erosion is rich in organic carbon and nitrogen, and the subsoil exposed is poor in organic carbon and nitrogen and often rich in inorganic carbon. The impacts of soil erosion on OC sequestration and the emission of GHGs are understudied and, therefore, not well understood, but it is certain that the impacts are massive when examined at a farm scale and an industry scale (or landscape and national scale) (Lobb et al. 2003). In areas of soil loss, OC is below the soil's natural capacity; this creates the potential to increase and stabilize OC in these areas. However, this potential may never be realized because of the depressed ability of the eroded soil to produce organic matter through plant growth. The burial of OC in areas where the eroded soil is accumulating in the landscape represents a tremendous amount "sequestration" as the buried OC is largely removed from the biological processes that produce GHGs at or near the surface (Lobb and McConkey 2006). The increased variability in soil properties and biological capacity increase inefficiencies in crop production inputs such as nitrogen, increasing the likelihood of N_2O losses in the areas where eroded soil, nutrients and increased runoff water are concentrating in the landscape.

The benefits of soil conservation and restoration

There are significant opportunities to improve soil and crop management practices to conserve soil OC stocks across all agricultural landscapes, and to increase these stocks in substantial areas of most landscapes – because most landscapes have been moderately to severely eroded. In stopping soil erosion (conservation), the soil variability within the landscape that contributes to conditions resulting in GHGs emissions will not increase and, therefore, GHG emissions should not increase. In reversing soil erosion (restoration), the soil variability within the landscape will decrease; it will become more uniform and stable in its soil properties, making greater and more efficient use of nitrogen and moisture and increasing its photosynthetic capacity, which should reduce the potential for GHG production and emission.

Selected soil and crop management practices

This project focuses on the use of soil and crop management practices in eroded landscapes as a means to achieve net-zero emissions. The management practices being studied for their potential to increase sequestration of OC in soil and reduce emission of GHGs from soil, are:

(i) **enhanced conservation tillage** to reduce soil erosion and prevent further degradation;
(ii) **advanced cropping practices** to produce more organic matter for the soil;
(iii) more effective utilization of on-site and off-site **alternative organic matter sources**; and
(iv) the novel soil management practice of returning eroded soil from areas of accumulation to areas of loss – **soil-landscape restoration**.

Research Approach

To maximize its impact, the project focuses on the use on practices on hilly farmland that has been eroded from past management, which is the majority of the agricultural landscapes in Canada. The research will be carried out in three predominant cropping systems across the county: wheat–canola production in Western Canada, corn-soybean production in Central Canada, and potato-barley production in Eastern Canada. Importantly, the research will be performed on farmers' fields that reflect the variability in soils and crops typical of these regions. Research activities will be focused at four universities: University of Alberta, University of Manitoba, University of Guelph, and Dalhousie University, and involve a team of 17 researchers from the natural and social sciences. Assembled into 6 coordinated and integrated Research Themes (RTs), exploring many research questions through the efforts of 6 postdoctoral fellows, 18 PhD students, 17 MSc/MA students and many graduate and undergraduate student research assistants. The proposed research builds upon a preparatory project funded by NSERC, which facilitated valuable consultation with many industry and government stakeholders. A board consisting of these stakeholders will oversee the design and execution of the project, with an interest in mobilizing the knowledge gained to all stakeholders, including individual farmers and academia.

Objectives / Outputs

The objectives of this research are: (i) To assesses the potential agronomic, environmental and economic performance of these soil and crop management practices on eroded landscapes. For these practices, we will provide more comprehensive, accurate and precise **data for use in modelling net emissions of GHGs**. (ii) To assess the relationships between soil erosion and their performance in these landscapes. This will provide the means to **scale of application/impact across the country**. (iii) To understand how knowledge is transferred through the industry and farming communities, what are the drivers that transform information into innovation and action and knowledge information and, what makes programs and policies effective in transforming agriculture management. This will provide a means to assess the **extent and rate of application/impact through communities**. All three outputs are required to assess progress towards the goal of net-zero emissions by 2050. Recommendations will consider these practices in an **integrated approach** – which of the practices, where and by whom, and, if possible, in the context of other practices and programs.