GLOBAL SYMPOSIUM ON SOIL ORGANIC CARBON, Rome, Italy, 21-23 March 2017

Monitoring, reporting, and verification of soil carbon sequestration on the cropland and grassland of Canada

Brian G. McConkey[1], Denis Angers[2], Darrel Cerkonwiak[3], Émilie Maillard[2], and Jianling Fan[1]*

[1]Agriculture and Agri-Food Canada, Swift Current, SK, Canada, *brian.mcconkey@agr.gc.ca and jianling.fan@agr.gc.ca
[2]Agriculture and Agri-Food Canada, Québec, QC, Canada, denis.angers@agr.gc.ca and emilie.maillard@agr.gc.ca
[3]Agriculture and Agri-Food Canada, Saskatoon, SK, Canada, darrel.cerkowniak@agr.gc.ca

Abstract
From 1990 to 2014, Canada has achieved soil organic carbon (SOC sequestration of 267 Mt of CO_2e in its cropland. This sequestration has reversed much of past land degradation and was largely the result of reducing the frequency of bare fallow and reduced tillage intensity. There are still opportunities to increase sequestration by converting more land from intensive to reduced tillage and by increasing C input to the soil through increased productivity, having more crops with relatively greater C input, and extending period of vegetation growth, such as from cover crops after annual crop harvest. Estimating SOC change on extensive grasslands is more difficult because of the difficulty of monitoring grazing practices and relatively poor understanding of rates SOC change in response to drivers. Meta-analyses across the available scientific literature have not resolved these challenges so more research is needed to develop a workable monitoring, reporting and verification (MRV) system for grasslands. The existing and potential Canadian MRV systems from of SOC change on agricultural land should be widely applicable to countries like Canada where the area of agricultural land is relatively large compared to the size of national economy and so where it is extremely difficult to economically justify monitoring by direct measurement of SOC change.

Keywords: SOC, model, cropland, grassland, measurement, sequestration, fallow, tillage

Introduction, scope and main objectives

Canadian farmers, supported by the Federal and Provincial governments, have had a long standing goal to sustainably achieve high soil quality. Soil organic carbon (SOC) content is an important measure of soil quality as it is related to fertility, structure, and resilience. In the past several decades the value of increasing SOC, or soil carbon sequestration, as a means to remove atmospheric CO2 has become more important. Canada developed an indicator of SOC status on croplands in late 1990s based on modelling with the Century model (McCrae et al. (eds). 2000. AAFC Publ. No. 2022/E). Under the United Nations Framework Convention on Climate Change (UNFCCC) puts an obligation on to report carbon stock changes. For its National Inventory Report of Greenhouse Gas Emissions under the UNFCCC, Canada developed a more rigorous estimation system also based on the Century model. This presentation provides an overview of the current reporting of SOC sequestration in Canada and challenges and opportunities for improving monitoring, reporting, and verification (MRV) of croplands and grasslands.

Methodology

Carbon changes for croplands are based on applying carbon change factors derived from the Century model to areas causing SOC change: land-use changes, changes in area of bare fallow, changes between annual and perennial crops, change in tillage practices, and changes in woody biomass crops such as fruit trees (Environment and Climate Change Canada. 2016. National Inventory Report 1990–

2014: Greenhouse Gas Sources and Sinks in Canada). These areas are monitored over time through survey and census. The C change factors have been validated against observed values from a pre-existing network of long-term field experiments in Canada. Meta-analyses of results of studies in the literature have been used to investigate opportunities for improved MRV of SOC of grasslands (Wang et al. 2016. Nature Scientific Reports, DOI: 10.1038/srep33190; Maillard et al., 2017. Agriculture, Ecosystems, and Environment, DOI: 10.1016/j.agee.2016.11.0).

Results

Canada has 52Mha of agricultural land, 45.4 Mha of cropland spread across the entire country and 6.6 Mha of permanent grassland (rangeland) in the semiarid western regions. Fig. 1 shows the general change in SOC across Canada in 2014. The Prairie region in western Canada accounts for 81% of cropland and its soils are predominantly sequestering SOC so it has a 2014 sequestration rate of 18.8 Mt $CO_2e\ yr^{-1}$. The sink in the prairies is primarily from reduction in fallow and reduction in tillage intensity. In contrast, the rest of Canada has many areas that are estimated to be losing SOC so it was net C source at a rate of 3.5 Mt $CO_2e\ yr^{-1}$.

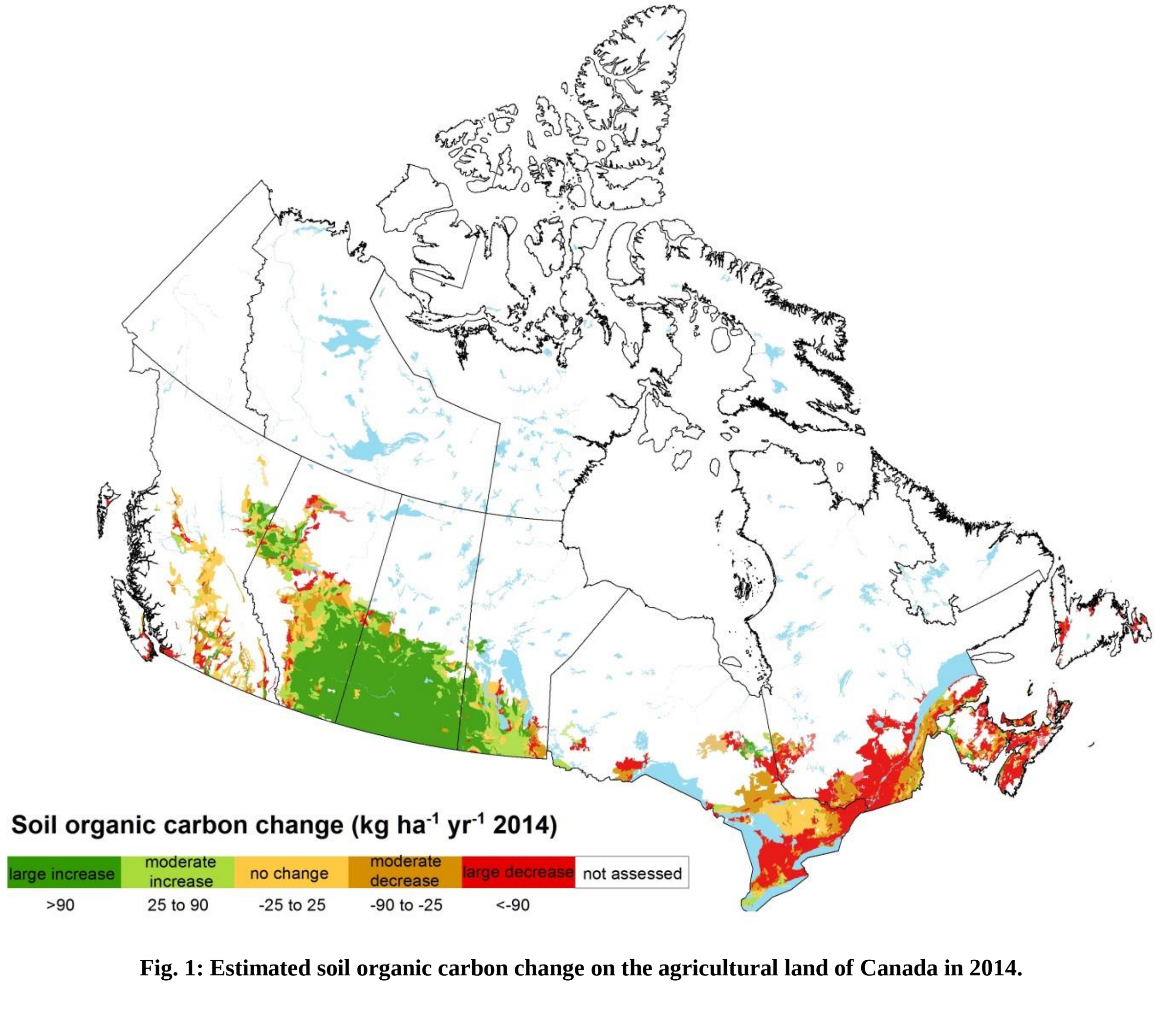

Fig. 1: Estimated soil organic carbon change on the agricultural land of Canada in 2014.

Canadian permanent grassland is overwhelming used to produce beef cattle. Meta-analysis has shown that compared to a continually ungrazed state, grazing grasslands increases SOC by 19 (Wang et al.

2014. Rangeland Ecology and Management, DOI: 10.2111/REM-D-14-00006) to 72 kg ha^{-1} yr^{-1} (Wang et al. 2016. Nature Scientific Reports, DOI: 10.1038/srep33190). However, there is insufficient data to develop an obvious relationship between C sequestration and particular soil state-grazing management systems. Further meta-analysis revealed that validating the expected small changes in SOC change for grassland is difficult due to the high spatial variability that reduces the power for detecting SOC change (Fig. 2). The variability increases with area of grassland and depth of measurement.

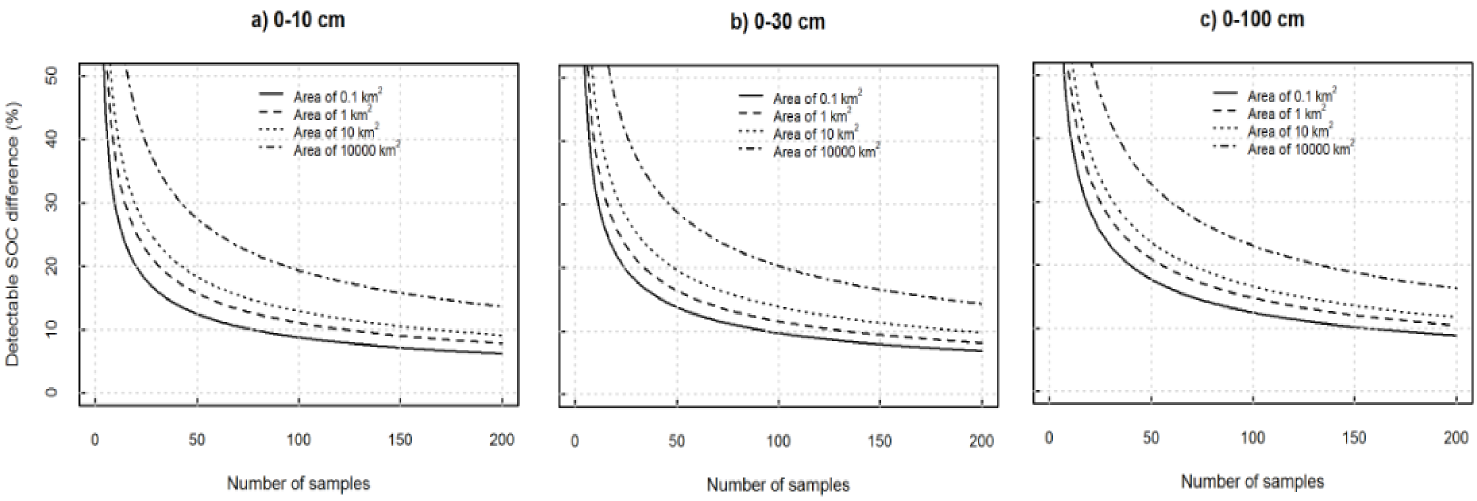

Fig 2: Detectable SOC difference for grasslands as a function of sample size, grassland area, and depth of measurement (adapted from Maillard et al., 2017. Agriculture, Ecosystems, and Environment, DOI: 10.1016/j.agee.2016.11.024).

Discussion

The large sink in the Prairies is attributed to the fact that those soils were degraded due to frequent bare fallow and intensive tillage during most of the 20th Century. Currently no-till is practiced on 62.3% of cropland in annual crops and, due to climatic and soil conditions, there is limited potential for further increases of no-till. The area of bare fallow has decreased from 8.0 Mha in 1990 to 1.2 Mha in 2014. Hence the major sink on croplands is expected to slowly decrease over time as soils move towards new equilibrium. There are still opportunities to change from intensive tillage to reduced tillage systems. The areas of declining SOC are attributed primarily to areas where there has been widespread switch from perennial pasture and forage to annual crops. This reflects a change for mixed livestock-crop farming to more crop-only farming. The adoption of practices to reduce or halt the SOC decline, such as reduced tillage and use of cover crops after harvest, is warranted. Research is underway to address the deficiency that the current methodology does not account for changes in C input to cropland. Crop yields are increasing by about 1.8% per year. An important factor for increasing C input has been the rapid increase in canola (*Brassica* spp), whose area has grown from 2.5 Mha in 1990 to 8.4 Mha in 2014. Compared to traditional crops, canola provides about 50% more C input per ha due to its large root system and low proportion of grain in above-ground growth. Given the large area of agricultural land relative to the Canadian economy, there is no appetite to invest in national systems to directly monitor SOC change on Canada's cropland using measurement. The C change factors derived from modelling are a convenient and transparent estimate of C change and have been used to calculate carbon footprints of specific agricultural products and in trading systems for emission offsets of C sequestered in cropland. Canada plans to continue to rely on MRV systems based on monitoring cropland management practices and using process modelling to estimate the SOC change. Canada's investments in MRV of cropland SOC status has enabled more informed decision making regarding soil management practices and policy.

Estimating SOC from Canadian grasslands remains a challenge. Observed SOC sequestration from grazing has been attributed to recovery from a more degraded soil condition that existed in first half of 20^{th} Century. Heavy grazing reduces the plant community condition and diversity but, because it results in shift to grass species that put more C below ground, there is no clear relationship with SOC change. Moderate to light grazing intensity is normal practice because that provides resiliency in grazing resources to manage regular droughts. There may be C sequestration opportunity from increasing grazing intensity from light to moderate. Grazing practices have been shifting towards more frequent movement of herds between pastures. This intersperses short periods with heavy grazing intensity with longer periods without grazing on each pasture. This combination has been shown to increase productivity and resilience as well as enable grazing pressure to be better matched to the characteristics of each pasture. Due to individual differences in grazing preferences, labour availability, livestock watering availability, and pasture characteristics, the range of grazing management practices is increasing. As a result, monitoring grazing systems is becoming increasingly difficult and SOC change needs to be considered for more individual pastures within a single grazing system. Based on the global meta-analysis, developing C change factors based on observation alone is unlikely given the low power of detecting SOC change (Fig. 2). Most Canadian grassland soils contain more than 30 Mg ha^{-1} in upper 30 cm so detectable SOC changes will only be evident after many decades assuming rates of C sequestration from good grassland management are not greater than 100 kg ha^{-1} yr^{-1}. There are continuing increases in capability of remote sensing from satellites with more frequent passes, more types and capabilities of sensors, and greater spatial resolution. More research is needed to the feasibility of monitoring grasslands with remote sensing and linking the monitored condition to SOC change. To validate the SOC change, one potentially effective approach is to develop an accompanying network of carefully designed experiments to understand and quantify SOC change on grassland and the relationship with monitored condition from remote sensing. Given the challenge to measure small changes in SOC on grasslands, there needs to be careful science to develop powerful sampling strategies for SOC change within any experiment network.

Conclusions

The Canadian experience shows the feasibility of a system for estimating SOC change on cropland based on 1) monitoring land management practices through survey and census, 2) modelling C change factors for areas of change of practices, and 3) validating modelled C factors with results from a national network of long-term experiments. The basic information to include changes in C input (type of crop, crop yield, and amount of livestock manure applied to cropland) is also available or can be estimated from available data that is monitored.

In contrast to cropland, Canada does not yet have a working system for estimating C sequestration on its extensive permanent grasslands. A potentially feasible system is one based on combining information from remote sensing with C change estimates related to state and/or changes in apparent grassland utilization and state. This system will require validation from a network of carefully designed experiments to capture SOC change that occur over decade or less.

Canada's investments in MRV of SOC status of agricultural land has enabled more informed decision making regarding soil management practices and policy. We believe that the existing and potential Canadian systems from MRV of SOC change on agricultural land should be widely applicable to countries like Canada where the area of agricultural land is relatively large compared to the size of national economy and so where it is extremely difficult to economically justify monitoring by direct measurement of SOC change.