THE KYOTO PROTOCOL AS A MECHANISM FOR IMPROVING SOIL QUALITY: CARBON MANAGEMENT ON THE NORTHERN GREAT PLAINS OF CANADA

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Abstract
Carbon (C) sequestration is one of the mechanisms for mitigating atmospheric greenhouse gases (GHG) in the fight against global climate change. In addition, a large number of other agricultural and environmental benefits can be linked to C sequestration in soils, including reduced rates of soil erosion, more efficient nutrient cycling, and reduced risk to water quality. In this paper we examine how policy aimed at enhancing "sinks" to help Canada reduce GHG emissions can also reduce the risk of agricultural impact on soil and water, and help with the transition to a more environmentally sustainable production system.

Additional Keywords: sequestration, land management, climate change, greenhouse gas

Introduction
The United Nations Framework Convention on Climate Change (UNFCCC) was negotiated in 1992 with the aim of stabilizing concentrations of GHG in the atmosphere at a level that would prevent anthropogenic interference with the climate system (UNFCCC, 1992). In order to do that, the 188 nations that ratified the Convention committed to more than reducing emissions of GHG - under Article 4 of the Convention, Parties agree to promote sustainable management and conserve and enhance sinks and reservoirs of GHG. Thus, to fully implement the UNFCCC and its subsidiary agreement, the Kyoto Protocol, the signatory countries have to protect and enhance the soil organic matter stored in croplands - of one of the world's largest reservoirs of GHG.

Agronomists and farmers have long recognized the connection between organic matter content and the fertility, resilience to degradation, and productivity of a soil. In fact, most of the research that has led to our understanding of the dynamics and management of soil C was undertaken with the aim of maintaining or increasing crop yields, or preventing soil degradation that would lead to reduced yields. We are beginning to understand that how croplands and their reservoir of C and nutrients are managed has broader environmental implications than crop productivity, including the link between land management and global climate change (Janzen, 2001). As Barry Commoner's (1971, pp. 33-48) second "law of ecology" succinctly puts it: "everything must go somewhere" - and for much of the C and nitrogen that was "lost" from croplands, that somewhere was the atmosphere.

Throughout most of agriculture's history, human populations were small and compared to the natural forces that control the global cycles of C, nitrogen, water, etc., their capacity to "modify" the environment was weak. Gradually however, as human populations have grown and the energy of fossil fuels was harnessed to technologies, including those of agriculture, the impact of human activities has come to rival that of nature. One of the consequences has been the GHG effect, which may lead to global change that we are unable to prevent or control, and cannot even predict. As Goody (2002) has observed, we cannot "justify a claim to any quantitative knowledge of climate 50 years from now – except perhaps that anthropogenic activity will result in changes, and we may be surprised by what those changes are".

However, linking land management and air quality in an international agreement like the UNFCCC might be an indication that as a global community we are beginning to understand the implications of John Muir's words written in almost a century ago: "When we try to pick out something by itself, we find it hitched to everything else in the universe" (Muir, 1911). The challenge is to learn how to act on the UNFCCC, not just for the sake of averting climate change, but in order to promote sustainable management. In developing policy and strategies for agriculture in response to emission reduction commitments, it is important not to lose sight of the purpose of agriculture. Farmers manage land, natural capital (solar energy, precipitation) and manufactured (nitrogen fertilizer, tillage equipment) inputs for the purpose of harvesting food and fibre, ideally in a manner that is sustainable in the long-term. If the creation of a market for C credits establishes a dollar value for sequestered C and makes crop production practices that enhance and maintain soil organic C more profitable and therefore used by more farmers, the market mechanisms of the Kyoto Protocol will have fulfilled their function. However, farmers are not in the C sequestration or GHG emission reduction business – they are in the business of producing crops (Janzen, 2001). An important job of researchers and policy makers is to help them do that profitably and with minimum impact to the environment both on and beyond the farm.

If we are creative and serious, we can find economical ways of reducing GHG emissions from agricultural in order to minimize the potential for climate change. However, since the residence times of the GHG in the atmosphere are decades to centuries, it is likely that no matter how successfully societies mitigate GHG emissions, farmers will still also have to adapt to climate change. We need to increase our understanding of how farming systems are buffered against climate change and future uncertainty, and how they can be made more resilient.

Land Management and Carbon Sequestration on the Canadian Prairies

Most of Canada's agricultural land, about 80%, is in the Northern Great Plains region, so efforts toward GHG mitigation and adaptation to climate change have to include strategies that are suited to the prairie region and its production systems. Removals of carbon dioxide (CO_2) from the atmosphere through C sequestration (sinks) in croplands offers significant mitigation potential, especially in short and medium terms.

The Northern Great Plains, or prairies, is a region of young soils and young agriculture. The landscapes were formed in the glacial deposits of the Pleistocene continental glaciation. The glaciers retreated ~10,000 years ago and were replaced by forests and then grasslands vegetation, which combined with the mineral-rich glacial parent materials to produce the region's fertile soils. European settlers, arriving at the turn of the 20th century, began transforming the grasslands into croplands, a process that was almost complete by mid-century.

In the agroecosystem, the rates and patterns of energy and matter exchange among the soil, air and water are profoundly different than those of the grassland ecosystems. In grassland, the amount of CO_2 converted into plant biomass by photosynthesis is in balance with the amount of biomass that decays and is emitted as CO_2 – additions and losses are in balance over time. Conversion of grasslands to cropland destroyed that balance. Organic matter losses were accelerated and biomass additions declined, leading to net emissions of CO_2 to the atmosphere and a loss of organic C. One of the major factors that causes an accelerated rate of organic matter loss is tillage, which breaks down stable structures and mixes the soil, exposing the soil organic matter to rapid consumption and release as CO_2 by microorganisms. At the same time, the harvest and export of crops reduces the amount of biomass returned to the soil. Within the first decades of prairie conversion to agriculture, about one-third of the soil organic was emitted to the atmosphere; where it has joined the other GHG added to the atmosphere by human activity that now threaten to "feedback" as climate change.

Managing croplands to sequester carbon dioxide

Remove strategies involve a shift from conventional to sink-enhancing practices that reverses the net flow of C from the atmosphere to the soil. CO_2 from the atmosphere is transferred, by photosynthesis, into plant biomass and from there into a C reservoir, such as soils or trees. Some potentially sink-enhancing land use and land management changes suitable for prairie agriculture include: converting poor quality cropland to perennial crops, eliminating summerfallow or reducing its frequency, converting from conventional, high disturbance tillage to reduced or zero tillage, increasing the proportion of perennial forages grown in crop rotations, supplying adequate nutrients through chemical or organic fertilizers, producing green manure or cover crops in cropping systems, improving the management of grazing lands and preventing overgrazing, and planting trees for shelterbelts, agroforesty or plantations. Janzen *et al.* (1998) provide a comprehensive review of management effects on soil organic C storage for prairie croplands.

Within the first couple of decades of prairie agriculture, soil scientists and agrologists knew that the rich stores of organic matter in prairie soils were being rapidly depleted by the early cropping practices. Systems of continuous cropping and reduced tillage were developed and recommended, but they were not taken up by farmers because they were not as profitable as conventional systems based on tillage and summerfallow (Janzen, 2001). It was only in the 1980s and 1990s, with the development of effective direct-seeding technology and low-cost herbicides that continuous cropping and zero tillage systems have become profitable. Since 1990 there has been a ~32% increase in zero tillage, a ~20% increase in perennial crops and a decline of ~40% in summerfallow acreage (Statistics Canada, 2002). These changes were made too late to avert organic matter loss but are well timed for GHG mitigation - estimates based on the C sequestration coefficients in Table 1 indicate that prairie croplands have been a net sink for CO_2 since about 2000 (Boehm *et al.*, 2004).

Table 1. C sequestration coefficients (Mg CO_2 ha^{-1} yr^{-1}) for selected prairie activities

	Prairie Soil Zones[1]		
Activity	**Brown**	**Dark Brown**	**Black**
Adoption of zero tillage	-0.73	-0.73	-1.34
Reduce Summerfallow	-0.15	-0.16	-0.08
Permanent Cover	-0.88	-1.15	-3.30

[1]Zero tillage and summerfallow coefficients (McConkey *et al.*, 1999); permanent cover coefficients (Smith *et al.*, 2000).

Not all soils will automatically gain C under zero-tillage or continuous cropping. It depends on the C state when the change in land management occurs (Paustian *et al.*, 1998). Most prairie croplands have the capacity to sequester C because they lost so much under past management, but it is unlikely that they will ever (or at least in the next decades) store as much C as grasslands. Thus, croplands will not be able to recover total soil emissions, but they can “remove” from the atmosphere some of the CO_2 emitted from soils over the past century. Given the benefits to both soil and air quality, we should take advantage of opportunities to restore soil C, even though the GHG mitigation potential is limited and will not offset emissions from combustion of fossil fuels or other human activities.

Carbon sequestration and soil quality

Soil organic C is probably the most universal indicator of soil quality for crop production, because it affects so many other chemical, physical and biological properties of the soil: plant nutrient levels, soil structure, water-stable aggregates, tilth, water holding capacity and the efficacy and fate of applied pesticides (Boyle et al., 1989; Larson and Pierce, 1991; Granatstein and Bezdicek, 1992; Ismail *et al.*, 1994). Cropping systems that enhance soil organic matter also tend to increase yields and biomass production, crop residue at the soil surface (Janzen *et al*, 1988; Bruce *et al.*, 1990; Carter, 1992; VandenBygaart *et al.*, 2003) and the size and stability of aggregates, whereas they tend to reduce soil erosion (Layton *et al.*, 1993; Six *et al.*, 1998, 1999; Bossuyt et al., 2002; Díaz-Zorita and Grove, 2002; Lützow *et al.*, 2002). As a result of their stable supply of biologically active and nutrient-rich organic matter (Janzen et al, 1987b, 1998; Campbell et al, 1991c), these soils support a large and stable microbial population and a greater nutrient cycling capacity that soils that are losing C (Hendrix et al, 1988; Carefoot et al, 1990; Havlin et al., 1990; Rasmussen and Parton, 1994). At the same time, they tend to be less “leaky” because nutrients are protected from loss by immobilization in the microbial biomass (Janzen *et al.*, 1987a, Nyborg and Mahli, 1989; Wood *et al.*, 1991; Haugen-Kozyra *et al.*, 1993).

The traditional wheat-fallow system of the driest parts of the Canadian prairies was designed to conserve water, but it had, in fact, a low water storage efficiency (Tracy *et al.*, 1990) whereas practices that enhance and maintain soil organic C tend to increase the water storage capacity (Peterson *et al.*, 1968; Bauer and Black, 1981; Emerson *et al.*, 1986). That is crucial on the Prairies where a growing season moisture deficit makes crop productivity dependent on the soil's store of available water. As soil organic C increases so do pore size, infiltration rate and available water holding capacity (Nyborg and Mahli, 1989; Carefoot *et al.*, 1990; Tracy *et al.*, 1990; Dao, 1993). Since more water is held in the soil, less water (carrying nutrients, soil particles and pesticides) leaks from the croplands into surface and ground water. Research is showing that over time, the hydrology of continuous-cropping and reduced tillage systems begins to resemble that of the grasslands. By holding more water on the cropland, some water bodies, especially small sloughs, ponds and ephemeral streams that formed as an artifact of agriculture may disappear (Hayashi *et al.*, 2003; Kamp *et al.*, 1999, 2003). However, it might also reduce wildlife habitat, which might limit the variety and size of some wildlife populations.

Carbon sequestration and air quality

Although rates of C accumulation vary depending on the form of the sequestered C, the magnitude of the land management change and the inherent productivity of the site, the IPCC (2000) Special Report on Land Use, Land-Use Change and Forestry concluded that there is large potential for CO_2 removals in agricultural land because areas involved are so extensive. For example, if cropland on the Canadian prairies managed under zero tillage, continuous cropping and permanent cover continues to increase at current rates, and C sequestration occurs at the rates given in Table 1, croplands could go from emitting 6 Tg CO_2 yr^{-1} in 1990 to removing about 10 Tg CO_2 yr^{-1} in 2008 (Boehm *et al.*, 2004). The removals more than offset the increase in emissions for the period, mainly from greater livestock production and N fertilizer use, such that total net agricultural emissions would decline from 54 Tg CO_2–Eq yr^{-1} in 1990 to 52 Tg CO_2–Eq yr^{-1} 2008. If the rate of adoption of sink-enhancing practices doubled removals could reach 30 Tg CO_2 yr^{-1} on a net basis (Boehm *et al.*, 2004).

Removals differ from emission reductions because removals are not permanent (sequestered C can be re-released to the atmosphere if land management reverts to practices that accelerate C losses relative to additions) and the soil's capacity to store C is finite. So, even though to the atmosphere, a CO_2 removal is the same as an emission reduction, their roles in GHG mitigation policy, especially in the long-term, are different.

Carbon sequestration and GHG mitigation policy

The international negotiations stalled in 2000 and 2001 over the issue of accounting for C sequestration in croplands, grazing lands and forests under the Kyoto Protocol. Parties from the EU and many developing countries argued that because of non-permanence, as well as issues related to measurement uncertainty, scale, and natural affects, the inclusion of sinks would undermine the environmental integrity of the Kyoto Protocol. Other Parties, including Canada, the U.S., Japan, Russia, New Zealand and Australia, negotiated in favor of including sinks in the Kyoto Protocol. They argued that since emissions of CO_2, CH_4 and N_2O from crop production are covered under the Protocol, removals should also be included to balance the account and to signal to land managers the importance of maintaining and enhancing sinks and reservoirs of C, as required under the UNFCCC. The Parties in favour of sinks did not question the validity of the concerns, but argued that they could be managed.

Non-permanence: Biological sinks, like C sequestration in agricultural soils, are not permanent. Carbon sequestered in soils can be released if soil management reverts to previous practices in which the rate of organic C loss from the soil exceeds the rate of additions. Reversibility is addressed in the Marrakesh Accords (Decision 11/CP.7 in FCCC/CP/2001/13/Add.1) by ensuring that once land is brought into the system for accounting of removals, it must be clearly identifiable, remain in the accounting system for all subsequent commitment periods. All emissions and removals resulting from human activities must be accounted for, including any release of CO_2 for which a credit was claimed in a previous period.

Ironically, removals in croplands might be at risk from the effect they are intended to mitigate - climate change. Although opinion is still divided, a warming of the climate could release C sequestered in soil by accelerating C losses and reducing biomass additions. In temperate regions, where low temperatures limit biological activity for much of the year, warming could increase the rate at which organic matter in soils is decomposed. At the same time, warming could increase the rate of evapotranspiration and the severity of the growing season moisture deficit, which might cause a decline in crop and biomass production.

Measurement: Uncertainty, Monitoring, and Verification: The Special Report on Land Use, Land-use Change and Forestry (IPCC, 2000) concluded that it is possible to measure, monitor and verify changes in soil C stocks with reasonable certainty. Canada is developing a protocol, the National Carbon and Greenhouse Gas (GHG) Emission Accounting and Verification System (NCGAVS), for estimating the amount and uncertainty of C stock changes and GHG emissions from agricultural activities at the landscape, provincial, regional, and national scales as part of the Land Use, Land-Use Change and Forestry Measurement, Accounting and Reporting System (LULUCF MARS) of Canada's National GHG Inventory. NCGAVS links land use and management databases to ecological models and temporal and spatial scaling processes to provide transparent and verifiable estimates of net emissions of GHG from agriculture. The C and N cycles are closely linked in soils, so it is important to understand mitigation in terms of the dynamics of both cycles and their interaction. Although this is a challenge because the processes that govern N_2O emissions from agricultural soils are highly spatially and temporally variable (Lemke *et al.*, 1998; Rypdal and Winiwarter, 2001; Brown *et al.*, 2001) and the measurement uncertainty is greater than for changes in soil C content, NCGAVS will also provide estimates of N_2O emissions.

Scale: The issue of scale arises because of the concern that credits for removals of CO_2 from the atmosphere into terrestrial sinks will reduce the amount of emission reduction Parties require to achieve their Kyoto targets. Some groups do not accept that removals provide the same atmospheric benefit as emission reductions. Canadian analyses indicate that C sequestration will contribute less than about 10% of Canada's effort to meet its Kyoto target. Crediting agricultural sinks does not mean that Canada (or probably any country) can meet its target without also achieving large emission reductions. What it does offer is an opportunity for balanced C accounting and to signal to land managers the importance of maintaining and enhancing sinks and reservoirs of GHG.

Natural and indirect effects: The final concern is that countries will get credit for C sequestration resulting from natural and indirect effects, such as CO_2 fertilization. Indirect and natural effects are difficult to measure and partition from other productivity factors (Lemon, 1977; IPCC, 2000). The IPCC report on LULUCF suggests that separation of natural from direct and indirect human effects can be approximated by the application of model-based inference, measures on control plots, or development of "natural-plus-indirect" background corrections (IPCC, 2000). The IPCC has been asked to work toward development of practicable methodologies for factoring out direct human-induced changes from indirect and natural effects, but because methodologies are currently lacking, they may not be available for the first commitment period.

Role of C Sequestration – Some Final Thoughts

Croplands should be managed to maintain and enhance organic C stores and the whole range of environmental benefits those practices offer – improved soil and air quality and reduced risk to water quality. However, C sequestration by itself cannot mitigate GHG emissions for the agriculture sector. If society is serious about reducing emissions, methods of reducing the N_2O and CH_4 emissions from primary crop production are needed in the medium-term, and renewable sources of energy to replace fossil fuels are needed in the long-term.

Soil scientist and agronomists have enthusiastically embraced the inclusion of sinks in the UNFCCC and Kyoto Protocol because it provides another reason to manage land to enhance soil organic C. The interesting new mechanisms for achieving improvements in air quality through better land management provided by the UNFCCC and Kyoto Protocol should be fully exploited, but we need to be realistic about how much C sequestration can contribute to long-term climate stabilization. The more difficult research and policy problem might be finding long-term GHG abatement strategies for reducing emissions from crop production or finding replacement for fossil fuels. It would not be prudent to overestimate the mitigation potential of sinks and underestimate the research investments those endeavors will require if society is serious about finding long-term solutions.

Ultimately, farmers are not in the business of C sequestration or GHG emission abatement. They are in the business of managing land to produce crops, or other commodities such as C credits, with the aim of adapting to pressures and sustaining production over the long-term. Since the residence times of the GHG in the atmosphere are decades to centuries, no matter how much GHG emissions are reduced over the next decades those pressures will probably include climate change. We need to increase our understanding of how farming systems are buffered against climate change and how they can be made more resilient. Does C sequestration offer some buffering against drought or warming and reduce the vulnerability of croplands to climate change? Will climate-warming cause a release of soil C, either by accelerating the rate of organic matter decomposition or reducing biomass production? If society shifts to an energy economy based on biomass rather than fossil feedstocks, can croplands produce enough biomass to maintain soil C and fuel an energy system?

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