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Research article

Carbon dynamics on agricultural land reverting to woody land in Ontario, Canada

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ABSTRACT

The 2015 Paris Agreement reinforces the importance of the land sector and its contribution to greenhouse gas (GHG) reductions. Thus, there is growing interest in improving estimates of the GHG balance in response to land-use changes (LUCs) involving agriculture and forestry, for national-scale reporting, and for carbon (C) offsets. Large agricultural areas in Europe, Russia and North America are reverting to forest, either naturally or through planting, after abandonment of agricultural land, and this trend may have a substantial impact on carbon budgets. We report results of a pilot project in the Mixedwood Plains ecozone of eastern Canada to analyze the change in the C budget on a landscape over 15 years on abandoned cropland where woody vegetation is regenerating. Thirty-six plots (2 km × 2 km) with paired aerial photographs taken circa 1994 and circa 2008 at a scale of 1:10,000 or larger were randomly selected from the 20 km × 20 km National Forest Inventory (NFI) grid. A spatially-explicit version of the Carbon Budget Model of the Canadian Forest Sector (CBM-CFS3) was used to estimate impacts of LUC on C stocks and fluxes. Polygons identifying areas of LUC within each photo plot were delineated, classified, and evaluated to provide input data for the model. The rate of C accumulation in our study area was found to be relatively constant over the entire simulation period, at 1.07 Mg C/ha/yr. Abandoned agricultural land reverting to woody lands could play an important role in regional and national C sequestration in Canada, but more research is required to quantify the areal extent of this LUC.

1. Introduction

The 2015 Paris Agreement of the United Nations Framework Convention on Climate Change (UNFCCC) reinforces the importance of the land sector and its contribution to greenhouse gas (GHG) reductions. Thus, there is growing interest in improving estimates of the GHG balance in response to land-use changes (LUCs) involving agriculture and forestry, for national-scale reporting, and for quantifying mitigation opportunities. Such assessments should be conducted at the landscape rather than site scale, hence, landscape assessment is the focus of the pilot study described here.

Conversion of native forest land to agricultural use, i.e. deforestation, is one of the most common and widespread LUCs (Foley et al., 2005) which, alongside agricultural land abandonment and reversion to forest cover, can impact carbon (C) budgets. Based on satellite derived land-cover data, historical land-use data, and global ecosystem modeling, an estimated 385–472 million ha of agricultural land have been abandoned globally between 1700 and 2000 (Campbell et al., 2008). Across much of Europe, as well as eastern North America, forest clearing for agricultural purposes has been followed by widespread agricultural abandonment and forest recovery (Flinn and Vellend, 2005; Birdsey et al., 2006). Estel et al. (2015) estimated that 46.1 Mha of farmland have been permanently abandoned across Europe. Schierhorn et al. (2013) estimated that 31 Mha of farmland have been abandoned in European Russia, Ukraine, and Belarus alone.

In Canada, farming and other land uses have greatly altered much of the landscape in populated areas, and most of the

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productive fields cleared for agriculture are still being farmed. However, many have been abandoned over the past 50 years as a result of changing agricultural practices, urban encroachment, and poor productivity. For instance, in eastern Canada (Ontario, Quebec, and the Atlantic provinces) 35% of farmlands were abandoned between 1951 and 1991 (Parson, 1999), while in the province of Quebec, 5% of farmlands were abandoned between 1997 and 2007 (Vouligny and Gariépy, 2008; Statistics Canada, 2012).

Our landscape-scale study focuses on abandoned agricultural lands reverting to woody lands in forested or treed areas common in the Mixedwood Plains ecozone in the provinces of Ontario and Quebec (Agriculture and Agri-Food Canada, 2014; Huffman et al., 2015). We refer to these lands as "agricultural to woody LUCs". We did not study prairie ecosystems or forest-grassland ecotones, where the natural vegetative cover is grassland. When fields are abandoned they can revert to forests, either through natural succession or through management actions, such as planting of trees. Agricultural land that has been abandoned and revegetated results in C sequestration at the site level (Harmer et al., 2001; Tremblay and Ouimet, 2013; Huffman et al., 2015; Amichev et al., 2016). However, assessment of the C balance at the landscape-scale, such as the 85,000 ha in the Mixedwood Plains of Ontario used in this study, also requires accounting for C losses in other areas due to removal of trees and conversion of land from woody vegetation to agricultural production. Thus, reliable estimates of terrestrial C sources and sinks at regional and local scales are required to account for their spatial variability, and to improve our understanding of the contribution of finer-scale activities to national or global C budgets (Crevoisier et al., 2006; Gerbig et al., 2003). Methods must be developed to facilitate scaling of results from site to national scales.

Field and modeling studies (Morris et al., 2010; Tremblay and Ouimet, 2013) have shown that afforestation, either by planting or natural succession in marginal agricultural or grassland sites, is an important mechanism to increase C uptake. Van Minnen et al. (2008) evaluated the effectiveness of C plantations of coniferous and deciduous trees around the world to decelerate atmospheric C accumulation by comparing the net ecosystem productivity (NEP) of plantations with natural succession in the same areas. The topic has not been extensively studied in Canada, with the exception of one study comparing C accumulation in plantations with natural succession on fallow lands over 50 years in Quebec, using vegetation and soil sampling. The study found that plantations had a C accumulation rate of about 1.7 Mg C/ha/yr higher than that of abandoned agricultural lands (Tremblay and Ouimet, 2013). On abandoned agricultural land in Ontario, soil C (top 10 cm) has been shown to increase at ~10 g C/m^2/yr over chronosequences spanning 80–100 years (Foote, 2007). In another study at three sites with different soil types in mature temperate forests in southern Ontario, C accumulation occurred mainly (~37%) in the aboveground biomass (Foote and Grogan, 2010).

In Canada, to comply with the UNFCCC reporting requirements, three federal government departments collaborate to produce GHG estimates for the annual national inventory report (NIR). Agriculture and Agri-Food Canada (AAFC) estimates annual GHG emissions on agricultural land, the Canadian Forest Service (CFS of Natural Resources Canada) estimates forestry-related sources and sinks, and Environment Canada develops annual estimates for trees in urban areas (settlement land) (Environment Canada, 2016). Since Canada has chosen 1 ha as the minimum area to be considered a forest, considerable areas of woody vegetation on managed agricultural land do not meet the definition of a forest. These include individual rows and clumps of trees and shrubs within agricultural land, and on abandoned agricultural land that is reverting to woody land. Hence, this woody biomass is currently excluded from inventory reporting to the UNFCCC. AAFC estimates of GHG sources and sinks on agricultural land include estimated woody biomass changes for orchards and vineyards, but not changes in other woody vegetation associated with cropland, such as clusters of trees and shrubs, treed windbreaks, or shelterbelts. Historically, for C storage reporting purposes, the net effects of the change in land-use of agricultural land to and from woody land have been considered C-neutral at the national scale, albeit with potentially significant regional effects (Kurz and Apps, 1999). The types of land-use changes of agricultural land to and from woody lands are the subject of this study.

AAFC and CFS collaborated on this pilot project in the Mixedwood Plains ecozone, with the objective to analyze annual change in C emissions and removals on lands moving between cropland and forest land (i.e., agricultural to woody LUCs), as well as to analyze continuous C accumulations on woody lands. Our study goals complement those of a previous study (Huffman et al., 2015) that focused on biomass stocks and their dynamics on Canada's cropland (including orchards and vineyards), as well as measuring their contribution to the national C balance. Other analyses have looked at the contributions of shelterbelts (Amichev et al., 2016).

2. Material and methods

Carbon dynamics were simulated using the Carbon Budget Model of the Canadian Forest Sector (CBM-CFS3; Kurz et al., 2009; Kull et al., 2016), the core model used by the CFS for reporting on GHG emissions and C stocks in the managed forest area of Canada (Stinson et al., 2011; Environment Canada, 2016). Until recently, CBM-CFS3 projects represented space as polygons of various sizes; however, this study used a recently developed system to apply the CBM-CFS3 to raster-based, spatially-explicit modeling. This new modification of the model is ideal for evaluating LUCs between agricultural and woody land because it can accommodate the small spatial units associated with these types of LUCs.

2.1. Data

Intersection points from the 20 km × 20 km National Forest Inventory grid (Gillis et al., 2005) were chosen at random, and federal and provincial archives were searched for pairs of high-quality aerial photographs at a scale of 1:10,000 or larger for the two times of interest (T1, circa 1994 and T2, circa 2008, two times for which high quality imagery was available). Thirty-six 2 km × 2 km photo plots were chosen (Fig. 1) within the Ontario portion of the Mixedwood Plains ecozone. For each photo plot, land-use categories were visually identified by an interpretation specialist, digitized, represented as a complex of polygons (Fig. S1), and summarized by T1 and T2 classes. Detailed methods are described in Huffman et al. (2015). The total area of the land use categories was 1190 ha.

2.2. Assumptions

Soil and forestry maps, reports, and expert knowledge were used to develop assumptions for soil and disturbance types, and leading tree species and their associated yield curves (JWRL Geomatics Inc., 2013; Huffman et al., 2015). As described below, data for the LUC polygons identified within each photo plot were processed to provide input to the CBM-CFS3 spatial modeling system.

2.2.1. Disturbance events

Within the 36 photo plots, we analyzed land-use categories and LUCs that could be associated with changes in woody-related C,