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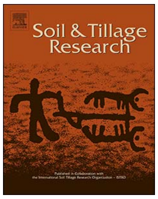

Crop rotation, tillage system, and precipitation regime effects on soil carbon stocks over 1 to 30 years in Saskatchewan, Canada

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ABSTRACT

For both agronomic and environmental purposes, it is relevant to assess the effect of various land management practices on soil organic carbon (SOC). In the North American Great Plains, fallowing was used to increase soil water storage and production of succeeding crops. In addition, tillage was done to prepare seed beds and to control weeds. But these management practices led to important SOC losses, mainly due to increased mineralization with tillage and reduced plant C inputs with fallowing. In recent years, reduction of fallowing, use of minimum and no-tillage management practices and diversification of crop rotations with the inclusion of pulse crops have been studied. But the results are variable according to soil and climatic situations. In addition, long-term data are not always available. In this context, the objective of the present work was to assess over time the effects of cropping systems involving the use of various tillage management, the presence or absence of fallowing (1981–2011), and the presence or absence of pulse crops (1997–2011) on plant C inputs and SOC stocks along a 0–30 cm silt loam soil profile at Swift Current, SK. First changes between SOC stocks were apparent five years after the start of the experiment involving changed crop systems and mainly in the surface 0–7.5 cm soil layer instead of 0–15 cm or 0–30 cm soil profiles. This study confirmed the accumulation of SOC under continuous wheat systems in comparison to fallow-wheat rotations, probably related to larger C inputs in the continuous wheat systems. Although the effect of tillage was quite scattered in time, it seemed to be more pronounced in the fallow-wheat rotations than in the continuous wheat systems, with higher SOC stocks with no tillage. Then, the replacement of fallow phase by pulse crops offered promising potential to rebuild SOC stock after fallow-wheat rotations, even if its efficacy might depend on the initial SOC content and/or its combination with a tillage reduction. Finally, even if a kind of equilibrium could set after changes from a traditional fallow wheat rotation, the SOC dynamics might be highly influenced by precipitation regime and all the carbon accumulated for decades could be lost in few years (less than five in this study). Indeed, in this semi-arid prairie, the increase of the apparent decomposition with precipitation exceeded that of the plant biomass C inputs.

1. Introduction

Soil organic matter and consequently soil organic carbon (SOC), its main component, are important for soil fertility and productivity, through their effects on physical, biological and chemical properties (Stevenson, 1994). In addition, in the context of climate change, there has been an increasing interest in estimating soil organic carbon (SOC) changes, as these changes affect the rate of accumulation of atmospheric carbon dioxide (Janzen, 2004). Consequently, for both agronomic and environmental purposes, it becomes essential to better understand the effect of various land management practices on SOC stocks.

In the North American Great Plains within Canada, water availability is the main constraint to crop production (Campbell et al., 2005). With the aim of maintaining water and controlling weeds, the traditional cropping systems involved frequent summer fallowing with extensive use of mechanical tillage for weed control during the fallow year (Curtin et al., 2000). Despite short-term enhanced crop yields (McConkey et al., 2012), these systems resulted in substantial decrease of SOC storage as a consequence of reduction of plant C inputs during the fallow year (Lemke et al., 2012), increase of soil erosion (Sainju et al., 2009) and organic matter decomposition promoted by frequent tillage (Curtin et al., 2000). This decreased SOC storage was coupled with a depletion of plant-available nutrients and decrease of overall soil productivity and environmental quality (McConkey et al., 2012). In recent years, significant changes in land management practices

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occurred. Potential ways to improve biological and economical sustainability of cropping systems included the adoption of no-till, annual cropping and the introduction of alternative crops into wheat-based rotations (Machado et al., 2015).

In literature there are contradictory results on the time of recovery of SOC stocks after the implementation of new practices, e.g., like continuous cropping sequences or no tillage. For example, Norton et al. (2012) concluded that significant SOC increases especially in slow and passive pools, after 12 yr of no-till continuous cropping were important indicators of recovery of soil quality in a relatively short period. However, after 18 years of management, Halvorson et al. (2016) were not able to detect meaningful differences in SOC among their treatments in contrast to their initial hypothesis that soil C would be increased more by continuous cropping compared with those having fallow. Curtin et al. (2000) hypothesized that the time necessary for the recovery of SOC stocks with no tillage compared to conventional tillage depend on crop rotation but also on climate. SOC response to tillage and cropping frequency seem to be variable according to the climate with greater SOC gain with no-till than tilled systems irrespective of cropping frequency in semi-arid prairie soils but a more obvious difference in SOC gain with continuous wheat in sub-humid prairie soils (Campbell et al., 2005). Consequently, there is a relevance to pursue studies on the effect of land management practices in different climatic zones. Moreover, these elements underline the necessity of carrying out long-term studies to better evaluate the dynamics of SOC change after the establishment of new practices. Another key role of these studies is to provide long-term information on the biological and economical sustainability of new cropping systems for growers who can be still skeptical (Machado et al., 2015). In recent decades, the areas of oilseed and pulse crops have increased as a consequence of the promoted development of new markets and perspective of better economic returns. But long-term effects of the replacement of fallow by pulse crops into wheat-based rotations on SOC stocks are not well known. Some studies report a SOC increase after the inclusion of pulse crops in cereal rotations (Robertson et al., 2015; Venkatesh et al., 2017) or no effect on SOC (Robertson et al., 2015). But to our knowledge, studies focusing specifically on the effect of the replacement of fallow by pulse crops are scarce and do not necessarily address SOC (e.g. Nielsen and Vigil, 2017).

In addition, in semi-arid climates, the influence of precipitation on the C balance is complex (Shrestha et al., 2013). Biological activity can vary hugely from year to year depending on precipitation including that which is stored from precipitation falling in period when low temperatures severely constrain activity. In experimental plots planted with big sagebrush or with crested wheatgrass located in Idaho (USA), Campos et al. (2017) observed enhanced decomposition rates with increased precipitation applied in the growing season and enhanced soil C stabilization with precipitation applied in the dormant season. In semi-arid temperate steppe of northern China, Zhao et al. (2016) concluded from their results that soil C release might increase under future precipitation increase scenarios. More studies are necessary to better understand the effects of the precipitation regime on the C balance in semi-arid climates.

In this context, the main objective of the present work was to assess the effects over time of different crop rotations involving the use of various tillage management, including the presence or absence of fallowing (1981–2011), and the replacement of fallow with pulse crops (1997–2011) on plant C inputs and SOC stocks for the 0–30 cm soil profile at Swift Current, SK. A secondary objective was to examine how SOC stock changes were affected by the overall precipitation regime.

2. Material and methods

2.1. Site and crop system description

The field site is located at the Agriculture and Agri-Food Canada Research and Development Centre near Swift Current in Saskatchewan, Canada (50°16′N, 107°44′W) within a cool temperate and dry climatic zone (IPCC, 2006), with mean annual temperature of 3.3 °C and mean annual precipitation of 334 mm (McConkey et al., 2003). The silt loam soil belongs to the Swinton series and is classified under the Canadian system as an Orthic Brown Chernozem (Classification Working Group, 1998), Haplic Kastanozem under the FAO system. The experiment was initiated in 1981 on wheat stubble as a randomized complete block design with four replicates. Plots were 15 m wide by 76 m long (Curtin et al., 2000). In the previous 70 to 80 yr, the land has been managed in a fallow-wheat rotation using conventional tillage methods (Curtin et al., 2000), which was the predominant farming system in the Brown soil zone. The soil prior to the initiation of the experiment had 32.6% sand, 27.6% clay (McConkey et al., 2003), 1.19 g cm^{-3} bulk density, and 6.5 pH at the 0–15 cm depth (Campbell et al., 1995).

In 1982, five cropping systems were implemented in a randomized complete block design with four replicates. There was wheat-fallow (FW) rotation under three levels of tillage: (no-tillage (NT), minimum tillage (MT) and conventional tillage (CT)). Both rotation phases were present each year. The two last cropping systems were continuous wheat rotations under no tillage (CW-NT) and minimum tillage (CW-MT). For the FW systems, the CT system involved spraying of an herbicide in the fall plus two to four tillage operations during the fallow period using a heavy duty cultivator and/or rodweeder, plus a single tillage operation with a heavy-duty cultivator and mounted harrows immediately before seeding with a hoe drill. The MT system involved herbicides for initial weed control (until July), followed by one or two tillage operations in July-August period with a heavy-duty cultivator or wide-blade cultivator, plus a single tillage operation with a heavy-duty cultivator and mounted harrows immediately before seeding. Finally, the fallow-wheat rotation under NT had a fall herbicide plus two to four applications as required during the fallow period. Wheat was direct seeded without seedbed preparation. The NT systems also received periodic post-harvest glyphosate treatments when required for control of foxtail barley starting in 1996. Concerning the continuous wheat, the CW-MT system involved one annual tillage, prior to seeding, using a heavy duty sweep cultivator with an attached rodweeder or mounted harrow, whereas the CW-NT system was direct seeded and included occasional post-harvest herbicide. The CW-NT system received annual glyphosate application for initial weed control.

In 1997, all the plots were split in two with one half maintained as the previous cropping system and the other half with a new one implemented. In the present article, only two new cropping systems originated from the split of the FW under CT and NT were considered. These new cropping systems were a pulse crop-wheat (PW) rotation under two levels of tillage: (NT, MT). Both rotation phases were present each year. The pulse crop varied between pea (1999, 2000, 2003, 2004, 2005, 2007, 2008, 2011) chickpea (1997, 1998, 2001, 2002) and lentil (2006, 2009, 2010). The PW-NT was on the previous FW-NT, and the PW-MT was on the previous FW-CT. Tillage practices for PW were similar to those for respective tillage systems for CW. The PW-NT follows typical farm behaviour in the area where tillage intensity was reduced first and then the rotation was made continuous and more diversified. Hard red spring wheat was sown at a rate of 67 kg/ha; common contemporary cultivars were used so there were several changes over time. Wheat was harvested at full maturity using a conventional, direct-cut header combine and the crop residues were returned to the soil. Fertilizer N was applied based on fall soil test. Fertilizer P was seed-placed, and prior to 1996, N was split between seed placed and broadcast before 1997. From 1997 onwards, all N had been side-banded 2–3 cm below and to the side of the seed row. Since 1996, the FW-MT and FW-NT also received additional 25 kg N/ha beyond recommended to investigate if extra N would enable these systems to make better use of observed better conserved soil water and to overcome the protein deficit compared with FW under conventional tillage (McConkey et al., 1996).