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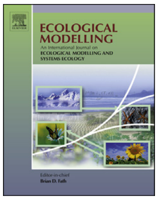

Simulating soil organic carbon changes across toposequences under dryland agriculture using CQESTR

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ABSTRACT

Soil organic carbon (SOC) and its management under dryland cropping systems are very critical for both crop productivity and environment health. The objective of this study was to evaluate the performance of CQESTR, a process-based C model, in simulating SOC changes across toposequences of selected fields and agriculture management practices along a precipitation gradient in a dryland region of Oregon, USA. Geo-referenced soil samples were collected from summit (SU), shoulder (SH), backslope (BS), footslope (FS), and toeslope (TS) positions during early 1980s and early 2000s. Simulation scenarios were developed based on field management practices, crop rotations, soil properties, and climatic data. CQESTR simulated results were compared with the measured SOC from each landscape position. Significant ($P < 0.0001$) correlations ($r = 0.93$) were found between the measured and the simulated SOC at SU, SH ($r = 0.91$), BS ($r = 0.83$), FS ($r = 0.89$), and TS ($r = 0.89$). The smallest correlation value at BS could be from soil deposition due to erosion. No significant changes in SOC were found between SU, SH, BS, and FS landscape positions; however, TS had the highest SOC ($10.8 \pm .8\,\mathrm{g\,C\,kg^{-1}}$). CQESTR successfully simulated SOC at most of the studied sites and landscape positions, except at TS for a location with high annual deposition of C-rich soil eroded from the upper landscape position. CQESTR could be used to predict SOC changes across toposequence and at the landscape scale level with reasonable accuracy. The results were supported by a linear relation with an r^2 of 0.89 and a low mean square deviation (MSD = 0.24) between the measured and the simulated SOC.

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1. Introduction

Cropland soils can be a source or sink of carbon dioxide (CO_2). Carbon dioxide fluxes are often inferred based on changes in measured carbon (C) stocks (Mosier et al., 2006). The global SOC pool is large although it is uncertain, with estimates ranging from 500 to 3000 Pg (10^{15} g) C (Scharlemann et al., 2014). Carbon sequestration in plants and soils is considered an important process in reducing net emissions of carbon dioxide (CO_2) to the atmosphere. Storing carbon in soils through sequestration not only reduces the emissions of CO_2 and increases the total content of soil organic matter (SOM) and associated SOC but also it improves soil health, air and water quality, increases crop yield and sustains agricultural production (Post and Kwon, 2000; Lal, 2002, 2004; Cai and Qin, 2006; Powlson et al., 2011). The loss of SOM from soils following conversion from native prairie or forest to crop production is well documented (Follett et al., 1997; Janzen et al., 1998; Paustian et al., 1998; Rasmussen and Albrecht, 1997; Lal et al., 1999; Bellamy et al., 2005; Leite et al., 2009; Plaza et al., 2012). Using historical records Liebig et al. (2005) estimated an average loss of SOC in the northwest USA region at $12.1 \pm 7.9\,\mathrm{g\,C\,kg^{-1}}$ soil for soil depths $\leq$30 cm. Lal et al. (1998) estimated the total C released by land use change at ~117 Pg. The magnitude and rate of SOC loss from cropland are influenced by C inputs, soil texture, degree of soil disturbance, SOC status prior to cultivation, erosion, and climate. Reversing SOC loss through C sequestration is being recognized as critical for long-term soil sustainability, meeting rising global food, feed, fiber, and fuel demands, as well as reducing CO_2 induced climate change (Lal, 2004).

Carbon sequestration is only possible under crop and tillage management practices that increase C inputs and reduce C losses from soils. Conversion from conventional tillage (CT) to conservation tillage practices (e.g., reduced till (RT) and no-till (NT))

Abbreviations: CP, common tillage practices; CT, conventional tillage; CRP, conservation reserve program; MSD, mean square deviation; NT, no-tillage; SOC, soil organic C; RT, reduced tillage; SOM, soil organic matter; WW–F, winter wheat with summer fallow rotation; WW–SP, winter wheat with pea rotation.

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has a significant impact on the SOM and associated SOC through reducing soil disturbance and rapid oxidation of organic substrates (Cambardella and Elliot, 1993; Six et al., 1999; Freibauer et al., 2004). Intensifying cropping systems, eliminating summer fallow, reducing tillage, and increasing crop yields through use of high-yield crops, fertilization, irrigation, and weed and pest control are also important measures for enhancing C sequestration (Rasmussen and Rohde, 1988; Rasmussen and Collins, 1991; Lugo and Brown, 1993; Peterson et al., 1998; Grant et al., 2001; Al-Kaisi and Grote, 2007).

Soil C models are especially useful tools in predicting impacts of agriculture management practices on SOC stocks. In the last few decades, several soil C models (e.g., CENTURY, CQESTR, CANDY, DAYCENT, DNDC, and NCSOIL RothC) have been developed to simulate SOM and improve our understanding of soil C dynamics. The effectiveness and performance of these models have been tested (Smith et al., 1997; Gollany et al., 2012a; Del Grosso et al., 2016). In this study the CQESTR model was used because of its suitability for field-scale SOC simulation at several depths. CQESTR is a process-based soil C balance model developed to simulate the long-term impacts of crop, tillage, and agriculture management practices on SOC stocks in a soil profile of up to five layers (Rickman et al., 2002; Liang et al., 2009; Gollany et al., 2012b). It takes into account most of the factors that have a significant effect on the decomposition of organic matter. These factors include crop yield and amount of crop residue returned to soil, nitrogen content of the crop residue and organic amendments added, root biomass and its distribution characteristics, tillage practices, type of tillage implements and their impact on soil-residue mixing and surface disturbance, monthly average temperature, and annual precipitation (Rickman et al., 2002). Other required model inputs are soil properties such as the percentage of initial SOM or SOC content and soil bulk density for each soil layer (horizon), soil texture and drainage classes and the number and thickness (depth) of soil layers which are user defined. The model has successfully predicted soil C dynamics in various climates and soil types (Leite et al., 2009; Liang et al., 2009; Gollany et al., 2011, 2012a; Plaza et al., 2012). However, its suitability across toposequences was not previously evaluated. Therefore, the CQESTR model will be further evaluated using data that represent different landscape positions, crop rotations, and agriculture management practices.

The objective of this study was to evaluate the performance of CQESTR in simulating SOC changes across toposequences of selected fields under various agriculture management practices along a precipitation gradient in a dryland region of Oregon, USA. We hypothesize that the CQESTR model can reasonably simulate SOC stocks across toposequences, and that agriculture management over 20 years will have a greater impact on SOC stocks in the top 20 cm than landscape position within the field.

2. Methods and procedures

2.1. Material and methods

2.1.1. Study area

This study was carried out on 27 fields in five counties (Wasco, Sherman, Gilliam, Morrow, and Umatilla) in northcentral Oregon, USA (Fig. 1). These counties represent a range of soils and a precipitation gradient from west to east. Mean annual precipitation (MAP) ranged from 215 to 1230-mm, with a mean of 390-mm (Daly and Taylor, 2000a). Mean annual temperature (MAT) varied from 5 to 12 °C with a mean of 9 °C (Daly and Taylor, 2000b). Soil temperature regime varied from mesic to frigid and soil moisture regime varied from xeric to aridic. Most of the soils were developed from loess mixed with volcanic ash and were well drained. Dominant soils under the studied locations are classified as fine-silty, mixed, superactive, mesic Typic Haploxerolls and Calcic Haploxerolls (Table 1). Soil depth for the majority of sites in the area ranged between moderately deep to very deep.

Table 1
Soil series and taxonomic classification for the studied sites in northcentral Oregon.

Soil Series	Soil Taxonomic Classification
Athena	Fine-silty, mixed, superactive, mesic Pachic Haploxerolls
Cantala	Fine-silty, mixed, superactive, mesic Typic Haploxerolls
Condon	Fine-silty, mixed, superactive, mesic Typic Haploxerolls
Cowsly	Fine, smectitic, frigid Xerertic Agrialbolls
Dufur	Coarse-loamy, mixed, superactive, mesic Calcic Haploxerolls
Mikkalo	Coarse-silty, mixed, superactive, mesic Calcidic Haploxerolls
Morrow	Fine-silty, mixed, superactive, mesic Calcic Agrixerolls
Palouse	Fine-silty, mixed, superactive, mesic Pachic Ultic Haploxerolls
Ritzville	Coarse-silty, mixed, superactive, mesic Calcidic Haploxerolls
Valby	Fine-silty, mixed, superactive, mesic Calcic Haploxerolls
Walla Walla	Coarse-silty, mixed, superactive, mesic Typic Haploxerolls

Common crop rotations consist of winter wheat (*Triticum aestivum* L.) with summer fallow (WW–F) and winter wheat with spring peas (*Pisum sativum* L.; WW–SP). This is in addition to those areas under conservation reserve program (CRP). Tillage management practices vary from common practiced tillage (CP), reduced tillage (RT), and conservation tillage without tillage (direct-seeding, NT). In conventional tillage (CT) the moldboard plow is continuously used all the time with all crop rotations, while in CP a rotation of three tillage implements: chisel plow, disk plow, and moldboard plow is used in a six year cycle. In RT, chisel plow is used all the time. In NT, seed and fertilizer are applied in one pass. Five CRP, two NT, two RT and seventeen CP fields were included in this study. The incorporation of spring peas in the crop rotation and the actual practice of NT were started in these counties circa 1996.

2.1.2. Soil sampling and soil analysis

Soil samples were obtained from 27 fields along transects and were analyzed for total carbon, organic carbon, and inorganic carbon at the end of the growing season in 1982-83 and 2002–2003. Soil samples covered two major land resources areas (MLRAs) in Northcentral Oregon: the Columbia Plateau (MLRA 8) and the Palouse and Nez Perce Prairies (MLRA 9). These two MLRAs represent about 59% of the total area of the five studied counties (about 1,478,576 m^2). Sampling locations were also selected to represent the different crop rotations and different tillage managements practiced in these counties.

Soil samples were collected from five different landscape positions (summit, SU; shoulder, SH; backslope, BS; footslope, FS; and toeslope, TS) along each transect as described by the USDA-NRCS (2002). These samples were used to validate the CQESTR model for landscape scale use. Three soil cores were collected from each landscape position using a Giddings probe 3.2-cm in diameter and 1.8-m in length (Giddings Machine Company, Windsor, CO, USA) at depth increments of 0–15, 15–30, 30–45, and 45–60 cm in 1982–83 and at 0–5, 5–10, 10–20, 20–30, 30–60 cm in 2002–2003. Two cores from each landscape position were composited. Collected soil samples were air dried at 40 °C, ground with a rolling pin, passed through nested 1- and 2-mm sieves with all visible organic matter not collected on a sieve picked out with tweezers, roller-milled for 4 h, and stored for subsequent analysis. Total soil C was determined by combustion analyzer method (Nelson and Sommers, 1996) using a C and N analyzer (Thermo Finnigan FlashEA 1112 Elemental Analyzer, Rodano, Italy). Total organic C was analyzed using a Skalar Primacs TOC Analyzer (Skalar Corp, Norcross, Georgia). Total inorganic carbon (TIC) was determined by subtracting organic C from total C for each sample. The third core from each position was dried at 105 °C and weighed to determine soil bulk density using the