Agriculture, Ecosystems and Environment 140 (2011) 372–381

Contents lists available at ScienceDirect

Agriculture, Ecosystems and Environment

journal homepage: www.elsevier.com/locate/agee

Modeling the change in soil organic carbon of grassland in response to climate change: Effects of measured versus modelled carbon pools for initializing the Rothamsted Carbon model

Xianli Xu*, Wen Liu, Gerard Kiely

Centre for Hydrology, Micrometeorology and Climate Change, Department of Civil and Environmental Engineering, University College Cork, College Road, Cork, Ireland

ARTICLE INFO

Article history:
Received 22 August 2010
Received in revised form
15 December 2010
Accepted 18 December 2010
Available online 20 January 2011

Keywords:
Soil organic carbon
Carbon pools
RothC model
Climate change
Grassland

ABSTRACT

The Rothamsted Carbon (RothC) model with its multi soil carbon pools is widely used to estimate soil organic carbon (SOC) change in response to climate and/or land use change. Many of these pools are conceptual and it is a challenge to correctly parameterize them. Taking Irish temperate grasslands as an example, we study the SOC fractionation procedure of Zimmermann et al. (2007) to partition the measured SOC into the pools required in RothC. This was done with the aim of predicting SOC change in response to climate change. We found good correlation between the measured and modelled values for the pools of BIO (microbial biomass) and HUM (humified organic matter), but poor correlation for the pools of DPM (decomposable plant material) and RPM (resistant plant material). The measured carbon pools more reasonably reflected the real environmental conditions than the modelled. Because of the fast decomposition rate and short term simulation (only 40 years), the RPM pool controlled the trends in the future SOC change. The difference in the trends of the predicted total SOC between using measured and modelled carbon pools (to initialize RothC) rapidly increased in the initial years and slowly decreased thereafter. In order to limit this difference to 1% within the first 3 years (the turnover period for RPM), the difference between the measured and modelled RPM pool should be constrained to be less than 10%. In response to higher temperature and, drier summers and wetter winters, RothC predicted a decrease in the SOC of Irish grasslands.

1. Introduction

The global soil organic carbon (SOC) pool is estimated at 1500 Pg (Batjes, 1996; Eswaran et al., 1995), which is roughly equivalent to the sum of the atmospheric pool estimate of 750 Pg and the biotic pool estimate of 600 Pg (Houghton, 1995; Lal, 2002; Schimel, 1995). Any small change in SOC may greatly impact atmospheric CO_2 concentration. Consequently there is much scientific interest in soil carbon stocks and their potential feedbacks to climate change (Davidson and Janssens, 2007). In order to predict the SOC change in response to climate change, many models (including Century, DNDC (DeNitrification–DeComposition), Daisy and RothC) were developed and most models are based on several conceptual carbon pools (with different turnover rates) within the soil profile (Coleman and Jenkinson, 1999; Jensen et al., 1997; Li et al., 1997; Parton et al., 1995). RothC is among these models, and it has been widely used for arable soils, grassland soils and forest soils (Coleman and Jenkinson, 1996; Coleman et al., 1997; Falloon and Smith, 2002; Ludwig et al., 2007, 2010; Smith et al., 2006). In this model, SOC is partitioned into four active pools and one inert organic matter (IOM). The four active pools are decomposable plant material (DPM), resistant plant material (RPM), microbial biomass (BIO) and humified organic matter (HUM). All of these pools except IOM decompose by first-order decay at rate constants (year^{-1}) of 10 for DPM, 0.3 for RPM, 0.66 for BIO and 0.02 for HUM. These constant rates were originally set by tuning the model to data from some of the long-term field experiments at Rothamsted (Coleman and Jenkinson, 1996). Decomposition rates are modified by temperature, moisture, and by soil cover (Coleman and Jenkinson, 1999). Relating these conceptual pools (note that BIO pool is measurable) to measured pools is not only a great challenge but also a requirement for wider model application. Once measured, these pools can be used to validate the models; on the other hand, these measured pools can also be used to initialize these models at any point in the landscape even without historical data (Zimmermann et al., 2007). Furthermore, it also enables the establishment of the functional relationships between soil organic matter (SOM) functioning and pools and turnover (Bruun et al., 2010). A soil (carbon pool) fractionation procedure to separate the SOC into different carbon

---

* Corresponding author.
E-mail addresses: xuxianliww@gmail.com (X. Xu), wenwen424@gmail.com (W. Liu), g.kiely@ucc.ie (G. Kiely).

0167-8809/$ – see front matter © 2010 Elsevier B.V. All rights reserved.
doi:10.1016/j.agee.2010.12.018

fractions, which can be directly related to those modelled pools in the RothC model was reported by Zimmermann et al. (2007). However, few studies have been conducted to test the Zimmermann approach (Dondini et al., 2009; Leifeld et al., 2009a,b). Grassland occupies some 62.7 M ha in the EU 25 plus Norway and Switzerland (Janssens et al., 2005). In Ireland, grassland is also the dominant land use accounting for 53% of the total land area in 2000 and 25% of the total SOC stocks to 1 m depth (Eaton et al., 2008). Rising temperature and shifting precipitation patterns towards increasing summer drier periods and wetter winters are expected in Ireland (McGrath et al., 2005). Despite this, the potential response of SOC in Irish grassland to climate change has not yet been assessed.

The objective of this study was: (1) to test whether the measured carbon fractions with the procedure of Zimmermann et al. (2007) are well related with the modelled pools as required by RothC; (2) to determine the effects of different initializations of the RothC model with measured or modelled carbon pools on the outputs of SOC; and (3) to examine the effects of climate change on SOC in the temperate grasslands of Ireland.

2. Materials and methods

2.1. Climate data

The climate inputs were derived from the study by McGrath et al. (2005) (http://www.c4i.ie) who used a regional climate model (RCM) to create a forty-year simulation of the past climate (1961–2000). After verification of the RCM model performance in recreating the recent past climate, McGrath et al. (2005) used the model to simulate the future climate for the period 2021–2060 for a range of IPCC emission scenarios. Average monthly air temperature and total monthly precipitation for 1961–2000 and for the A1B, A2 and B1 emission scenarios (2021–2060) were extracted from McGrath et al. (2005) and used as inputs to the RothC model. The total monthly open-pan evaporation was calculated using the method of Penman (1948).

2.2. Soil data

Eight grassland sites in Southern Ireland (Fig. 1 and Table 1) were examined in 2007 for detailed carbon fractions at three depths (0–10, 10–25 and 25–50 cm) following the procedure proposed by Zimmermann et al. (2007). It is a basic physical and chemical fractionation procedure as shown in Fig. 2a.

Thirty grams of the soil (<2 mm) were added to 150 ml water, and dispersed by ultrasonic vibration with an output-energy of 22 J ml^{-1}. This dispersed suspension was then wet sieved over a 63 μm aperture sieve until the rinsing water was clear. The fraction (>63 μm), containing the sand fraction and stable aggregates (S + A) together with POM (particular organic matter), was dried at 40 °C and weighed. The suspension <63 μm was filtered through a 0.45 μm aperture nylon mesh and the material >0.45 μm was dried at 40 °C and weighed. An aliquot of the filtrate was frozen to measure the amount of the dissolved SOC (DOC). POM was separated by stirring the fraction <63 μm with sodium polytungstate at a density of 1.8 g cm^{-3}. The mixture was centrifuged at 1000 × g for 15 min and the light fraction was decanted. Both fractions (S + A and POM) were washed with deionised water to remove all sodium polytungstate, dried at 40 °C and weighed.

A chemically resistant carbon fraction (rSOC) was extracted from the fraction <63 μm by NaOCl oxidation. Oxidation was done with 6% NaOCl at room temperature after a modified method of Kaiser and Guggenberger (2003). One gram of s + c was oxidized for 18 h at 25 °C with 50 ml of 6% NaOCl adjusted to pH 8 with concentrated HCl. The oxidation was centrifuged at 1000 × g for 15 min, decanted, washed with deionised water and centrifuged again. This oxidation step was repeated twice.

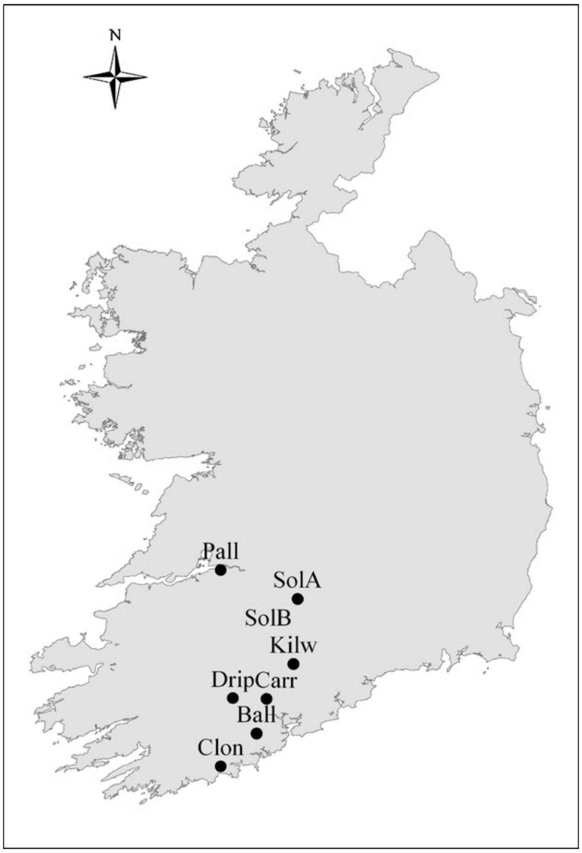

Fig. 1. Location map of the eight sites used in this study (note: SolA and SolB are very close to each other so that their symbols are overlapped).

In this study, the carbon fractions for surface depth (0–10 cm) of the eight sites were used because RothC is suitable for surface soils (Coleman and Jenkinson, 1999). The measured carbon fractions (%) were converted to t C ha^{-1} with known soil bulk densities, which has the same units as the output from RothC.

According to Zimmermann et al. (2007), the measured carbon fractions– sum of POM and DOC correspond to the modelled values– sum of DPM and RPM. The sum of POM and DOC was separated into DPM and RPM using the ratio of DPM: RPM from the modelled DPM and RPM pools for each site. The measured carbon fractions– sum of S + A and s + c − rSOC correspond to the modelled ones– sum of BIO and HUM, and was separated into BIO and HUM by the ratio of BIO: HUM from the modelled BIO and HUM pools for each site. The recalcitrant silt and clay fraction (rSOC) is associated with IOM. The detailed procedure (a flowchart) is shown in Fig. 2b (after Zimmermann et al., 2007). All the pools converted from the measured carbon fractions were called measured pools in this study.

2.3. Application of RothC-26.3

RothC was firstly used to calculate the annual plant inputs (M1) to soils at the mode of known total soil carbon content. Originally, the model approximates IOM using the equation (IOM = 0.049(total SOC)$^{1.139}$) proposed by Falloon et al. (1998), but the calculated IOM is almost three times less than the measured (Fig. 3a) and the relationship between the measured IOM and total SOC (Fig. 3b) is largely different from that of Falloon et al. (1998). In another study on croplands, Leifeld et al. (2009a) indicated that the sizing