Available online at www.sciencedirect.com
ScienceDirect
Soil & Tillage Research 91 (2006) 217–226
Soil & Tillage Research
www.elsevier.com/locate/still

A method for estimating coefficients of soil organic matter dynamics based on long-term experiments

C. Bayer [a,*], T. Lovato [b], J. Dieckow [c], J.A. Zanatta [a], J. Mielniczuk [a]

[a] *Departamento de Solos, Universidade Federal do Rio Grande do Sul, 91501-970, P.O. Box 15100, Porto Alegre, RS, Brazil*
[b] *Departamento de Solos, Universidade Federal de Santa Maria, 97105-900 Santa Maria, RS, Brazil*
[c] *Departamento de Solos e Engenharia Agrícola, Universidade Federal do Paraná, 80035-050 Curitiba, PR, Brazil*

Received 25 January 2005; received in revised form 25 November 2005; accepted 18 December 2005

Abstract

The one-compartment C model $C_t = C_0 e^{-k_2 t} + k_1 A/k_2 (1 - e^{-k_2 t})$ is being long used to simulate soil organic C (SOC) stocks. C_t is the SOC stock at the time t; C_0, the initial SOC stock; k_2, the annual rate of SOC loss (mainly mineralization and erosion); k_1, the annual rate to which the added C is incorporated into SOC; and A, the annual C addition. The component $C_0 e^{-k_2 t}$ expresses the decay of C_0 and, for a time t, corresponds to the remains of C_0 ($C_{0\ \mathrm{remains}}$). The component $k_1 A/k_2 (1 - e^{-k_2 t})$ refers, at time t, to the stock of SOC derived from C crops (C_{crop}). We herein propose a simple method to estimate k_1 and k_2 coefficients for tillage systems conducted in long-term experiments under several cropping systems with a wide range of annual C additions (A) and SOC stocks. We estimated k_1 and k_2 for conventional tillage (CT) and no-till (NT), which has been conducted under three cropping systems (oat/maize −O/M, vetch/maize −V/M and oat + vetch/maize + cowpea −OV/MC) and two N-urea rates (0 kg N ha^{-1} −0 N and 180 kg N ha^{-1} −180 N) in a long-term experiment established in a subtropical Acrisol with $C_0 = 32.55$ Mg C ha^{-1} in the 0–17.5 cm layer. A linear equation ($C_t = a + bA$) between the SOC stocks measured at the 13th year (0–17.5 cm) and the mean annual C additions was fitted for CT and NT. This equation is equivalent to the equation of the model $C_t = C_0 e^{-k_2 t} + k_1 A/k_2 (1 - e^{-k_2 t})$, so that $a = C_0 e^{-k_2 t}$ and $bA = k_1 A/k_2 (1 - e^{-k_2 t})$. Such equivalences thus allow the calculation of k_1 and k_2. NT soil had a lower rate of C loss ($k_2 = 0.019$ year^{-1}) than CT soil ($k_2 = 0.040$ year^{-1}), while k_1 was not affected by tillage (0.148 year^{-1} under CT and 0.146 year^{-1} under NT). Despite that only three treatments had lack of fit (LOFIT) value lower than the critical 5% F value, all treatments showed root mean square error (RMSE) lower than RMSE 95% indicating that simulated values fall within 95% confidence interval of the measurements. The estimated SOC stocks at steady state (C_e) in the 0–17.5 cm layer ranged from 15.65 Mg ha^{-1} in CT O/M 0 N to 60.17 Mg ha^{-1} in NT OV/MC 180 N. The SOC half-life ($t_{1/2} = \ln 2/k_2$) was 36 years in NT and 17 years in CT, reflecting the slower C turnover in NT. The effects of NT on the SOC stocks relates to the maintenance of the initial C stocks (higher $C_{0\ \mathrm{remais}}$), while increments in C_{crop} are imparted mainly by crop additions.

Keywords: Tillage; Cropping systems; C model; Coefficients; Subtropical soil; SOC stocks

1. Introduction

In spite of the significant amount of data from long-term experiments pertaining to the influence of tillage on soil organic carbon (SOC) stocks, few are the initiatives seeking to explore these data to estimate, for no-till and conventional tillage systems, the coefficients k_1 and k_2 of the SOC model

* Correspondence to: Rua Luis de Camões, 623 Apto 501, Bairro Santana, 90620-150 Porto Alegre, RS Brazil. Tel.: +55 51 33166040; fax: +55 51 33166050.
E-mail address: cimelio.bayer@ufrgs.br (C. Bayer).

0167-1987/$ – see front matter
doi:10.1016/j.still.2005.12.006

$$C_t = C_0 e^{-k_2 t} + \frac{k_1 A}{k_2}(1 - e^{-k_2 t}) \quad (1)$$

This is a simple one-compartment SOC model based on first-order kinetics that was developed by Hénin and Dupuis (1945). Although not being process-based and complex like, for example, CENTURY (Parton et al., 1987) or ROTHC models (Jenkinson et al., 1987), it has been widely used to simulate the dynamics of the total SOC or nitrogen stocks (Woodruff, 1949; Greenland, 1971; Dalal and Mayer, 1986; Bayer et al., 2000) and has proved useful for a less detailed modelling in sites where input requirements to run those more complex models are not always available. In this model, C_t is the SOC stock at time t; C_0, the initial SOC stock at time $t = 0$; k_2, the annual rate of SOC loss by mineralization and erosion; k_1 refers to the annual rate by which the added C is incorporated into SOM; and A, the annual C addition.

Usually the k_1 and k_2 coefficients are determined through isotopic techniques of ^{14}C tracers or ^{13}C natural tracers (Cerri, 1986; Balesdent et al., 1990; Balesdent and Balabane, 1992; Gregorich et al., 1995). Although their accuracy, these tracer techniques are relatively costly and not all researchers have access to them. On the other hand, we suppose it is possible at least to estimate the k_1 and k_2 coefficients, and therefore obtain understanding about the soil organic matter dynamics through the one-compartment model, by only considering some commonly obtained data from long-term experiments, as C_0, A and C_t.

The first component of Eq. (1), $C_0 e^{-k_2 t}$, expresses the decay of C_0 and, at a time t, corresponds to the remains of C_0 ($C_{0\ \mathrm{remains}}$). The second component, $k_1 A/k_2$ $(1 - e^{-k_2 t})$, expresses, at time t, the stock of SOC derived from crop additions since $t = 0$ (C_{crop}).

The first derivative of Eq. (1) can be expressed as

$$\frac{dC}{dt} = k_1 A - k_2 C \quad (2)$$

and represents the temporal variation in the SOC stock. Considering a 1-year period, the components $k_1 A$ and $k_2 C$ would represent the annual C addition and C loss, respectively. When C addition and C loss equalize, dC/dt is zero, meaning that SOC stock has achieved a steady state condition. Considering $k_1 A = k_2 C$, the SOC stock at steady state (C_e) is expressed as follows (Dalal and Mayer, 1986; Bayer et al., 2000):

$$C_e = \frac{k_1 A}{k_2} \quad (3)$$

The k_1 coefficient for aboveground residues ranges between 0.077 year^{-1} and 0.230 year^{-1}, averaging 0.122 year^{-1} (Bolinder et al., 1999; Gregorich et al., 1995). Roots generally present higher k_1 values because of the higher lignin contents and the physical protection imparted by soil aggregates (Balesdent and Balabane, 1992, 1996).

The k_2 coefficient is affected by climatic conditions (temperature and rainfall), soil characteristics (texture and mineralogy) and management practices, particularly soil tillage. In tropical regions the k_2 values, which may be as high as 0.10 year^{-1} (Cerri, 1986; Cerri and Andreux, 1990; Bayer et al., 2000), are generally higher than in temperate regions, where values are often lower than 0.02 year^{-1} (Balesdent et al., 1990). Sandy soils also present higher k_2 values compared to clayey ones, where SOM physical protection imparted by soil aggregates and organo-mineral interactions is more intense (Bayer, 1996). Soils managed under conventional tillage, due to the exposition of SOM to more oxidizing conditions, presents higher k_2 coefficients than soils under conservation tillage (Bayer et al., 2000; Lovato et al., 2004).

We assumed that is possible to estimate the k_1 and k_2 coefficients for different tillage systems from a long-term experiment, provided that in this experiment each tillage system is subjected to a set of cropping systems that provides a broad range of C additions (A) and thus of SOC stocks (C_t) and that A and C_t of all treatments, as well as C_0, are known. The major assumptions are that k_1 and k_2 for a given tillage system are constant during the experimental period and throughout a wide range of crop C additions (A). This assumption is supported by results reported by Paustian et al. (1992) and Larson et al. (1972) evaluating 32- and 11-year-old experiments, respectively. These authors observed a linear relation between SOC stocks and carbon addition varying from 0 to 2.5 $\mathrm{Mg\ ha^{-1}\ year^{-1}}$ and from 0 to 6.5 $\mathrm{Mg\ ha^{-1}\ year^{-1}}$, respectively.

The objectives of this study were to (i) present and evaluate the accuracy of a simple method to estimate k_1 and k_2 coefficients of the one-compartment SOC model $C_t = C_0 e^{-k_2 t} + k_1 A/k_2 (1 - e^{-k_2 t})$ by using data from long-term experiments; (ii) evaluate the effect of tillage systems on the magnitude of these coefficients; and (iii) simulate, for a 20-years period, the total SOC stock (C_t), the remains of C_0 ($C_{0\ \mathrm{remains}}$), and the SOC derived from crop additions (C_{crop}), as influenced by tillage systems, cropping systems and N fertilization in a subtropical Acrisol.