

# Evaluation of Soil Organic Matter Models

Using Existing Long-Term Datasets

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**Springer**

Published in cooperation with NATO Scientific Affairs Division

Proceedings of the NATO Advanced Research Workshop "Evaluation of Soil Organic Matter Models Using Existing Long-Term Datasets", held at IACR-Rothamsted, Harpenden, UK, May 21-26, 1995

Library of Congress Cataloging-in-Publication Data

Evaluation of soil organic matter models using existing long-term datasets / edited by David S. Powlson, Peter Smith, Jo U. Smith.  
p. cm. -- (NATO ASI series. Series I, Global environmental change ; vol. 38)

Includes bibliographical references and index.

ISBN 3-540-60602-5 (hard : alk. paper)

1. Humus--Mathematical models--Evaluation--Congresses.

I. Powlson, D. S. (David S.) II. Smith, Pete, 1965-

III. Smith, Jo U., 1964- . IV. NATO Advanced Research Workshop "Evaluation of Soil Organic Matter Models Using Existing Long-term Datasets" (1995 : IACR-Rothamsted) V. Series.

S592.8.E93 1996

631.4'17--dc20

95-45659

CIP

ISBN 3-540-60602-5 Springer-Verlag Berlin Heidelberg New York

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Printed in Germany

Typesetting: Camera ready by authors/editors

Printed on acid-free paper

SPIN: 10475257 31/3137 - 5 4 3 2 1 0

## Modelling approaches of soil organic matter turnover within the CANDY system

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### Introduction

The development of the CANDY system (CARbon and Nitrogen DYNAMICS) has been based on experience of organic matter turnover and nitrogen dynamics gained over a long period, a major part of the scientific work in Bad Lauchstädt. The main objective in developing the model was to give farmers a tool for calculating short term dynamics of nitrogen transformations and long term changes in the carbon content of the soil. For this reason the system consists of a database interface and several model components. The main component is the CANDY module, written in TURBO - PASCAL which calculates daily changes of water, temperature, carbon and nitrogen for a 2 m deep soil profile. Alongside this daily-timestep nitrogen simulation, there is a long term carbon module that calculates the amount of decomposable carbon in steady state for a given crop rotation. The calculation is specific to the site and management practices and is based on averaged turnover conditions, yields and inputs of organic material.

Other modules of the CANDY system are designed to

1. analyse the specific turnover conditions of a given combination of soil, climate and management,
2. calculate an environmentally compatible nitrogen fertilizer recommendation using the simulated amount of mineral nitrogen in soil at a given time and the predicted nitrogen mineralization from organic pools and
3. display graphics of simulation results.

## Model description

The CANDY system is an integration of different simulation modules with a database system. The database provides model parameters, measured values, initial values, weather data and management data. A simulation can be characterized by the set of initial values, the specification of site specific information including soil parameters and weather conditions and a list of management activities to be considered during the simulation.

The soil parameters required are bulk density, particle density, water capacity, wilting point and a texture parameter (TEX) describing the fraction of particles with a size  $\leq 6 \mu\text{m}$  (clay+fine silt) per unit volume of soil. These parameters have to be specified for each horizon. For some soil types standard parameter records are available.

The meteorological module of the CANDY system requires daily values for precipitation, air temperature and global radiation or sunshine duration. These inputs may be read from a database or can be generated with the help of a special weather generator ( Oelschlägel, 1992). Outputs are daily values for corrected precipitation, global radiation, air temperature and potential evapotranspiration.

The soil water module uses the corrected precipitation and potential evapotranspiration as input values. State variables are soil water content and the water equivalent of the snow cover. This submodel is based on a capacity model (Koitzsch & Günther 1990) and calculates snow accumulation and melting, crop interception, evapotranspiration and drainage.

The next step in the chain of submodels is the soil temperature module, where the heat flow equation is solved using an approach of Suckow (1986). At the lower boundary it is assumed that no heat flow occurs. The soil surface temperature, calculated by an empirical approach using air temperature of the last three days and crop coverage, is used as the upper boundary condition.

Another module of the system calculates the changes of the soil state variables as a result of tillage, addition of nitrogen fertilizer and manure or other fresh organic matter, irrigation, plant emergence or harvest.

Using an empirical approach special crop state variables like height, coverage, root depth and nitrogen demand are calculated. The nitrogen demand can be calculated by means of an "s-shaped" function depending on the expected yield or on the water consumption of the crop.

The crop module can be switched off in order to simulate the carbon dynamics only. In this case the yield is used as an input value to calculate the amount of roots and plant residues.

The module of organic matter turnover and nitrogen dynamics is the main part of CANDY. The model includes three kinds of organic material: fresh organic matter (FOM, material added to the soil), activated soil organic matter (the most important fraction for all turnover processes) and stabilized soil organic matter. Stabilized soil organic matter and the activated soil organic matter together make up the pool of decomposable soil organic matter (Fig. 1).

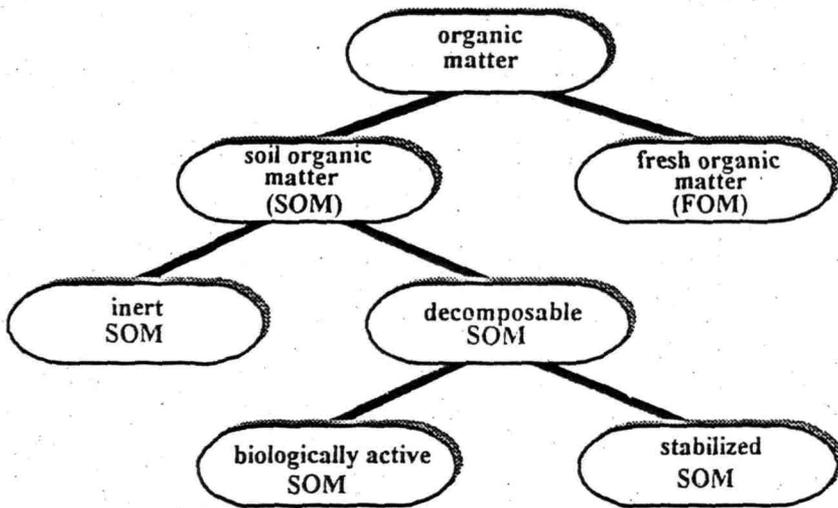


Figure 1 Pools of organic matter in soil

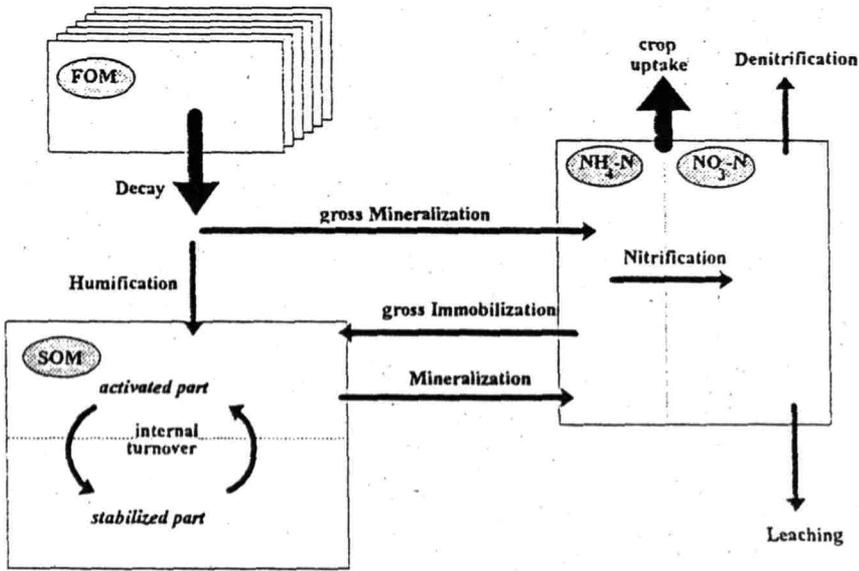


Figure 2 Scheme of Carbon and Nitrogen turnover modeling in CANDY

The inert organic matter pool is not included in the turnover processes. The amount of inert carbon  $C_i$  is calculated with respect to the soil texture parameter  $TEX$ :

$$C_i = const * TEX$$

The constant factor *const* in most cases is observed within the range of 0.4 to 0.6. The difference between total organic carbon and inert organic carbon is considered to be decomposable. The source of all decomposable carbon is fresh organic matter that enters the soil via manuring or plant debris. It is assumed, that an input of plant residues occurs only after harvest. The amount of this fresh organic matter is calculated depending on the crop yield.

The model is able to handle up to six different pools of fresh organic matter. The fresh organic matter undergoes the decay process shown in Fig.2. As a result of this decay new soil organic matter is produced (humification). The amount of newly synthesized soil organic carbon ( $C_{REP}$ ) depends on the efficiency factor  $\eta_{FOM}$  of the FOM under consideration. Nitrogen mineralization and immobilization are dependent on the C to N ratio of the fresh organic matter.

The decay of the activated soil organic matter also results in mineralization. Exchange between the activated ( $C_A$ ) and the stabilized ( $C_S$ ) pools of soil organic matter has an important effect

on long term dynamics. This exchange does not influence the mineral nitrogen pool but makes the decomposable organic matter available for mineralization over a long period of time.

All turnover processes are modelled using first order kinetics.

$$\frac{dC_{FOM}(t)}{dt} = -k_{FOM} C_{FOM}(t)$$

$$\frac{dC_{REP}(t)}{dt} = \eta_{FOM} k_{FOM} C_{FOM}(t)$$

$$\frac{dC_A(t)}{dt} = \frac{dC_{REP}}{dt} - (k_m + k_s) C_A(t) + k_A C_S(t)$$

$$\frac{dC_S(t)}{dt} = k_s C_A(t) - k_A C_S(t)$$

where  $k_{INDEX}$  are the rate constants referring to

*FOM*: fresh organic matter

*REP*: reproduction of soil organic matter

*A*: activated soil organic matter

*S*: stabilized soil organic matter

*m*: decay (mineralization) of activated soil organic matter

The rates of reaction processes are adjusted with respect to environmental conditions such as soil moisture, soil temperature and soil aeration. The effect of these environmental conditions is described by means of reduction functions ( $r_T$ ,  $r_w$  and  $r_{AIR}$ ) with an output range between 0 and 1:

temperature:

$$r_w(\theta) = \begin{cases} 4 \frac{\theta}{PV} \left( 1 - \frac{\theta}{PV} \right) & \text{if } \frac{\theta}{PV} \leq 0.5 \\ 1 & \text{if } \frac{\theta}{PV} > 0.5 \end{cases}$$

moisture: 
$$r_w(\theta) = \begin{cases} 4 \frac{\theta}{PV} \left(1 - \frac{\theta}{PV}\right) & \text{if } \frac{\theta}{PV} \leq 0.5 \\ 1 & \text{if } \frac{\theta}{PV} > 0.5 \end{cases}$$

aeration: 
$$r_{AIR}(d, TEX, T, \theta) = \exp \left( -d \sqrt{\frac{S(TEX) r_T(T) r_w(\theta)}{\epsilon_{AIR} (\epsilon_{AIR} - \epsilon_p)}} \right)$$

where  $T$ : soil temperature       $\theta$ : soil moisture       $PV$ : pore volume  
 $\epsilon_{AIR}$ : fraction of air filled pore space       $d$ : depth of soil layer  
 $S(TEX)$ : texture depending parameter       $\epsilon_p, Q_{10}$ : constants

In contrast to other models, these reduction functions are applied to the time step as opposed to reaction coefficients - thus calculating the biological active time:

$$t := t^* R(x, t^*)$$

where  $t$ : biological active time,

$t^*$ : standard time

$$R(x, t) = R(d, TEX, T, \theta) = r_T(T) r_w(\theta) r_{AIR}(d, TEX, T, \theta)$$

The sum of these daily values of biological active time for one year can be used to characterize turnover activities with respect to different land uses or soil conditions. The long term average over each year ( $\Sigma t_{bat}$ ) can be used for rough calculations of carbon accumulation. In this case the flux of synthesized carbon is replaced by the amount of carbon reproduced ( $C_{REP}$ ) per year (in terms of biological active time):

$$\frac{d C_{REP}}{dt} = \frac{C_{REP}}{\Sigma t_{bat}} = \sum_{FOM} \frac{C_{FOM}^* \eta_{FOM}}{\Sigma t_{bat}}$$

With this simplification the time course of the accumulation of decomposable carbon ( $C_{DEC}$ ) can be described as follows:

$$C_{DEC} = C_{DEC}^0 * (A_1 * e^{\lambda_1 t} + A_2 * e^{\lambda_2 t}) + \sum_{FOM} \frac{C_{FOM}^* \eta_{FOM}}{\Sigma t_{bat}} * (B_1 * e^{\lambda_1 t} + B_2 * e^{\lambda_2 t} + \frac{1 + \xi}{k_m})$$

where  $\xi = \frac{k_s}{k_d}$

$$\lambda_{1/2} = -\frac{k_m + k_A + k_S}{2} \pm \sqrt{\frac{(k_m + k_A + k_S)^2}{4} - k_m k_A}$$

$$A_1 = -\frac{k_A * k_m + \lambda_2 * (k_A + k_S)}{(\lambda_1 - \lambda_2) * (k_A + k_S)} \quad A_2 = \frac{k_A * k_m + \lambda_1 * (k_A - k_S)}{(\lambda_1 - \lambda_2) * (k_A + k_S)}$$

$$B_1 = \frac{1 + \lambda_2 * \frac{k_A + k_S}{k_m * k_A}}{\lambda_1 - \lambda_2} \quad B_2 = -\frac{1 + \lambda_1 * \frac{k_A + k_S}{k_m * k_A}}{\lambda_1 - \lambda_2}$$

$C_{DEC}^0$  : initial amount of decomposable carbon

$k_{INDEX}$  are the rate constants referring to

*FOM*: fresh organic matter

*REP* : reproduction of soil organic matter

*A* : activated soil organic matter

*S* : stabilized soil organic matter

*m* : decay (mineralization) of activated soil organic matter

The calculation of the steady state level of decomposable carbon can easily be applied to crop rotations in order to estimate their impact on soil organic matter:

$$C_{DEC} = \frac{1 + \xi}{k_m} * \frac{C_{REP}}{\Sigma t_{bat}}$$

These simplifications were used to create two very simple models for the accumulation of decomposable carbon, the first working with an annual time step and the second calculating only the steady state level. In this case it is possible to estimate the biological active time from soil texture (particles < 6  $\mu\text{m}$ ), the long term average of precipitation and air temperature.

The daily timestep model also describes nitrification and denitrification with respect to nitrate concentration and the amount of activated soil organic matter and nitrate leaching by convective water movement. This assumes that only the dissolved nitrogen in the water content above the wilting point is available for transport (Franko & Oelschlägel, 1993). The performance of the model concerning temperature, water and nitrogen dynamics has been reported by Franko *et al.* (1995a).

All functions for data input, running simulations and analysis of results are integrated in a user-interface, which allows non-modellers an easy access to the system. When the model is applied to a large area, the heterogeneity of the soil must be taken into account. For this

purpose the model has been integrated within a Geographic Information System, supplying soil and management data for the model inputs and creating thematic maps from the simulation results (Franko *et al.* 1995b).

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