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CN-SIM: a model for the turnover of soil organic matter. II. Short-term carbon and nitrogen development

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Abstract

A computer model is presented, which describes the transformations of C and N in the soil. The development has been divided into two interdependent tasks, the first is long-term simulation of soil organic carbon simulation capabilities, and the second is short-term simulations of C and N, as described in this paper. A number of existing, independent laboratory experiments, covering a range of amendments, have been used for the latter task. The amendments include a variety of different crop residues and animal manures. These experiments include measurements of ^{13}C and ^{15}N in various pools, and the model facilitates the simulation of these isotopes. Non-linear optimisation procedures were utilised wherever feasible, and in order to test the robustness and generality of the model, cross-validations and sensitivity analyses were performed. In general, the model yielded good to acceptable descriptions of the measured data.

Keywords: Soil organic matter; Simulation model; Non-linear optimisation; Nitrogen; Carbon

1. Introduction

Both in conventional and organic farming there is an increasing emphasis on the issue of sustainability. This comprises the challenge of achieving or maintaining a high level of soil organic matter (SOM) and thus inherent soil fertility, while keeping the concentration of inorganic nitrogen low during periods subject to leaching losses. Given these potentially conflicting goals, C/N turnover models might help to tune and time mineral and organic fertilizer inputs, as well as other field operations. Organic farming in particular depends highly on the amount and timing of net nitrogen (N) mineralization from organic matter turnover, since only limited external inputs of N are usually available.

A good understanding and quantitative description of the processes involved is therefore required. This involves both the long-term dynamics of soil organic carbon (C), and the more short-termed N mineralization–immobilization turnover (MIT) performed by the soil organisms. Though many details of these C and N transformations are well known, basic knowledge is still limited about the chemical and physical properties determining substrate availability, and the rates of decomposition of crop residues and animal manure as well as the stabilisation of organic matter.

The high complexity of this topic leads to the need for mathematical models, which may both serve as a framework for the present understanding of C and N transformations in soil and for predictions of the immobilization and subsequent release of N, as well as the build-up or degradation of C. This is also the major aim of the present model. A number of detailed C and N models have already

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been published, sharing many structural features, but with greatly varying complexity. The added organic matter has been considered one pool (Johnsson et al., 1987; Andrén and Kätterer, 1997; Nicolardot et al., 2001), two pools (Parton et al., 1987; Hansen et al., 1991; Coleman and Jenkinson, 1996) or three pools (Verberne et al., 1990; Molina, 1996; Henriksen and Breland, 1999a). The soil microbial biomass may not be modelled explicitly (Johnsson et al., 1987; Parton et al., 1987; Andrén and Kätterer, 1997), modelled with one pool (Verberne et al., 1990; Coleman and Jenkinson, 1996; Nicolardot et al., 2001), two pools (Hansen et al., 1991; Molina, 1996) or three pools (Henriksen and Breland, 1999a). Non-biomass pools with a turnover time of a few months to a few years may be absent (Johnsson et al., 1987; Hansen et al., 1991; Coleman and Jenkinson, 1996; Andrén and Kätterer, 1997; Henriksen and Breland, 1999a; Nicolardot et al., 2001) or utilised (Parton et al., 1987; Verberne et al., 1990; Molina, 1996). Organic matter with a turnover-time of decades or more, 'humus', may be undivided (Johnsson et al., 1987; Verberne et al., 1990; Molina, 1996; Andrén and Kätterer, 1997; Henriksen and Breland, 1999a; Nicolardot et al., 2001), or divided into 'active' and 'passive' or 'refractory' compartments (Parton et al., 1987; Hansen et al., 1991; Coleman and Jenkinson, 1996).

However, for most of the existing models, parameter calibration has only been carried out on a limited number of datasets or on data from only one country or region. Furthermore, as discussed in Petersen et al. (2004), objective and rigorous optimisation procedures have not been applied in the development and parameterisation of most of these models, hence their general value over a broad range of conditions may be questioned.

Given these possible limitations of existing models, we chose the following aims for development of a new model:

1. To base the development on a large data set from both short-term laboratory and long-term field experiments performed under various conditions,
2. To obtain robust and general model parameters utilising non-linear optimisation methods,
3. To evaluate the model generality and sensitivity,
4. To relate the modelling to the biological processes in the soil.

A comprehensive collection of independent datasets, covering a range of soil types and amendments, was included, and a major focus has been on limiting the number of required parameters, in order to obtain a robust model. In order to achieve generality, the ambition has been to simulate a large number of measurement series acceptably, rather than developing a model, which simulates a few measurement series excellently. The model was further developed under the constraint of excluding dynamically responsive C/N ratios in soil microbial pools, in order to facilitate usage in existing soil–plant models, e.g. *Daisy* (Hansen et al., 1991), without major re-programming of the principles for MIT.

2. Materials and methods

2.1. Model description

The carbon flow of CN-SIM (v. 1.0) can be seen in Fig. 1. An in-depth description of model structure, functionality and parameter nomenclature and values is provided by Petersen et al. (2004). Briefly, added organic matter is subdivided between the added matter pools AOM1 (slowly decomposable) and AOM2 (easily decomposable). For partly decomposed organic materials such as animal manure, a fraction (f_{NOM}) is routed directly to the native organic matter ('humus') pool NOM. This fraction is exclusively determined on the basis of long-term data. Following decay of AOM1 and AOM2, a fraction (f_{SMB1}) is routed to the microbial biomass pool SMB1 ('autochtonous'), while the remaining goes to SMB2 ('zymogenous'). Outgoing matter from SMB2 is routed to the soil microbial residue pool SMR, which subsequently is utilised by SMB1. The 'humification' occurs when matter from SMB1 enters NOM. The refractory or inert matter is represented by the IOM pool, which is assumed totally inert. The decay of all pools, except IOM, is assumed to follow first-order reaction kinetics. The turnover rate is modified by temperature and soil water potential. Furthermore, the clay content modifies the turnover of SMB1 and SMB2. The turnover of the SMB pools is a composite of maintenance (M_{SMBi}) released as CO_2, and decay rate (k_{SMBi}) routed to

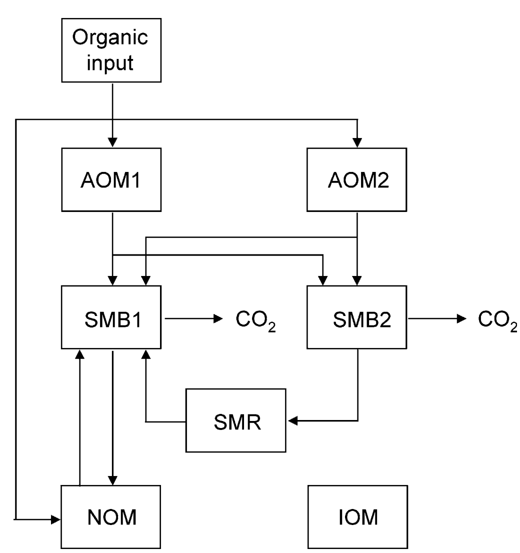

Fig. 1. Model structure and C flow for CN-SIM (v. 1.0). AOM1 and AOM2 are added organic matter, SMB1 and SMB2 are soil microbial biomass, SMR and NOM are soil organic matter pools. IOM represents inert organic matter. See Petersen et al. (2004) for a more comprehensive description.