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# 9 Soil organic carbon balance using Century model

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## Abstract

*Mathematical modelling has widely been used during the last 20 years to estimate and predict soil organic carbon (SOC) balance and nutrients dynamic on the landscape scale. The model simulations are applied and developed to assess the long-term effects of climate and management practices on SOC in the different land use. However, there are characteristics of the models, such as simplifications, complex nonlinear interactions etc., which limit their use and imply wide evolution to improve the models performance. The present work illustrates the differences among the main SOC models developed for forest, agricultural and grassland land-use, and*

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*their limits and prospects. Particularly the CENTURY model and an application of this model in a Mediterranean agroecosystems, characterized by organic and conventional managements, are described.*

# 1. Introduction

The terrestrial ecosystems occupy an area of approximately 130 x $10^6$ $km^2$ [1]. The development of various Terrestrial Ecosystem Models (TEMs) provides to apply the field studies of different ecosystems in landscape scale studies. This new approach of ecosystems studies derives from the necessity of understanding the complex interaction between the biogeochemical models (ecosystem function) and biogeographical models (ecosystem structure) [2].

Soil organic matter models, that belong to biogeochemical models, have been used extensively during the last 20 years to improve our understanding of soil organic matter (SOM) dynamics [3]. Also mathematical modelling has been used to predict soil carbon evolution [4, 5, 6, 7]. These models have the ability to simulate the complex processes in the humification and degradation of organic matter and describing the relationship between a number of soil properties controlling soil carbon evolution [8].

The use of soil organic matter models (simplified representations of a complex reality) is an important research tool to investigate soil organic matter evolution, and to examine the consequences of various intervention measures [9]. An understanding of the distribution and dynamics of soil C at the regional level is also an important step for quantifying regional and global C balances and assessing the response and feedbacks of terrestrial ecosystems to climate change [10].

Detailed and long-term field experiments are often difficult to conduct due to financial or personnel limitations. The application of simulation models, which have been developed with data measured under more accommodating conditions and whose mathematical relationships apply to a wide range of conditions, is therefore an attractive option [11]. There is increasing need to develop models to assess the long-term effects of management practices on soil environmental quality, and to test these models across a wide range of environments [3].

However, there are characteristics of the models, such a simplifications, complex nonlinear interactions etc., which limit their use and imply wide evolution to improve the models performance.

The present work illustrates the differences among the main SOC models developed for forest, agricultural and grassland land-use, their limits and prospects. Particularly the CENTURY model and an application of this model are described in a Mediterranean agroecosystems, characterized by organic and conventional managements.

## 2. Modelling soil organic carbon dynamics in forest, arable and grassland soils

The Soil Organic Matter Network (SOMNET) database [12] identified 33 SOM dynamics models available for use today and the database is being continuously updated [13]. A great variety of models designed for different spatial scales and time steps can be classified into four groups according to the conceptual approach to SOM turnover in soil: 1) process-based (single or multicompartment), 2) cohort, 3) food-web chain and 4) combined [14, 15].

The most utilized models are process-based multi-compartment, characterized by: a) subdivision of the SOM into several “homogeneous” pools each with its unique decomposition rate, b) assumption that decomposition of SOM follow first-order kinetics, c) defined relationship between the dynamics of C and N pools [16].

The structure of process-based models are represented by C pools of properties pooled with flows of C between the pools [12, 17].

Many different models of a system are developed, where the structure of the model, the processes that have to be included and the degree of simplification that is permitted, are determined by the purpose of the model is developed [9] and by the ecosystem of the model is produced.

A summary of structure and characteristics of some models to simulate the soil organic carbon dynamics and soil nutrients cycling are reported in table 1. These models are created for different soil–plant systems: agricultural, grassland and forest land, some of these are developed afterwards also for the others ecosystems. Most of the existing soil C models are inherently fine-scale, on the order of square meters or hectares, in their original design concept. Many models are structurally complex [10] and assume that decomposition follows first-order kinetics, a constant fractional loss per unit time of different organic matter fractions, with the potential rate being modified by a variety of soil environmental conditions [16]. The temporal and spatial resolutions of models, data and how they are integrated have a major influence on the error and uncertainty of regional estimates. Soil C models are developed within the disciplines of ecosystem ecology and soil science, where the concept, experimentation and data used to derive these models pertained to fine spatial scale, for which assumptions of spatial homogeneity in climate and soil conditions were considered defensible [10].

Yasso is a dynamic soil carbon model used in forestry applications [18, 19]; it simulates the evolution of soil carbon, in terms of carbon release from soil on an annual basis. It needs estimates of litter production, information on litter quality and basic data on climate to run. This is the youngest model described in this work.

**Table 1.** Characteristics of some models utilized for regional study of soil organic carbon. SOM: Soil Organic matter; T: temperature; P: precipitation; TN: Total Nitrogen; MBC: Microbial Biomass; PET: Potential Evapotraspiration; LIG: lignine ; HUM: Humus; ET: actual Evapotranspiration; HI: harvest index.

| | Reference | Input data | time step | Spatial/ temporal scale | List of carbon pools | depth | Systems limitation |
|---|---|---|---|---|---|---|---|
| **Yasso** | [18, 19] | Litter (non-woody, fine woody, coarse woody); monthly and annual air T; precipitation, PET. | year | $m^2$ , years | Litter, SOM (EXT, CEL, LIG, HUM1, HUM2) | Organic soil, 1m mineral soil | only for upland forest soils |
| **ROMUL** | [20] | Litter (leaves, branches, stem, coarse and fine roots); Soil T in organic layer and in mineral layer; Soil moisture; Soil texture; TN. | month, day | $m^2$ , years, month | Litter, SOM (labile and stabile humus) | Organic soil, 1m mineral soil | Only for upland forest soils |
| **Forest-DNDC** | [21, 22, 23] | Plant production, aboveground litter, root litter, Daily min, max or avg Temperature, Rainfall N concentrations and chemical N input, soil texture; | daily | Day, regional | two layers with five pools: very labile litter, labile litter, resistant litter, humads and humus. | 50 cm – 1,5 mineral soil | Only for upland and wetland forest ecosystems |
| **CASA** | [35,36] | Litter, ET, PET, air T and P, irradiation, HI | month | Regional/ continental | SOM pools (active, slow, passive) | organic, top soil (30 cm) and subsoil (1-2 m) | Only for regional scale |
| **ICBM** | [27, 28] | Environmental input to soil, humification coefficient, fraction of initial Y decomposition, fraction of the initial O decomposition | year | ha, Regional year | Young (Y) and old (O) carbon | 0-25 cm | Only two carbon pools described. |
| **DAISY** | [32, 33, 34] | Air T and P; N input ( fertilizer); texture; global radiation | Weekly | ha, years month | SOM pools (added, MBC and dead native) | 40 cm | Not accurate partitioning of carbon pools. Only agricultural soils. |
| **RothC** | [29, 30, 31] | Litter is input externally; monthly air T; PPT & PET or open pan evaporation; clay content, vegetation cover. | Month | Regional / continental scale application | litter (resistant and decomposable); SOM pools (MBC, humus and inert organic matter) | 1 m | Only for upland forest soils |
| **EPIC** | [39, 40] | Daily air T and P; radiation; texture; bulk density, C content. | Daily | Up to 100 ha, year. | Litter (structural and metabolic), SOM pools (MBC, slow humus, passive humus) | From the top soil (5cm) to 1 m. | More long-term studies to develop the model ability. |
| **CENTURY** | [41, 42, 43, 44] | Monthly air T and P; soil texture; litter lignin and N input (fertilizer); nutrient content (N, P, S). | Month, daily | $m^2$ , years, month | Litter (metabolic and structural); SOM pools (active, slow, passive). | 20 cm | Only for top 20 cm, no peatlands, not separate the humified portion of the litter from mineral soils |

ROMUL [20], like Yasso, developed to describe a forest soil organic matter, is based on the concept of succession stages of soil organic matter decomposition marked by different groups of soil fauna. The model allows the calculation of the dynamics of soil organic matter and the corresponding dynamics of nitrogen, including the evaluation of the mineral nitrogen available for plants.

The Forest DNDC model [21, 22] was developed to predict forest growth and production, soil carbon and nitrogen dynamics, carbon sequestration and soil-borne trace gas emissions in upland and wetland forested ecosystems [23]. It integrates two existing models: Wetland –DNDC, a hydrology-driven model [22, 24], and PnET-N-DNDC, an upland forest biogeochemical model [25, 26].

The Introductory Carbon Balance Model (ICBM) was developed as a minimum approach for calculating soil carbon balance in a 30 years period perspective. The model has two carbon pools: Young (Y) and Old (O) soil carbon. This model request five parameters to calculate this two carbon pools: environmental annual input to soil, humification coefficient, fraction of initial Y decomposition per year, fraction of the initial O decomposition per year and external influence coefficient [27]. ICBMr is the model adapted to using annual data classified according to production region, soil and crop types [28].

RothC [29, 30, 31] is Rothamsted C model, in which the turnover of C in aerobic soil is sensitive to soil type, temperature, moisture and plant cover. Nitrogen and C dynamics are not interconnected, the inert organic matter component is quantified using C-dating, and starting values are obtained by running the model to steady-state. This model was validated only for the forest ecosystem.

DAISY model [32, 33, 34] is tested for simulation of soil carbon, water and nitrogen dynamics and crop growth in agro-ecosystems. The model simulates also the production in crop rotations under alternate management strategies.

The Carnegie-Ames-Stanford-Approach (CASA) [35,36] created to estimate the NPP (Net Primary Production) for the agricultural lands, applies an equation that involves the total incident photosynthetically active radiation. Carbon turnover is calculated mechanistically through a process-based plant and soil carbon cycling model [37, 38].

Environment Policy Integrated Climate (EPIC) [39, 40] are tested to simulate many agroecosystem processes including plant growth, crop yield, tillage, wind and water erosion, runoff, soil density and leaching. The modules which describe C and N dynamics are developed afterwards, built on concepts from the CENTURY model.

The CENTURY model, developed for the grassland [41], simulates soil C, N, P and S dynamics, primary productivity and water balance. Subsequent model modifications have expanded its applicability to agricultural systems [42], forest [43] and savannah systems [44].

Clearly the choice of the model depends on parameters evaluation and mainly on quality of forecast, owing to the deviation between the expected distribution of the model and the real situation. The mains criticism from many authors about the utilize of a models depend on the spread opinion that the models tend to reduce a complex natural system on a low number of factors which have a linear interactions and not look on the complex non-linear interactions which affect the system; however the exclusion of these interaction and the simplification does not seem to basically modify the system.

# 3. The CENTURY as carbon balance model of arable soils

## 3.1. An overview of CENTURY model

Created in 1987 by Parton et al. [45] and developed subsequently, this complex model is compartmentalized into 10 subprograms, each with its own parametrization.

The CENTURY model consists of several major submodels: an SOM/decomposition submodel, a water budget submodel, and a plant production submodel [46].

The model, that uses a monthly time-step, requests two kind of soil parameters: a general or non-site specific parameters, which include the maximum specific decomposition rates for each compartment; the constant that splits the flows of decomposition products and the parameters that control the effects on soil texture, temperature and moisture on decomposition rates [47]; a site specific parameters and initial conditions, such a soil texture (sand, silt and clay content), bulk density, soil depth and total soil C and N content.

The weather inputs include mean monthly minimum and maximum temperature, monthly precipitation of several years and standard deviation. Some authors related the use of data set from 20 to 30 years [47, 48]; alternatively, precipitation data could be interpolated using splines or kriging [49] to create a smoother spatial distribution, making the assumption that climate, although variable in short time scales, is constant over the longer periods modelled [50].

The soil organic carbon submodel describes three carbon pools: active, slow and passive.

The scheme of the SOM submodel are reported in fig. 1.

The active pool represents soil microbes and microbial products and has a turnover time ranged between months to few years depending on the environment and sand content. The soil texture influences the turnover rate of the active soil carbon pool (higher rates for sandy soils) and the efficiency of stabilizing active pool into slow pool (higher stabilization rates for clay soils). The slow pool includes resistant plant material derived from the

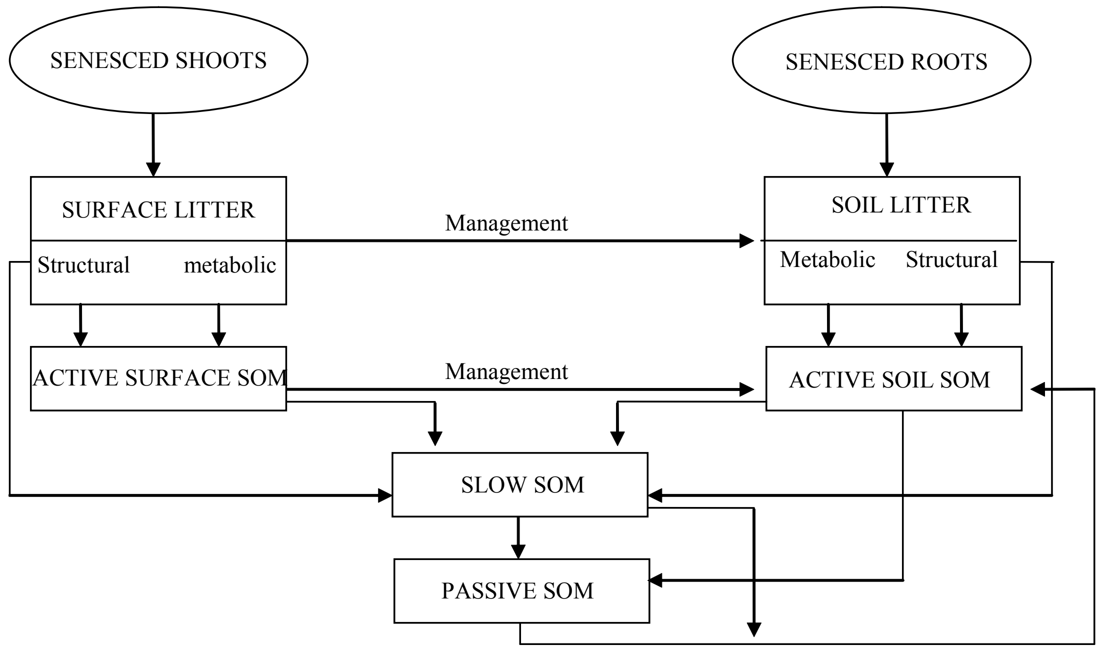


**Figure 1.** CENTURY soil organic matter (SOM) submodel, adapted from Gijsman et al. [11].

structural pool and soil-stabilized microbial products arised from the active pool. The turnover time of this pool ranged from 20 to 50 years. The passive pool is very resistant to decomposition and includes physically and chemically stabilized soil organic matter and has a turnover time ranged between 400 to 2000 years [51]. The percentage of these pools can be calculated by a direct methods using analytical techniques or by a indirect method involving simulation of steady state organic matter levels. The proportions of the decomposition products which enter the passive pool from the slow and active pools increase with increasing soil clay content.

In agroecosystem simulations using CENTURY, management-related driving variables are added to the ecological driving variables. Information can be specified for crop rotations, dates of planting and harvesting, fertilizer and organic amendment addition, herbicide use, grazing, irrigation, fire, tillage practices and erosion [46].

## 3.2. Advantage and limits of CENTURY

CENTURY has been successfully used in temperate ecosystems [3, 52, 53], in tropical agroecosystem [54, 55] and tested on data sets in wheat-fallow agriculture in the US Great Plains. The model was especially developed in the last years, with le latest version 5, to deal with a wide range of cropping system rotations and tillage practices for system analysis of the effects of management and global change on productivity and sustainability of agroecosystems, and it fully couples the carbon, nitrogen and water cycles in the plant-soil system [56].

The accuracy on model detail permitted the development of carbon budget studies between the different management, because the management use 11 parameters representing the various cultivation events, such as the depth of disturbance, the breaking of clods etc…[57].

CENTURY is able to simulate the effects of tillage on soil organic carbon but cannot predict the amount of soil carbon redistribution. Furthermore the model simulates only the top 20 cm and does not separate the humified portion of the litter from mineral soils. For this reason CENTURY does not describe the variation on soil organic matter among the soil horizons and the water content dynamics across the deep layers.

Using the models, several authors showed a limited success of the simulation predicting inter-annual variability of some parameters (yield and N). However, better results were found in the annual prediction on soil organic carbon and nitrogen off- take [52].

The simulation results, obtained in several studies after some model adjustments, made to improve the effects of the main parameters that affect the soil organic matter in areas of study, often underestimate or overestimate, compared to the measured data. Some authors describe from 25% to 70% of underestimate carbon stocks in an agricultural system [58, 47] and Motavalli et al. [55] studying forest soils reported a CENTURY overestimate about 51% on carbon stock.

In tropical soils, where the phosphorous represent a limit for the plant growth, the model simulation cannot be easily applied, as reported by Gijsman et al. [59].

# 4. C balance on soil under organic and conventional management: a case of study in a Mediterranean country

In 2004 italian research group was involved in an international project CarbIUS (Carbon Regional Balance Italy-USA). The general aims of the project were: i) to identify spatial and temporal variability of carbon sources and sinks as well as the relative contribution of the different anthropogenic and biogenic components, ii) to estimate the impact of land use changes and human population dynamics on the carbon balance, iii) to quantify the effects of climate and natural disturbances on the terrestrial carbon stocks and fluxes, iv) to apply a new methodologies to investigate carbon metabolism at the plot, ecosystem and regional scale, for the years 1990 and 2000. The last analysis was to compare all results obtained between Italy and Oregon-California region, both characterized by a mediterranean climate [60].

Inside this project the Soil Organic Carbon (SOC) balance in agricultural Italian lands in the years 1990 and 2000 were investigated using CENTURY ecosystem model v.5. The objective of this work was to assess agricultural Italian soils contribution to atmospheric $CO_2$ enrichment and to estimate whether the agricultural system can be utilized to acquire carbon “credits”, according to Kyoto provisions. In this section we report the results obtained of a CENTURY application in some Italian agricultural sites subjected to organic and conventional management, extrapolated and adapted from Grego et al. [61] and Di Tizio and Grego [62]. In this study CENTURY model, employed utilising input parameters available on national literature, screening monthly data, processing and relating the different parameters from data base (input), carrying out annual SOC balance. SOC annual balance of four Italian sites, were compared. The four sites are located in Center and North of Italy under Mediterranean climate conditions: Frosinone (latitude 41° 38′ 0″ N, longitude 13° 21′ 0″ E), Latina (latitude 41° 28′ 0″ N, longitude 12° 54′ 0″ E ), Capestrano ( latitude 42° 16′ 10″ N, longitude 13° 46′ 0″ E ), Centallo (latitude 44° 30 9″ N, longitude 07° 35′ 20″ E). The four sites are under different management, crops and rotations: maize monoculture in Latina; conventional crop rotation (maize-maize-durum wheat-fallow) in Frosinone, organic crop rotation (sunflower-common vetch-field beans-spelt) in Capestrano and organic apple orchard in Centallo. The management of monoculture and conventional crop rotation are characterized by conventional tillage, chemical inputs (fertilizers) and mechanical weed control; the organic management are characterized by reduced tillage, organic amendments and burial of crop residues. The results of soil carbon pools (active, slow and passive) for each soil are reported in table 2. The initial content of soil organic carbon was highest in the organic apple orchard (2330 g C $m^{-2}$, 2240 g C $m^{-2}$, 2140 g C $m^{-2}$ and 1890 g C $m^{-2}$, for organic apple orchard, conventional monoculture, conventional and organic crop rotation, respectively). The results showed the loss of total organic carbon higher in conventional crop rotation system than monoculture, organic crop rotation and organic orchard (4.2, 2.2, 2.5, and 3%, respectively) in the year 2000. What is interesting to notice from the simulations results about the carbon pools annual balance concerns the difference of losses from the three pools in all management systems: the active carbon pool have the higher loss in both conventional soils than organic soil (55, 61.3, 5.8 and 21 g C $m^{-2}$, respectively), whereas the organic crop rotation soil seems to have the highest loss of carbon from the slow pool (≈ 40 g C $m^{-2}$) and the organic orchard soil showed a small increase of this pool (≈ 40 g C $m^{-2}$). The passive carbon pool showed a similar values for all soils and the annual variation resulted unimportant, due to the high turnover of the passive pool. The carbon losses from the active and slow pools depend on the management events (especially tillage practices), weather and physical characteristics of the three sites, which had a sandy-clay-loam texture; these three parameters bring a larger changes in CENTURY results [51].

**Table 2.** Soil organic carbon pools and annual balance for the four sites in the year 2000 simulated by CENTURY model v.5.

| | Conventional monoculture | | Conventional crop rotation | | Organic crop rotation | | Organic orchard | |
|---|---|---|---|---|---|---|---|---|
| **Initial measured content of SOC (g C $m^{-2}$) (a)** | 2240 | | 2140 | | 1890 | | 2330 | |
| **Final simulated content of SOC (g C $m^{-2}$) (b)** | 2190 | | 2050 | | 1843 | | 2343 | |
| **Annual C balance (g C $m^{-2}$) (a-b)** | - 50 | | -90 | | -47 | | +13 | |
| **Loss of TOC (%)** | 2.2 | | 4.2 | | 2.5 | | -0.5 | |
| **Active C pool (initial – final) (g C $m^{-2}$)** | 180 | 125 | 174.4 | 113.1 | 48.2 | 42.4 | 225 | 204 |
| **Slow C pool (initial – final) (g C $m^{-2}$)** | 1310 | 1290 | 1240 | 1210 | 1100 | 1060 | 1360 | 1400 |
| **Passive C pool (initial – final) (g C $m^{-2}$)** | 743 | 743 | 726 | 727 | 739 | 741 | 741 | 741 |

The variation of carbon pools and total organic carbon occurred in one year have been rather reduced in all soils under different management; however, the soils cultivated under organic management showed a different trend regarding the active and slow pools, confirming a positive trend on soil organic carbon showed in the long term simulation studies [50]. Anyhow further studies in organic managed soils (preferably long-term experiment) are required to understand the accuracy of the model describing the effect of the management on soil carbon dynamics.

The CENTURY model, although applied for a short term simulation, described accurately the soil organic carbon trend affected by several parameters, and made possible a long term prediction on SOC balance in the 0-20 cm simulation layer, but did not show the SOC changes within the soil profile.

In conclusion the application of CENTURY model provided information which are impossible to find with just measured values, as long period studies on SOC evolution at national scale are not available in 1990 and 2000 year, and given possibilities to understand the SOC dynamics.

Generally, the modelling approach on SOC studies permits to complete experimental data and offers possibilities on long period scenario, examining the adoption of alternative management decisions.

The limits of this approach can be solved by focusing a choice of the model, their parameterisation and validation. The differences between the measured and simulated values (underestimate or overestimate of the models) do not prejudice their use, since the models do not replace but support the real conditions.

# References


1. Gordon W.S., Famiglietti J.S., Fowler N.L., Kittel T.G.F., and Hibbard K.A. 2004, Ecol.Appl. 14(2), 527.
2. McGuire A.D., Melillo J.M., Kicklighter D.W., and Joyce L.A. 1995, J.Biogeogr., 22, 785.
3. Parton W.J., and Rasmussen P.E. 1994, Soil Sci. Soc. Am. J., 58, 530.
4. Jenkinson D.S., and Rayner J.H. 1977, Soil Sci., 123, 298.
5. Parton W.J., Stewart J.W.B., and Cole C.V. 1988, Biogeochemistry, 5, 109.
6. Pastor J., and Post W.M. 1985, Development of a Linked Forest Productivity-Soil Process Model. Oak Ridge National Laboratory Environmental Sciences Division, Publication No 2455, NTIS, Springfield, VA.
7. Smith O.L. 1982, Soil microbiology: A model of decomposition and nutrient cycling. CRC Press Inc. Boca Raton. FL.
8. Somaratne S, Seneviratne G., and Coomaraswamy U. 2005, Soil Sci. Soc. Am. J., 69, 1580.
9. Van Keulen H. 2001, Nutr.Cycl.Agroecosys., 61, 33.
10. Paustian K., Levine E., Post W.M., Ryzhova I.M. 1997, Geoderma, 79, 227.
11. Gijsman A.J., Hoogenboom G., Parton W.J., and Kerridge P.C. 2002, Agron. J., 94, 462.
12. Molina J.A.E., Smith P. 1998, Modeling carbon and nitrogen processes in soils, advances in agronomy. In: Advances in Agronomy, vol.62, San Diego: Academic Press, 253.
13. Polyakov V., Lal R. 2004, Environ. Intl., 30, 547.
14. McGill W.B. 1996, Review and classification of ten soil organic matter (SOM) models. In: Powlson D.S., Smith P., Smith J.U., editors. Evaluation of soil organic matter models. Berlin: Springer, 111.
15. Smith P. 2002, Organic matter modeling. In: Lal R., editor. The encyclopedia of soil science. New York: Dekker, 917.
16. Paustian K. 1994, Modeling soil biology and biochemical processes for sustainable agriculture research. In: Pankhurst Z.E., Doube B.M., Gupta V.V.S.R., Grace P.R., editors. Soil biota management in sustainable farming systems. Melbourne: CSIRO Information Services, 182.
17. Parton W.J., Ojima D.S., Cole C.V., Schimel D.S. 1994, A general model for soil organic matter dynamics: sensitivity to litter chemistry, texture and management. In: Bryant R.B., Amold R.W., editors. Quantitative modelling of soil forming processes. SSSA Special Publication, vol.39. Madison, WI, USA: Soil Science Society of America, 147.
18. Liski J., Palosuo T., Peltoniemi M., Sievanen R. 2005, Ecol.Model., 189, 168.
19. Peltoniemi M., Palosuo T., Monni S., Mäkipää R. 2006, For. Ecol. Manag., 232, 75.
20. Chertov O.G., Komarov A.S., Nadporozhskaya M., Bykhovets S.S., Zudin S.L. 2001, Ecol. Model., 138, 289.
21. Li C.S., Frolking S., Frolking T.A. 1992, Geophys. Res.-Atmosph. J., 97, 9759.
22. Zhang Y., Li C.S., Trettin C.C. 2002, Glob. Biogeochem. Cycles, 16.

23. Miehle P., Livesley S.J., Li C.S., Feikema P.M., Adams M.A. and Arndt S.K. 2006, Glob. Ch. Biol., 12, 1421.
24. Cui J., Li C.S., Sun G. 2005, Biogeochem., 72, 147.
25. Li C.S., Aber J., Stange F. 2000, Geophys. Res.-Atmosph. J., 105, 4369.
26. Stange F., Butterbach-Bahl K., Papen H 2000, Geophys. Res.-Atmosph. J., 105, 4385.
27. Andrèn O., and Kätterer T. 2001. Basic principles for soil carbon sequestration and calculating dynamic country-level balances including future scenarios. In: Lal R., Kimble J.M., Follett R.M. and Stewart B.A., editors. Assessment Methods for Soil Carbon . Lewis Publishers, Boca raton, FL, 495.
28. Andrèn O., Kätterer T., Karlsson T. 2004, Nutri. Cycl. Agroecosyst., 70, 231.
29. Coleman K., & Jenkinson D.S. 1996. RothC.-26.3, A model for the turnover of carbon in soil. In: Evaluation of Soil Organic Matter Models using Existing Long-Term Datasets (eds D.S. Powlson, P.Smith & J.U. Smith), 237, NATO ASI Series I, Vol.38, Springer-Verlog, Heidelberg.
30. Jenkinson D.S., Rayner J.H. 1977, Soil Sci., 123, 298.
31. Jenkinson D.S., Hart P.B.S., Rayner J.H., Parry L.C. 1987, Intecol Bull., 15, 1.
32. Hansen S., Jensen H.E., Nielsen N.E., Svendsen H. 1991, Fertil. Res., 27, 245.
33. Abrahamsen P., Hansen S. 2000, Environ. Model. Soft., 15, 313.
34. Mueller T., Magid J., Jensen L.S., Svendsen H., Nielsen 1998, Ecol. Model., 111, 1.
35. Potter C.S., Randerson J.T., Field C.B., Matson P.A., Vitousek P.M.V., Mooney H.A., Steven A.K. 1993, Glob. Biogeochem. Cycles,7, 811.
36. Field C.B., Randerson J.T., Malmstrom C.M. 1995, Remote Sens. Environ., 51, 74.
37. Tao F., Yokozawa M., Zhang Z., Xu Y., Hayashi Y. 2005, Ecol. Model., 183, 385.
38. Fujita D., Ishizawa M., Maksyutov S., Thornton P.E., Saeki T., and Nakazawa T. 2003, Tellus, 55B, 530.
39. Wiliams J.R. 1995. The EPIC model. In: Singh, V.P. (ed.), Computer Models of Watershed Hydrology. Water Resources Publications, Highlands Ranch, CO, 909.
40. Izaurralde R.C., Wiliams J.R., McGill W.B., Rosenberg N.J., Quiroga Jakas M.C. 2006, Ecol. Model., 192, 362.
41. Parton W.J., Schimel D.S., Cole C.V., Ojima D.S. 1987, Soil Sci. Soc. Am. J., 51, 1173.
42. Paustian K., Parton W.J., Persson J. 1992, Soil Sci. Soc. Am.J., 56, 476.
43. Sanford R.L., Parton W.K., Ojima D.S., Lodge D.J. 1991, Biotropica., 23, 364.
44. Seward P.D., Woomer P.L. 1993, Use of CENTURY model to simulate the effects of erosion control, stover management and manuring on field maize at Kabanyolo, Uganda. Tropical Soil Biology and Fertility Programme, Nairobi, Kenya.
45. Parton W.J., Schimel D.S., Cole C.V., Ojima D.S. 1987, Soil Sci. Soc. Am. J., 51, 1173.
46. Metherell A.K., Harding L.A., Cole C.V., Parton W.J. 1993. CENTURY soil organic matter model environment: technical documentation, Agroecosystem Version 4.0. Great Plains Systems Research Unit Technical Report No 4. USDA, Fort Collins, CO.
47. Carvalho Leite L.F., de Sà mendonça E., de Ameida machado P.L.O., Fernandes Filho E.I., Lima Neves J.C. 2004, Geoderma, 283.
48. Ardö J., & Olsson L. 2003, J. of Arid Environm., 54, 633.

49. Seaquist J.S. 2001, Mapping primary production for the west African Sahel with satellite data. Ph.D. thesis, Lund, Lund University, 59.
50. Adderley W.P., Simpson I.A., Lockheart M.J., Evershed R.P., and Davidson D.A. 2000, Human Ecol., 28 (3), 415.
51. Natural Resource Ecology Laboratory 2004, Century Soil Organic Matter Model User's Guide and reference, Colorado State University, Fort Collins, CO USA.
52. Kelly R.H., Parton W.J., Crocker G.J., Grace P.R., Klir P.R., Korschens M., Richter D.D. 1997, Geoderma, 81, 75.
53. Del Grosso S.J., Parton W.J., Mosier A.R., Hartman J., Brenner D.S., Ojima D.S., Schimel D.S. 2001, Simulated interaction of soil carbon dynamics and nitrogen trace gas fluxes using the DAYCENT model. In: Modeling Carbon and Nitrogen Dynamics for soil management (Shaffer M.J., MA L., Hansen S. Eds), 303, Lewis publishers, Boca Raton, FL.
54. Parton W.J., Sanford R.L., Sanchez P.A., Stewart J.W.B. 1989, Modeling soil organic matter dynamics in tropical soil. In: Dynamics of soil organic matter in Tropical Ecosystems (Coleman D.C., Oades J., Uehara M.), 153.
55. Motavalli P.P., Palm P.C.A., Parton W.J., Elliot E.T., Freys S.D. 1994, Biol.Biochem., 26, 935.
56. Levy P.E., Wendler R., Van Oijen M., Cannel M.G.R., Millard P. 2004. Water Air Soil Poll. 4, 67.
57. Zimmerman P.R., Price M., Peng C., Capehart W.J., Updegraff K., Kozak P., Vierling L., Baker E., Kopp F., Duke G., Das C. 2005. Mitigation and Adaptation Strategies for Global Change 10, 307.
58. Pennock D.J., Frick A.H. 2001. Soil & till. Res. 58, 183.
59. Gijsman A.J., Oberson A., Tiessen H., and Friessen D.K. 1996. Agron.J., 88, 894.
60. Papale D., Castaldi S., Ciccioli P., Corona P., Di Tizio A., Masci A., Miglietta F., Reichstein M., Vannini A., Valentini R., 2005. Assessment of full carbon budget of Italy: the CarbIUS project. Fourth Annual Conference on Carbon Capture & Sequestration . May 2-5, Alexandria Virginia.
61. Grego S., Di Tizio A, Papale D. 2005. Stima del bilancio del carbonio su scala regionale: Progetto CARBIUS. Atti del Convegno Nazionale della Società Italiana Scienza del Suolo (SISS), Bari, 21-24 giugno.
62. Di Tizio A., Grego S. 2006. Soil organic carbon balance and CO2 emission from agricultural italian land modelling with CENTURY. Acts of International Workshop of Development of Models and Forest Soil Surveys for Monitoring of Soil Carbon, Koli, Finland, 5-8 April.