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Simulating trends of soil organic carbon in seven long-term experiments using the SOMM model of the humus types

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Abstract

Using the SOMM model of the humus types (Mor, Moder, Mull), simulations of SOM dynamics at seven long-term experiments were attempted as a part of a model evaluation exercise. The model comprises three compartments (undecomposed litter, partially humified litter, humus of mineral topsoil) and considers six processes of mineralization and humification as influenced by litter nitrogen and ash contents, soil C/N ratio, temperature and moisture. Results of simulations performed without any site-specific calibration mostly underestimate soil organic matter (SOM). Despite this lack of precision, general trends in SOM over time were often captured. Success of simulation was limited by difficulties in obtaining direct information about soil moisture regime, litter quantity and litter quality (nitrogen and ash content). Inadequacies in the model, such as no

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consideration of soil properties, may also account for some of the errors. Despite the limited success of the evaluation, it is encouraging that the model conceived for forested ecosystems, with additional development, may be applicable to non-forested systems. The exercise underlines the necessity of constant direct contact between modeller and data holder for a success of an evaluation.

Keywords: soil organic matter; humus types; modelling; long-term SOM experiments; model evaluation

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1. Introduction

The model of soil organic matter dynamics (SOMM) represents a quantification of the 'humus types' concept (Mor, Moder and Mull) existing in Forest Pedology since the last century (Müller, 1887; Wilde, 1958; Duchaufour, 1961). It is a very fruitful concept unifying pedogenetic, biological, silvicultural and ecological aspects. The SOMM model was created firstly as a tool for theoretical analysis, and has been used to examine the soil compartment in a forest ecosystem model (Chertov, 1990; Chertov and Komarov, 1997b).

The experimental basis for the SOMM model is a set of classical laboratory experiments on how the rate of organic litter decomposition in controlled conditions is affected by temperature, moisture and chemical composition of the material (Kostychev, 1889; Waxman and Tenney, 1927; Waxman and Gerretsen, 1931; Kononova, 1951; Mikola, 1954; Alexandrova, 1970). The experiments allowed quantification of the activity of the complex of microorganisms (*Fungi*, *Actinomycetes* and *Bacteria*) and micro fauna. Data from laboratory experiments by Chernova (1978) for soil arthropods, and for earthworm activity (Perel and Sokolov, 1964; Striganova et al., 1987), have been used to quantify the role of these decomposers in organic debris humification. The model represents three compartments (*L*, undecomposed litter; *F*, partially humified litter; *H*, humus of mineral topsoil) considering six processes of mineralization and humification by three groups of organisms-decomposers influenced by litter nitrogen and ash contents, soil C/N ratio, temperature and moisture (Fig. 1). SOMM is perhaps the only model in the evaluation exercise which has (1) data from laboratory experiments entirely as a model basis; (2) consideration of both microorganisms and soil fauna activity in SOM transformations; (3) organic (*L* and *F*) and mineral (*H*) fractions of SOM.

The SOMM model has undergone preliminary evaluation by independent short-term laboratory and field experiments. It has also been used for a wide range of qualitative simulations of humus profile formation in all natural zones. The first version of the model (Mor model) and the present form have been fully reported by Chertov (1985, 1990) and by Chertov and Komarov (1995, 1996, 1997a). Described below are the results of an evaluation of the SOMM model

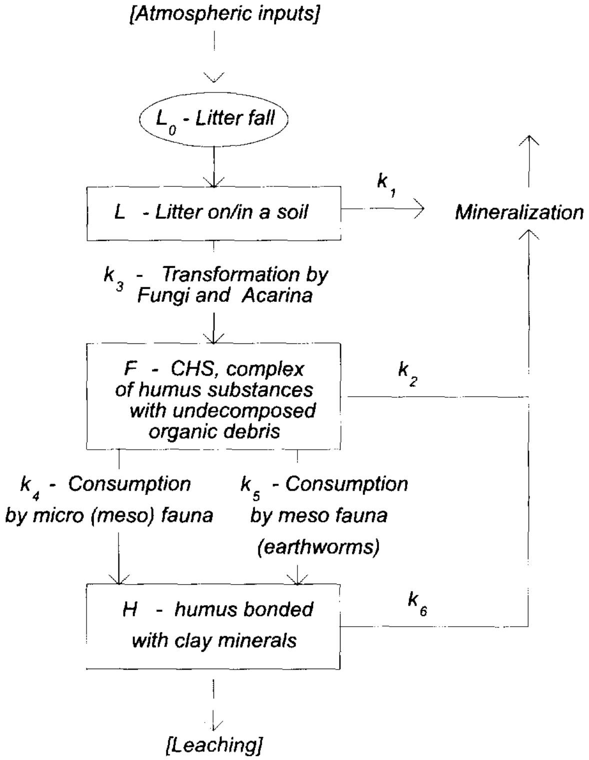

Fig. 1. Flow chart of the SOMM model.

using long-term field experimental datasets from different countries and various land uses.

2. Materials and methods

The following input parameters are necessary to run the model: total litter mass (crop and root residue); nitrogen and ash content of the litter, %; data on soil moisture regime as daily or monthly means, mass %; soil temperature data; initial SOM and soil nitrogen content in model compartments (L,F,H). The procedure for compiling the input parameters is outlined below because some were absent from the datasets and had to be calculated. The Rothamsted scenarios are described below in detail; similar procedures were repeated for the other datasets. The most important input data for all experimental plots are shown in Table 1. The datasets used are described in detail in Smith et al. (1997).

Table 1
Input parameters of crop residue mass, nitrogen and ash content and soil moisture data used in simulation scenarios

Experiment	Treatment and/or crop	Litter C input (t/ha)	Litter N (%)	Litter ash (%)	Moisture of mineral topsoil (mass%/month[a])		Initial soil	
					maximal	minimal	C (t/ha)	N (t/ha)
Rothamsted Park Grass	Nil, hay	0.05–0.70	1.3	6.0	50.0/1	2.0/8	93.3	6.70
	Farmyard manure, hay	0.35–1.30					96.9	6.80
	Sodium nitrate, hay	0.50–1.25					86.1	6.60
Rothamsted Geescroft Wilderness	Broadleaved forest	3.14	1.3	6.0	50.0/1	2.0/8	53.5	3.10
Bad Lauchstädt	Sugar beet	0.50	1.2	5.0	20.0/9	12.0/7	88.3	7.60
	Spring barley	0.40–1.50	1.0	6.0				
	Potatoes	0.25–0.90	1.2	2.0				
	Winter wheat	0.60–1.70	1.0	6.0				
Prague–Ruzyne	Cereals	1.0	1.0	6.0	20.0/4	14.0/7	52.5	6.40
	Sugar beet	0.25	1.2	5.0				
Calhoun	Loblolly pine plantation	0.80–3.40	0.40	2.0	50.0/1	24.0/10	31.5	0.40
Tamworth	Lucerne + clover	0–0.32	2.5	10.0	35.0/8	1.0/2	64.4	6.50
	Wheat	0–0.26	1.0	6.0				
Waite	Wheat	0.01–0.08	1.0	6.0	25.0/6	5.0/1	52.8	4.80

[a] Months' names expressed as their numbers.

2.1. Rothamsted Park Grass

Three plots, cut for hay twice annually since 1856 and having different fertilizer regimes were used (Table 1). Total litter input as grass roots and litter was calculated every year using data from the hay harvest. At the start of simulation a 20/80 hay/litter ratio was used for the total litter inputs based on grassland biological productivity data (Rodin and Bazilevich, 1965, Makarevich et al., 1978). However, the estimate of Poulton (1995), a 50/50 ratio has been used in the scenario, though the modellers question whether this is correct. The nitrogen and ash content of plant residues in the experiment have been set to 1.3 and 6.0% respectively.

Soil moisture, as monthly mean values (mass %) in 0–50 cm layer, have been calculated for the period 1959–1991 as

$$W_{\mathrm{min}} = W_0 + (\mathrm{RAIN} - \mathrm{EVAPG}) * 100/(500 * 1.2)$$

where W_{min} is soil moisture (%); W_0 is initial soil moisture; RAIN is monthly rainfall (mm); EVAPG is evaporation over grass (mm), corresponding to evapotranspiration from grass vegetation. If the calculated soil moisture was higher than water holding capacity (50%) then we assumed that soil moisture was 50%, because excessive water percolates down the soil profile. The moisture of organic compartments L and F has been postulated as being equal to 5 W_{min}. For the period before 1959 the soil moisture regime has been assumed constant for 83 years.

Because SOMM treats data on SOM only, the initial soil carbon contents (%) have been recalculated to SOM (kg m^{-2}) using data on the A1 layer thickness, bulk density and a coefficient 2.0 (instead of standard 1.774) for conversion of organic C to SOM. We have used this coefficient on the basis of a comprehensive study of Ponomareva and Nikolaeva (1980) showing that the carbon content of humic substances corresponds to 50% in temperate zone soils. Because the division of the total SOM pool into two compartments (F and H) is obligatory to run the SOMM model, the initial SOM content in all datasets was been separated into two parts in the ratio of 10/90 for F and H, taking into account the most frequent proportion of litter SOM/topsoil SOM. The simulations at Rothamsted Park Grass have been run for the A1 horizon only (0–23 cm).

The dry matter content of farmyard manure was calculated as 20% of fresh material. Using preliminary verification data (Chertov and Komarov, 1997a) the organic manure input in the SOMM model in all exercises has been treated as a partially humified material (F) because: (1) there is some basis for this in reality; (2) if the organic manure is considered as an input of undecomposed litter (L), then the model shows large simulation errors. The nitrogen content in mineral fertilizers has been used as an input parameter for running the model.

The time of simulation was 116 years since the first soil carbon measurements were made in 1876. Some preliminary runs with various hay/litter ratios for the 33-year period after 1959 were made when more precise data for soil moisture could be calculated.

2.2. Rothamsted Geescroft Wilderness

The dataset represents a small plot of former agricultural lands left for natural afforestation at Rothamsted Experimental Station since 1883, and now it is a mixed broadleaved forest. Because total litter input in forest ecosystems is 1.5–2.5 higher than leaf litter fall (due to high levels of root debris), the annual litter input is estimated to be twice that of the measured data for leaf litter (1.57 t C/ha). Nitrogen and ash content of the total litter has been postulated as 1.3 and 6% respectively. The simulation of Rothamsted Geescroft Wilderness was run for a 33-year period only (1959–1991) using the more precise dataset on soil moisture calculated for Rothamsted Park Grass. The initial amounts of C and N in 1959 have been interpolated from the data for 1904 and 1965 using the idea of 'equivalent thickness' because of the increasing thickness of the humus horizon and the resulting decrease in bulk density. The simulation of SOM dynamics have been carried out for the A1 horizon, taking into consideration the 'equivalent thickness', and the forest floor.

2.3. Bad Lauchstädt and Prague–Ruzyne

These two Central European datasets represent the results of long-term agricultural experiments with different rotation systems and various fertilization treatments. The simulation scenarios for the datasets have been compiled in the same way as for Rothamsted Park Grass.

The amount of crop residues (litter fall) in Bad Lauchstädt for winter wheat, spring barley and potatoes has been calculated as the proportion of the crop yield (0.4, 0.36 and 0.05 of whole crop dry matter respectively) on a basis of data provided by E. Ritzkowski (pers. commun.). The sugar beet residues were set to 1 t/ha independent of yield. The ash and nitrogen contents in crop residues (roots mostly) have been compiled as represented in Table 1. Because of the absence of data on evapotranspiration for different agricultural crops the soil moisture regime has been assumed to be optimal for all years of simulation, i.e. without periods of high winter moisture or summer drought. The model runs were for the A1 horizon only (0–30 cm).

Fixed amount of plant residues were used for simulation of the Prague–Ruzyne dataset: 2 t/ha for cereals and 0.5 t/ha for sugar beet with the same nitrogen and ash contents as for Bad Lauchstädt. The same approach regarding the soil moisture regime was used as at Bad Lauchstädt. Simulations were performed for the 0–50 cm soil layer at Prague–Ruzyne.

2.4. Calhoun Experimental Forest

The dataset is for a loblolly pine plantation on former agricultural land in southeast USA, so recorded data on needle litter input and its nitrogen and ash content were available. The litter input has been increasing for 15 years from the beginning of loblolly pine growth to a maximal value corresponding to 6.8 t/ha of total litter fall (leaf and root litter, calculated in the same way as for Rothamsted Geescroft), that is 3.4 t C/ha annually. The most difficult part in initialising the Calhoun Experimental Forest scenario was a compilation of soil

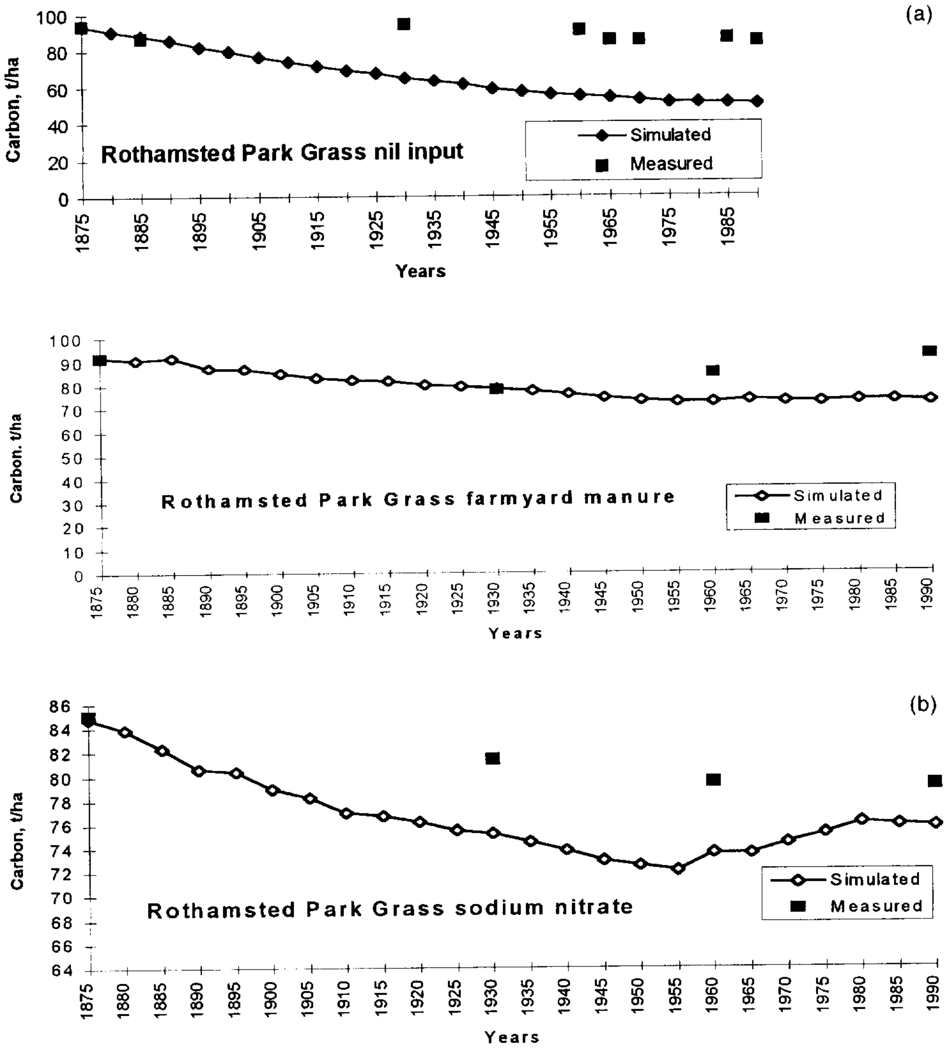

Fig. 2. Results of SOMM runs with the Rothamsted Park Grass datasets for humus horizon (0–23 cm).

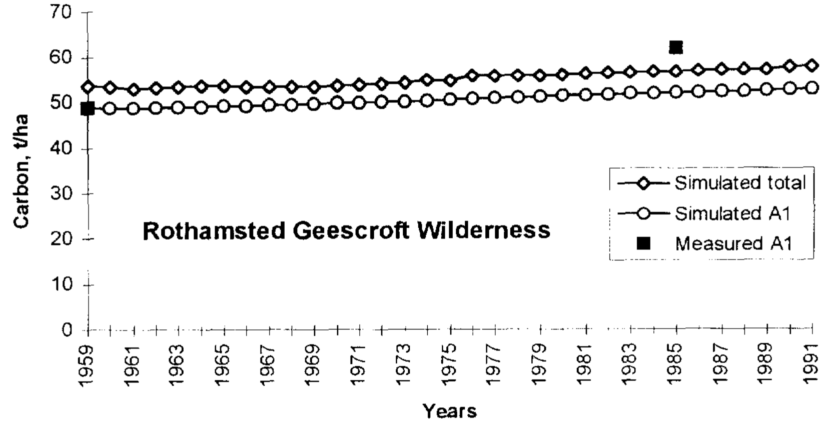

Fig. 3. Results of SOMM run with the Rothamsted Geescroft Wilderness dataset in 'equivalent depth' of humus horizon and forest floor.

moisture regime, because of a lack of data on tree canopy transpiration; this was estimated using the modeller's and dataholder's personal experience. The scenario uses the same soil moisture regime each year. Runs of the Calhoun Experimental Forest dataset were performed for the 0–35-cm layer of topsoil and the forest floor.

2.5. Tamworth and Waite

The two Australian arid zone datasets (Tamworth and Waite) generalize the results of long-term agricultural experiments with different rotation systems. The annual litter input in Tamworth and Waite was estimated using the same approach as used for Bad Lauchstädt with the same nitrogen and ash content.

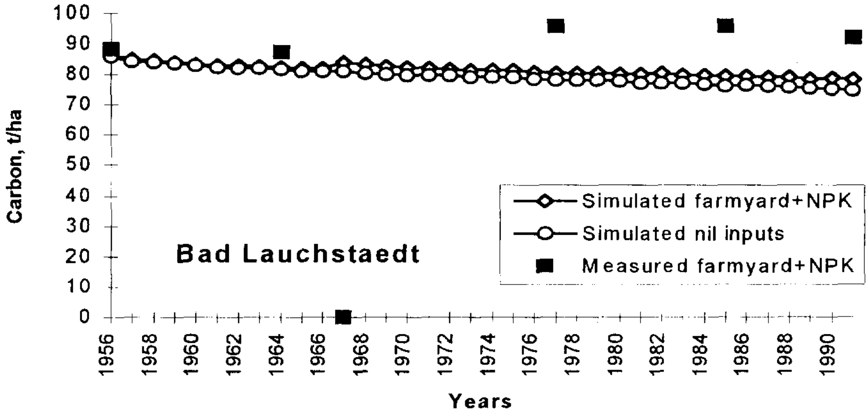

Fig. 4. Results of SOMM runs with the Bad Lauchstädt dataset for humus horizon (0–30 cm).

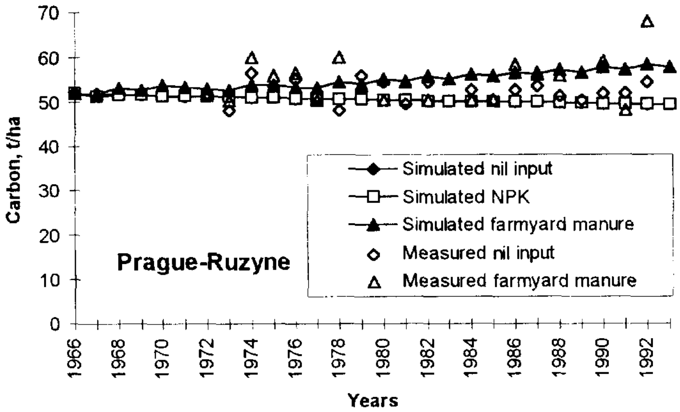

Fig. 5. Results of SOMM runs with the Praha–Ruzyne dataset for 50 cm soil layer. Simulated NPK curve overlaps nil input curve in the figure.

The water regime was obtained with the approach used for Rothamsted Park Grass. An additional difficulty in calculating the water regime is the phenomenon of intra-soil water condensation in dry months in arid zones though the other reason for such a relatively high soil moisture during dry months could be the influence of the ground-water table, which is thought to be a factor of Vertisol formation in Tamworth. The occasional experimental data-point at Tamworth showing a relatively high soil moisture (up to 30% in 20–30 cm layer) during dry months when it must be equal to zero in topsoil, also suggests that ground water is exerting an influence on soil moisture. As a result, the soil moisture estimates were compiled with increased water contents during dry periods. It was only possible partially to take this into account for Waite

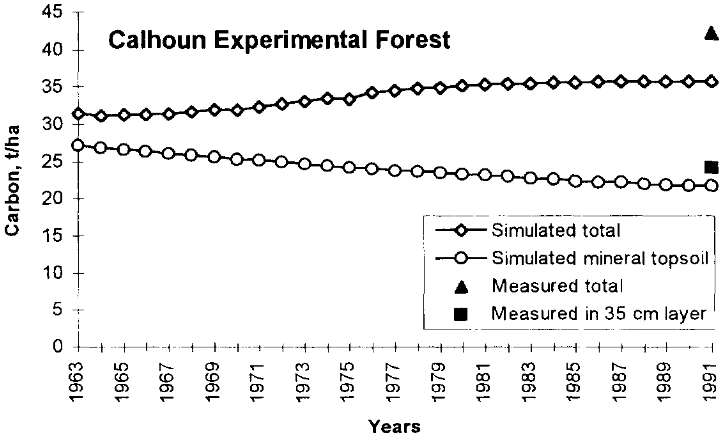

Fig. 6. Results of SOMM runs with the Calhoun Experimental Forest dataset for 35 cm soil layer and forest floor.

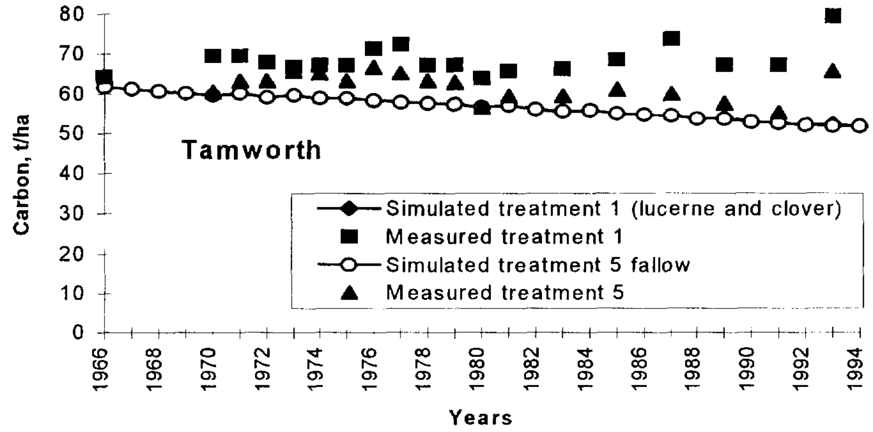

Fig. 7. Results of SOMM runs with the Tamworth dataset for 50 cm soil layer. Simulated results of treatment 5 practically fully overlap those of treatment 1 in the figure.

Alfisols, however, because of the absence of any obvious influence of ground water. For Tamworth and Waite, the simulations have been made for the 0–50-cm layer of topsoil.

2.6. All datasets

The results of the simulations are represented graphically for each dataset (Figs. 2–8, 10). Additionally the generalized results are expressed as a comparison of $\Delta C_{\text{simulated}}$ versus $\Delta C_{\text{measured}}$ where $\Delta C =$ (simulated or measured C at time t) − (measured initial C) in Fig. 9. In all the simulations the initial measured C was set to initial simulated C. Because very frequent measurements of SOM were made at Prague–Ruzyne and Tamworth, only every fifth value

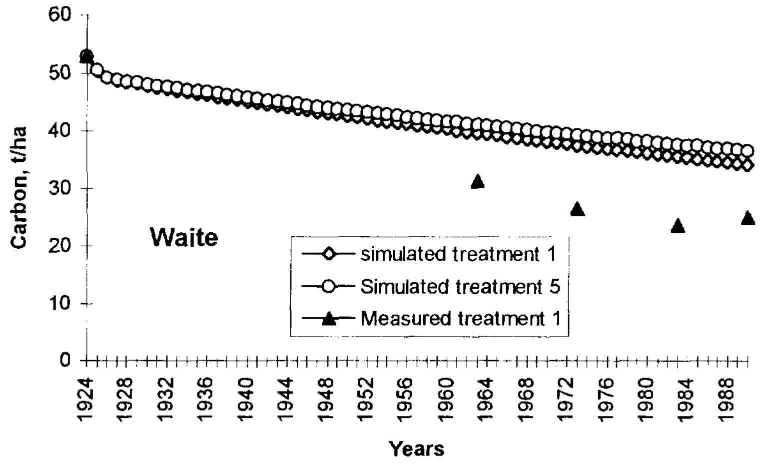

Fig. 8. Results of SOMM runs with the Waite dataset for 50 cm soil layer.

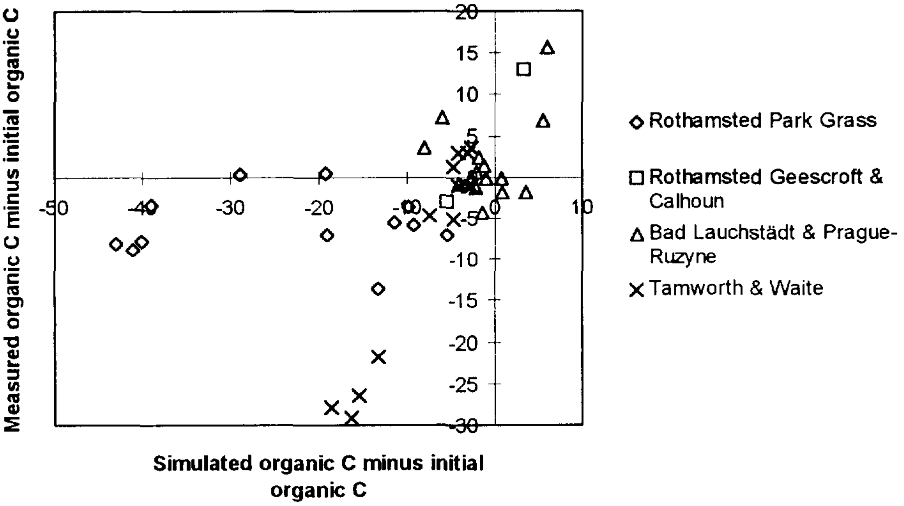

Fig. 9. Simulated versus measured carbon changes in comparison with initial C level (t/ha) at SOMM evaluation.

was used for Fig. 9, to avoid placing undue weight upon these datasets in the overall evaluation.

It should be noted that no site-specific calibration was performed in the course of any simulation. The modellers believe that such calibration is methodologically incorrect, allowing almost any model to achieve satisfactory results. The procedure for compiling scenarios for the evaluation of SOMM includes possible sources of simulation error other than the absence of site-specific calibration. These include the difficulty in calculating total litter input at agricultural sites, and its nitrogen and ash content and, particularly, great

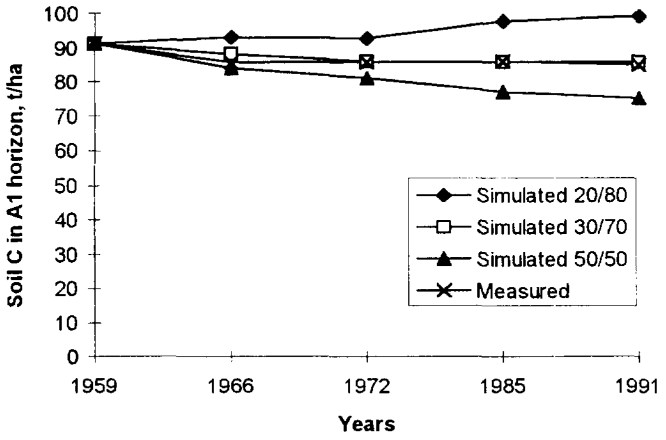

Fig. 10. Effect of hay/litter ratio (used for accounts of total litter) on precision of simulation at Rothamsted Park Grass nil input for 33 years.

problems in calculating soil moisture levels. Tamworth was the only dataset with directly measured soil moisture which was surprising to the modellers since soil water regime data are widely available in Russian studies.

3. Results and discussion

The simulation of Rothamsted Park Grass data (Fig. 2) shows a regular underestimation of the carbon pool in the humus horizon. With the nil input treatment, the simulation demonstrates a decreasing SOM content while the measured content is practically stable. At the same time, the preliminary results for 1959–1991, with more precise soil moisture data, show a more accurate simulation when (a) a hay/litter ratio of 20/80 is used, (b) a 30/70 ratio for SOM pools in the A1 layer, and the whole soil profile (double the initial A1 pool) are used. The effect of different hay/litter ratios is shown in Fig. 10. Our findings are supported by Makarevich et al. (1978) who showed that the ratio of above ground/below ground phytomass (and litter) changes for different soils: with richer soil conditions, there are less roots and thus less dead root input. As a result of this, total litter for unfertilized and fertilized treatments should be based on different hay/litter ratios but this has not been taken into consideration in the simulations. The estimate for a grass root debris input of 20% of measured root mass (Poulton, 1995) is considered to be too small because of the known high rate of fine root production and death in grasslands during the growing season (Rodin and Bazilevich, 1965). The absence of directly measured data on the contribution of roots to the decomposing organic matter is a problem when modelling trends in SOM content.

The simulation of Bad Lauchstädt and Tamworth agricultural datasets (Figs. 4 and 7) demonstrates the same tendency to underestimate the SOM content. The Prague–Ruzyne and Waite datasets (Figs. 5 and 8) suggest different tendencies. Prague–Ruzyne simulations show good correspondence to measured data. Simulations of the Waite datasets demonstrate, surprisingly, an overestimation of final soil carbon content which could be the result of uncertainty in calculating litter input and soil moisture.

The simulation of forest datasets (Geescroft, Fig. 3; Calhoun, Fig. 6) shows the underestimation of SOM carbon pools in mineral topsoil. This is, in part, due to the absence of data on the contribution of ground vegetation to total litter input. In the Rothamsted broadleaved forest and in a sub-tropical loblolly pine plantation on former agricultural land, the ground vegetation plays an important role in the biological cycle. However, there are no data on its biomass in the datasets used. Furthermore, some uncertainty also exists when calculating root litter, this being a potential source of simulation errors. Nevertheless, the illustration of SOM formation is totally realistic in both cases. In the Rothamsted Geescroft Wilderness (Fig. 3) the SOM accumulation in the A1 horizon takes place with a small stable pool of forest floor corresponding to the Mull humus type. In the Calhoun Experimental Forest (Fig. 6) the formation of Mor (raw humus) with a strong accumulation of the forest floor has been clearly detected. Moreover the model indicates a stable 'behaviour': the changes in litter input in Rothamsted Geescroft Wilderness simulations and a 3-fold increase of litter input (up to 10 t C/ha) in the Calhoun dataset, when used in preliminary SOMM runs, leads to the formation of the same humus types. The other models evaluated do not simulate the formation of the humus profile of forest soils.

The general trends in comparison of simulated versus measured organic carbon changes are represented in Fig. 9. It shows that SOMM both underestimated and overestimated organic carbon changes at different sites. Rather few results show good correspondence between measurements and simulation. What are the reasons for the relatively poor model performance?

The modellers are surprised that the results generated by SOMM show such realistic (but not precise) estimates of SOM dynamics because (1) SOMM was initially a forest model being created for theoretical analysis, and (2) there are many uncertainties in the scenarios used. These uncertainties, potentially forming a large source of errors, include the following. (a) The amount of total litter (carbon input to soil) has not been directly measured except for litter fall in the two forest datasets; they have mainly been estimated. Variation of these values can lead to large changes of simulated results. For example, for litter inputs we used the estimated hay/litter ratio of 50/50 for Rothamsted Park Grass but this gave poor results (Fig. 2). Using different proportions (Fig. 10) we could achieve a very precise simulation with 1.8% error. (b) There are no directly measured data on litter nitrogen and ash content except for the Calhoun dataset. (c) Soil moisture data have been compiled and sometimes estimated on a basis of modellers' and dataholders' scientific intuition; Rothamsted Park Grass and Geescroft Wilderness datasets only have the more accurately calculated parameters of soil moisture for 1959–1991. These uncertainties in scenario compilation may lead to irregular errors of SOMM simulation results. Manipulating the parameters of litter input, its chemical properties and soil moisture within realistic limits would be expected to improve the simulations.

It seems to us that the lack of data on litter input and soil water regime could restrict the application of SOMM to agricultural situations. None of the SOM models discussed in this issue uses direct data on soil moisture, but rather use evapotranspiration as an integral parameter influencing SOM mineralization; see also Pastor and Post (1985). So to run SOMM, a soil hydrological sub-model is needed. However, it is the modellers' opinion that using evapotranspiration as a basis is a serious drawback because such the models cannot be used for simulation of SOM dynamics itself where composts or mulches have been used which may affect evaporation, or in bare soil or industrial land having no vegetation cover. Furthermore, the idea of 'litter fall' existing in forest ecology is not always understood by agronomic scientists who may identify litter fall with above-ground crop residue without consideration of both root debris and litter chemical properties.

Some imperfections in the SOMM model could also be sources of simulation errors. In the model: (1) SOM transformation rates are not dependent on soil properties; only nitrogen and ash content of fresh litter and C/N ratio of stable humus are considered in the model; (2) the model treats SOM in mineral horizons altogether, without division into layers; (3) there is no clear division of humified organic material (F) into a pool of A0 (humified forest floor) and the same of mineral topsoil ('labile humus'); (4) all the calculations are as SOM (not as carbon); (5) some rate variables need additional experimental validation; especially the rate of stable humus mineralization (k_6 in Fig. 1) which may be too high causing a high rate of humus mineralization, perhaps leading to regular underestimation of the SOM pool in mineral topsoil. A long-term laboratory experiment is currently being performed in an attempt to solve these problems.

The results obtained in the model evaluation are a good starting point for the further development of SOMM. On the basis of this evaluation exercise we conclude that for the most fruitful results to be obtained, an evaluation must be conducted with constant direct contact between modeller and dataholder, and with the inclusion of local agro(forest)-ecophysiologists, soil hydrologists and other specialists if necessary.

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References

Alexandrova, L.N., 1970. Istochniki gumusovyh veshchestv v pochve. Trans. Leningrad Agric. Inst. 142, 5–25.

Chernova, N.M., 1978. Ekologicheskie suktsessii pri razlodzenii rastitelnyh ostatkov. Nauka, Moscow.

Chertov, O.G., 1985. Imitatsionnaya model mineralizatsii i gumifikatsii lesnogo opada i podstilki. Zhurn. Obshchey Biologii (Journal of Fundamental Biology, Moscow), 46 (6): 794–804 (with English summary).

Chertov, O.G., 1990. SPECOM—a single tree model of pine stand/raw humus soil ecosystem. Ecol. Modelling 50, 107–132.

Chertov, O.G., Komarov, A.S., 1995. On mathematical theory of soil forming processes, I. Theoretical background; II. SOMM—a model of soil organic matter dynamics; III. Basic ideas of a mineral phase modelling. Pushchino Res. Center of Russian Academy of Sciences, Pushchino, Preprint, 41 pp.

Chertov, O.G., Komarov, A.S., 1996. SOMM—a model of soil organic matter and nitrogen dynamics in terrestrial ecosystems. In: Powlson, D.S., Smith, P., Smith, J.U. (Eds). Evaluation of Soil Organic Matter Models Using Existing Long- Term Datasets. NATO ASI Series, Vol. 138, Springer-Verlag, Heidelberg, pp. 231–236.

Chertov, O.G., Komarov, A.S., 1997a. SOMM—a model of soil organic matter dynamics. Ecol. Modelling 94, 177–189.

Chertov, O.G., Komarov, A.S., 1997b. Simulation model of Scots pine, Norway spruce and Silver birch ecosystems. Proc. IBFRA Conf., St. Petersburg, August 1996, Moscow, pp. 161–167.

Duchaufour, Ph., 1961. Précis de pédologie. Paris. Russian translation Mir, Moscow, 1970.

Kononova, M.M., 1951. Problema Pochvennogo Gumusa. Nauka, Moscow; English translation 1966, Problem of Soil Humus. Pergamon Press, Oxford.

Kostychev, P.A., 1889. Obrazovanie i svoistva peregnoya. St.-Peterburg (Cit.: 1951, Selected Works. Nauka, Leningrad, pp. 251–296, in Russian).

Makarevich, V.N., Titov, Ju.V., Druzina, V.D., Kirilova, V.P., 1978. Reaktsia sukhodolnogo luga na mineralnyie udobreniya. Nauka, Leningrad.

Mikola, P., 1954. Kokeellisia tutkimuksia metsäkarikkeiden hajaantumisnopeudesta. Comm. Inst. For. Fenn. 43 (1) 50 pp. (with English summary).

Müller, P.E., 1887. Studien über die naturlichen Humusformen und deren Entwicklung auf Vegetation und Boden. Berlin.

Pastor, J., Post, W.M., 1985. Development of a Linked Forest Productivity–Soil Process Model. Oak Ridge National Laboratory, ORNL/TM-9519, 168 pp.

Perel, T.S., Sokolov, D.F., 1964. Kolichestvennaya otsenka uchastia dozhdevyh chervey v pererabotke opada. Zool. J., Leningrad, 43 (11): 1618–1625 (with English summary).

Ponomareva, V.V., Nikolaeva, T.N., 1980. Gumus i Pochvoobrazovanie. Nauka, Leningrad.

Poulton, P.R., 1995. Estimating carbon inputs in the Park Grass experiment. Paper presented to NATO Advanced Symposium at Rothamsted Exp. Station, May 21–26, 1995.

Rodin, L.E., Bazilevich, N.I., 1965. Dinamika organicheskogo veshchestva i biologicheskii krugovorot zolnyh elementov v osnovnyh tipah rastitelnosti zemnogo shara. Nauka, Moscow, Leningrad.

Smith, P., Smith, J.U., Powlson, D.S., McGill, W.B., Arah, J.R.M., Chertov, O.G., Coleman, K., Franko, U., Frolking, S., Gunnewiek, H.K., Jenkinson, D.S., Jensen, L.S., Kelly, R.H., Li, C., Molina, J.A.E., Mueller, T., Parton, W.J., Thornley, J.H.M., Whitmore, A.P., 1997. A comparison of the performance of nine soil organic matter models using datasets from seven long-term experiments. In: Smith, P., Powlson, D.S., Smith, J.U., Elliott, E.T. (Eds.), Evaluation and Comparison of Soil Organic Matter Models Using Datasets From Seven Long-Term Experiments. Geoderma 81(1–2), 153–225, this issue.

Striganova, B.R., Kudriashova, I.V., Tiunov, A.V., 1987. Pishchevaya aktivnost dozhdevych chervey *Eisenia hordenskioldi* (Eisen) (*Oligochaeta, Lumbricidaea*). Pochvovedenie (Moscow), 1, 72–77 (with English summary).

Waxman, S.A., Gerretsen, F.S., 1931. Influence of temperature and moisture upon the nature and extent of decomposition of plant residues by microorganisms. Ecology 12 (1), 33–60.

Waxman, S.A., Tenney, F.G., 1927. The composition of natural organic materials and their decomposition in the soil. Soil Sci. 24 (2), 317–324.

Wilde, S.A., 1958. Forest Soils. John Wiley and Sons, New York.