Ch. 9: Soil Organic Matter model

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9 Soil Organic Matter model

9.1 Introduction

The organic matter model in Daisy simulates the inputs and turnover of organic matter driven by the effects of farming practices on organic matter dynamics at field scale, both in the short and the long term. The Daisy code (Hansen et al. (1990), Hansen et al. (1991), Abrahamsen and Hansen (2000)) has been validated on several occasions (Shaffer et al., 2001) and has been one of the most accurate in particular with regard to both short- and long-term predictions of soil organic matter (Vereecken et al. (1991), de Willigen (1991), Diekkrüger et al. (1995), and Smith et al. (1997)). The organic matter in Daisy comprises three main compartments:

1) The added organic matter (AOM) which for a cultivated soil may include organic fertilizers and other exogenous organic amendments, as well as, crop residuals, including unharvested shoot and roots, rhizodeposition and dead leaves incorporated to the soil by earthworms during plant growth.
2) The soil microbial biomass (SMB), the living part of the organic matter, excluding roots.
3) Soil organic matter (SOM), which can no longer be traced back to its origin, and will typically have a slower turnover than AOM and SMB pools.

The Daisy code allows each compartment to be divided into a user specified number of pools, as well as adjusting the turnover rates, substrate use efficiency, the rates of maintenance (for the SMB pools), and directions of flow. Thus, Daisy can be useful as a framework for experimentation with organic matter models. The original default organic matter model in Daisy (Hansen et al., 1990) defined a system with two pools of SOM and SMB, and two pools of AOM for each type of fertilizer applied and crop residues left on the field. The default model has been modified twice. The first modification was by Mueller et al. (1997) and was an adjustment of the turnover rates of the SMB pools, so the biomass content of the soil matched the levels measured in the fields. The change did not affect the long-term dynamics of the system. The second change in parametrization was by Bruun et al. (2003). This was a complete recalibration that considered the carbon input from rhizo-deposition. This change was more radical, involving both turnover rates and directions of flow, and made the system much more adaptable to new levels of input. This adaptability to input level has also been directly observed in the field (Heidmann et al., 2001). The recalibration also introduced a new soil organic matter pool, the SOM3-pool, which represents a deactivated, biologically inert SOM pool of very recalcitrant organic matter. The resulting model, which is the current default organic matter model in Daisy, is explained in the next section.

In connection with writing this documentation, it was discovered that an error in the parameterisation of the pathway from SMB2 to SOM2 has been present in the model since the C++-version of Daisy was introduced. The consequences and actions taken because of this error is described in Section 9.11 and appendix 9.4.

9.2 Where does the organic matter come from?

When the soil horizons are defined, they include the texture and soil organic matter content. The humus fraction as defined in the horizons is assumed to contain 58 % carbon and has a bulk density of 1.3 [g cm^{-3}]. This defines the total amount of organic matter i.e. the sum of all the defined pools. Different options for initialisation of these pools (i.e. distributing the organic carbon between the model pools in the beginning of the simulation) are described in section 9.9.

During a simulation, organic fertilizers (input) and plant residues (leaves, stubble, root exudates, other unharvested plant material) are added to the total organic matter, mainly via the AOM-pools. However, in some cases, a fraction of the material (e.g. in the case of composted materials or manure) may be added directly to the SOM-pools. AOM-pools are described in section 9.6 and SOM pools in section 9.8.

9.3 Incorporation of organic material

The carbon pool at the surface is a balance between added organic matter (dead plant material, surface applied organic fertilizer) and incorporation by either tillage or by biological activity.

9.3.1 Incorporation by tillage

Incorporation of organic material at the surface happens when tillage is performed. A <*swap*> operation like ploughing causes the top layer to swap place with a deeper layer. The surface material follows the top layer. See Chapter 11 for details. A <*mix*> operation like rotavation or harrowing causes a specified fraction of surface material to be incorporated within a mixing depth. Again, see Chapter 11 for details.

9.3.2 Bio-incorporation

Incorporation can also take place by earthworms or other macro-fauna. This bio-incorporation is described by a modified Michaelis-Menten expression:

$$R_{bio-inc} = \frac{R_{max} \cdot f(T) \cdot f\left({}^{C}/_{N}\right) \cdot C_{surf}}{k_{half} + C_{surf}} \tag{9.1}$$

where

$R_{bio-inc}$ = the rate of bio-incorporation [g DM m^{-2} h^{-1}]

R_{max} = the maximum rate of bio-incorporation, default 0.5 [g DM m^{-2} h^{-1}]

C_{surf} = the amount of carbon available on the surface [g DM m^{-2}].

$f(T)$ = the dependency of the rate on temperature, plf-function [-]

$f(C/N)$ = the dependency of the rate on the C/N-ratio, plf-function [-]

k_{half} = the half-saturation constant, default 1 [g DM m^{-2}]

The maximum rate of bio-incorporation is estimated, but can be compared to the values presented by Curry and Schmidt (2007). They cite a range of 10-17 mg DM g^{-1} (fresh matter) d^{-1} (no temperature reference). 5 t h^{-1} of fresh grass would then

produce rates of 0.21 to 0.35 g DM m^{-2} h^{-1}, while eq. 9.1 would give a value of 0.41 (setting the modifiers to 1). For 3 t, the same numbers would be 0.13-0.21 compared to 0.38. Thus, the default value of R_{max} may be on the high side.

Temperature dependency

The temperature function is by default a very simple plf-function, with a value of 0 up to 4 °C, a value of 1 from 6 °C and upwards, and linearly interpolated values between the two. It can be changed by the user.

C/N-dependency

The dependency of the rate on the C/N-ratio is also a plf-function, where the value drops with increasing C/N-ratio. The default values are shown below but can be changed by the user.

C/N [-]	50	100	120
Factor [-]	1	0.1	0.01

Distribution with depth

During the bio-incorporation, carbon can be lost due to respiration. By default, the fraction lost is 0 (from Daisy 7, before it was 0.5). The incorporated material is distributed according to a plf-function defining the lowest depth of the distribution, a point above which the distribution is considered uniform, and the soil surface, by default (-80 [cm] 0) (-18 [cm] 100) (0 [cm] 100), see Figure 9.1. The value "100" is a value that, together with the specified depths, defines the blue area in Figure 9.1, and thus the amount of carbon incorporated in each calculation cell in Daisy.

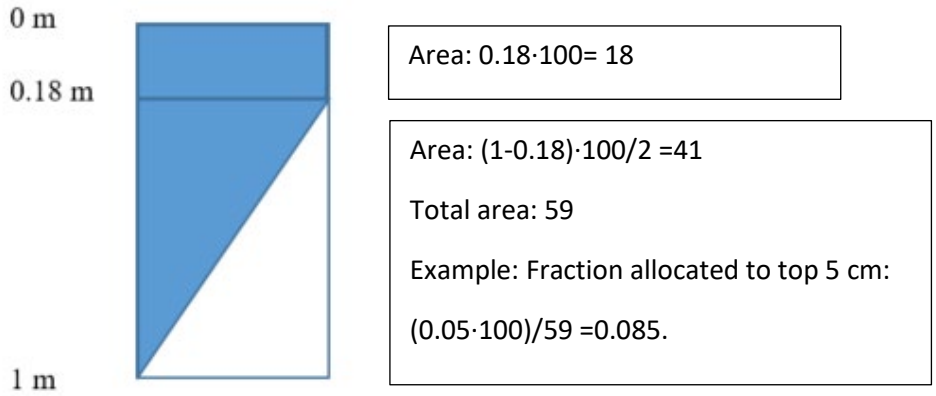

Figure 9.1. Bio-incorporated material is distributed according to the principles shown in this figure.

Description of incorporated material

The organic material that has been through the bio-incorporation process is assumed to have been partly digested by biota and thus allocated to AOM-pools as described in section 9.6.4.

9.4 Overview of the organic matter turnover in Daisy

The current default organic matter model is depicted in Figure 9.2. The figure is explained below. More information on the different organic pools is given in section 9.6-9.8. The figure shows two pools of each type (AOM, SMB and SOM) in the organic matter breakdown cycle, and one pool (SOM3) outside this cycle, remaining inert to decomposition within biologically relevant timescales. For all pools in the cycle, the amount of carbon (C [g cm^{-3}]) turned over and decomposed is directly proportional with the size of the pool (1st order process). The C-content in a pool will depend on the balance between C-addition and breakdown:

$$\frac{\partial C}{dt} = \frac{C_{input}}{dt} - k \cdot C \qquad (9.2)$$

where C_{input} [g m^{-2}] is material added or produced from other pools, k [h^{-1}] is the turnover rate. All the pools in Figure 9.2 have a fully drawn outgoing line, describing the breakdown process. From the SOM1 pool the outgoing line is marked with the text “44y”. This indicates the corresponding half-life (defined as $ln(2)/k$), where k is the turnover rate from above) of this particular pool. A half-life of 44 years for the SOM1 pool means that if there was no input to the pool, the pool would be half the original size after 44 years. For the pools with a faster turnover, this time is given in days, e.g. the SMB2 pool has a turnover halftime of 69 days.

Organic material usually enters the system as “Added Organic Material”, AOM. Each type of added material is split into a “slow” (AOM1) and a “fast” (AOM2) AOM-pool, by means of factors specified for each type of organic material. By default, the two pools have half-lives of 144 and 14 days respectively. However, these parameters can be specified separately for each type of material added, and as is indicated in Figure 9.2 by the stippled boxes behind the AOM-pools, each addition of AOM can have its own parameters, see section 9.6. If the added material contains material that is already digested, it can be transferred from a third AOM-pool (AOM3 on Figure 9.2) to the SOM-pools via a buffer (by default to SOM2).

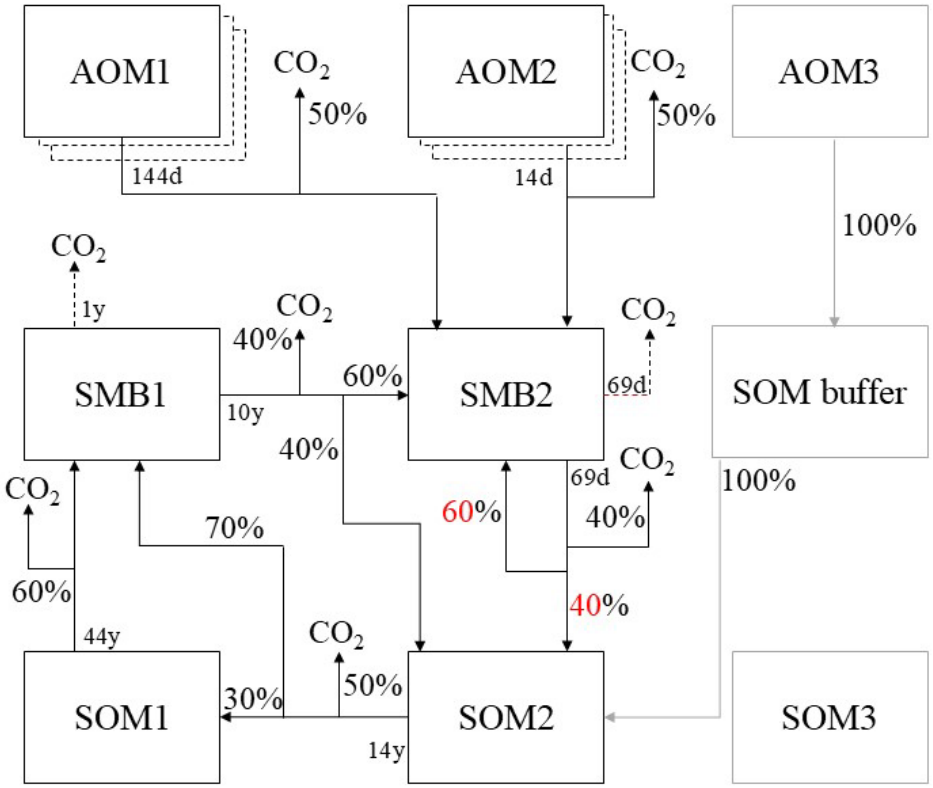

Figure 9.2. Current standard organic matter model in Daisy. Black boxes are required in a simulation, while grey boxes may be activated for particular purposes. AOM3 is included only when part of the added material has to bypass the microbial population. SOM3 is included if a fraction of the organic material in a horizon is considered inert. The SMB2 to SOM2 pathway (numbers marked with red) is parameterized with the SOM2025 parameterization (available from Daisy version 7), which is similar to the pathway parameterization original Fortran version (Hansen et al. (1990); Hansen et al. (1991)). In earlier C++ versions of Daisy (before version 7) 40 % of the decayed material from SMB2 was recycled to SMB2 and 60 % was moved to SOM2 (see more in Section 9.11 and appendix 9.4.).

By default, all material in the AOM-pools is broken down by the soil microbes in SMB2 (the fast SMB-pool), and in this process, a certain fraction (50 % in Figure 9.2) of the carbon is lost as CO_2. As the microbes in SMB2 are living organisms, they respire, and this is described by a 1st order carbon loss with a half-life of 69 days (stippled arrow). The SMB2-microbes feed on SMB1-microbes, but they also feed on each other, and the last of these processes are described as a 1st order process with a half-life of 69 days. During this process, 40 % of the carbon is lost, and of the rest, 40 % ends up back in the SMB2-pool, and 60 % goes to the "fast" soil organic matter pool, SOM2.

The SOM2-pool is digested by the "slow" microbes in SMB1. The half-life of this process is 14 years, and during this process, 50 % of the carbon is lost as CO_2. Of the rest of the material, 70 % feeds the SMB1-biomass, while 30 % ends up in the "slow" organic matter pool, SOM1. The "slow" microbes (SMB1) also feed on SOM1, which has a decay half-life of 44 years. In this case 60 % of the carbon is lost as CO_2, and the last 40 % is used to build up the SMB1-pool. As SMB1 consists of living organisms, respiration (stippled arrow) is described with a half-life of 1 year. As mentioned above, the "fast" microbes (SMB2) also feed on the "slow"

microbes (SMB1). This is described with a half-life of 10 years and a CO_2-loss of 40 %. The rest of the carbon is allocated to SMB2 (60 %) and to SOM2 (40 %). Thus, material added as AOM will end up in an unending breakdown cycle, driven by the microbial biomass.

Other processes, e.g. denitrification, may to some extent depend on the organic matter turn-over and in some cases, it may be of interest to distinguish between slow and fast turn-over processes. A turnover rate can be specified that signifies the threshold between slow and fast processes. In that case, CO_2-contributions from all fast processes will be pooled and used as input for these other processes. The default threshold value is 0.0001 [h^{-1}] which translates to half-lives of approximately 289 days.

The turnover of the pools and microbial respiration (SMB pools) is affected by abiotic factors, the soil temperature, and the moisture, and some of the pools are affected by the clay content of the soil. It is also possible to define a relationship with pH (one factor for all pools). The half-lives and the corresponding turnover rates listed in Figure 9.2 correspond to 0% clay, 10°C, and field capacity (defined as -100 hPa). The turnover rates will decrease with increasing clay content and decreasing temperature. For soil water content, there is an optimum around field capacity and the rate decreases towards saturation and dry conditions as seen on Figure 9.3.

Special functions

The *horizon* parameter *turnover_factor* changes the turnover rate of all pools in the horizon if changed from its default value of 1.

All organic matter dynamics can be left out of the calculation by selecting *none* as the organic matter model for the soil column.

9.4.1 Dependency on clay

The default model

The effect of clay content is associated with a chemical as well as a physical protection of organic matter against decomposition. Several chemical adsorption mechanisms may be envisaged in addition to physical adsorption mechanisms (see e.g. Cotrufo and Lavallee (2022) and Lützow et al. (2006) for details). In arable soils, most of the soil organic matter is incorporated into domains of primary particles which, by clustering, form soil micro-aggregates, aggregates, and cloths. In the interior of domains and clusters of microaggregates, the soil pore system is made up of micropores with diameters in the range of 0.1-10 µm, which is comparable to the range of dimensions of bacteria, and fungal hyphae (Dexter, 1988) and in the size range where occlusion at the clay microstructure level (<20 µm) might occur (Lützow et al., 2006). According to Lützow et al. (2006), occluded OM is spatially protected against decomposition due to: (i) reduced access for the microorganism and their enzymes, which control further food web interactions; (ii) reduced diffusion of enzymes into the intra-aggregate space; and (iii) restricted aerobic decomposition due to reduced diffusion of oxygen. It is primarily the pore-size distribution that controls the above-mentioned processes as it influences the proportions of pores filled with water as well as those being a possible habitat for microorganisms.

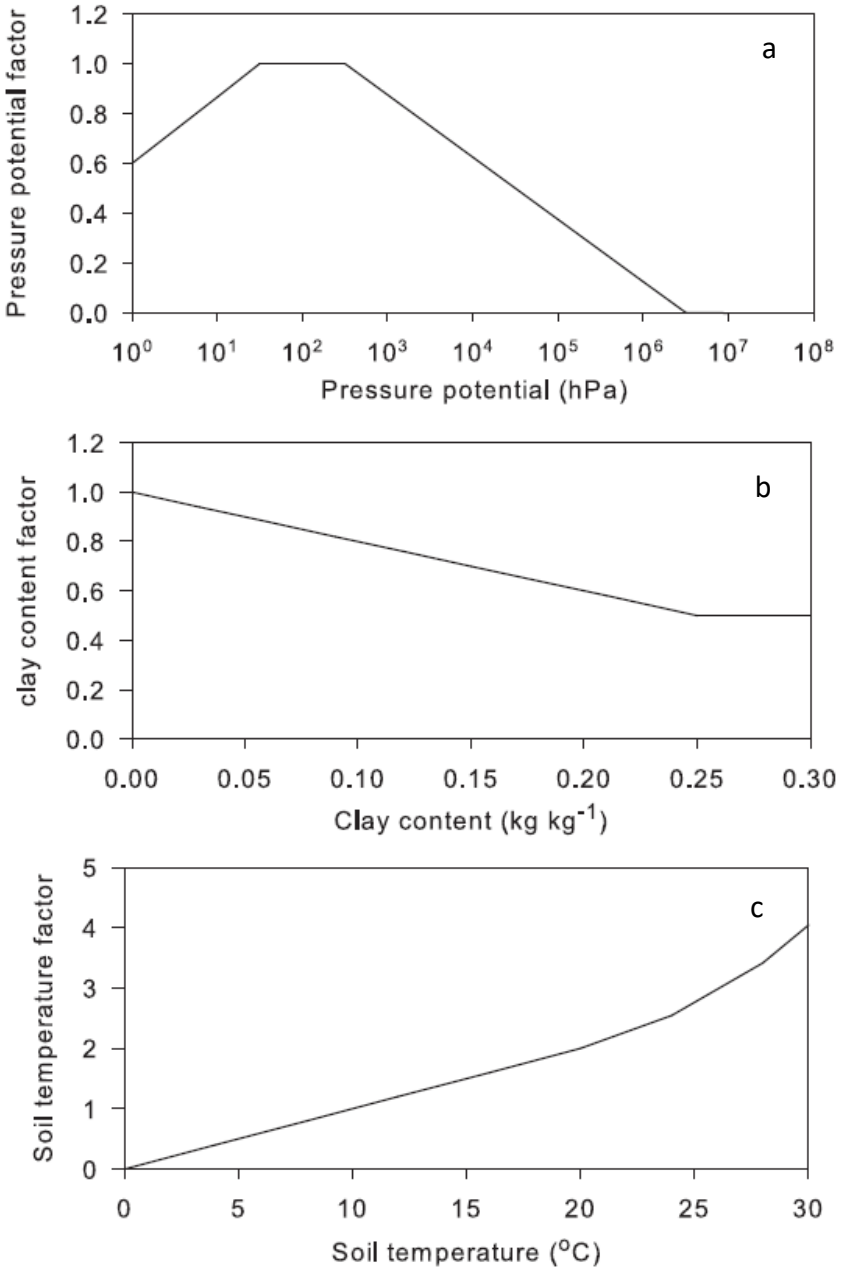

Figure 9.3. Effect of abiotic factors (a) pressure potential, b) clay content and c) soil temperature) on organic matter turnover.

Thus, protection of organic matter against decomposition or decay varies with the degree of aggregation and sorption capacity which both depends on the clay content of the soil. As suggested by van Veen et al. (1984) and (1985), it is assumed that the protection of organic matter and microorganisms against decomposition or decay increases with clay content to a maximum at a certain clay content of the soil. Thus, in the present model the default function used to account for the effect of clay content of the soil on the rate of decomposition or decay of organic matter is given in eq. 9.3 and shown in Figure 9.3b.

$$F^{clay}(f_{clay}) = \begin{cases} 1.0 - a \cdot f_{clay}, & f_{clay} < 0.25 \\ 1.0 - a \cdot f^{*}_{clay}, & f_{clay} \geq 0.25 \end{cases} \quad (9.3)$$

where

$F_{clay}(f_{clay})$ = the modifier function for clay [-],

f_{clay} = the amount of clay expressed as fraction [-] or [kg kg^{-1}],

f_{clay} = limit for the effect of clay content (0.25 kg kg^{-1}),

a = constant set to 2.

In practice, the function is specified as a plf-function with the default-values (factor (0 1) (0.25 0.5) (1 0.5)) and linearly interpolation between them. The function of clay content is multiplied with the maintenance and turnover rates of SMB1 and all SOM pools.

The microbial biomass which is formed at a high rate after heavy input of e.g. stable manure is therefore assumed to be less protected and partly for that reason decomposed at a relatively high rate. Therefore, the decay rates for AOM-pools and SMB2 are not multiplied with the clay factor.

Dependency on clay, biomod

An alternative description of dependency of clay stems from the "BIOMOD"-project and was used in connection with a different definition of pools and relationships, see (Petersen et al., 2005a, , 2005b, and 2007). The assumed structure and the BIOMOD clay factor are described in Appendix 9.1.

9.4.2 Dependency on pressure potential, ψ

Only a small fraction of the organic matter in soil is likely to be in close proximity of microorganisms at any time. Consequently, transport processes through the liquid phase of the soil are certainly of importance for the decomposition rate of organic matter in soils. As transport processes in soils are considerably influenced by the soil water content, it is realized that the turn-over rate of organic matter in soil is strongly related to the corresponding pressure potential of soil water. Miller and Johnson (1964) found from incubation experiments that the evolution of CO_2 was small at low pressure potentials and that the evolution of CO_2 increased to a maximum value at pressure potentials in the range from -5.0 m (H_2O) to -1.5 m (H_2O). Orchard and Cook (1983) and Stott et al. (1986) found that the effect of soil water content on the rate of CO_2-evolution could be expressed as eq. (9.4) and (9.5), respectively:

$$Y = -0.385 \cdot \log(-100 \cdot \psi) + 2.5;\ r^2 = 0.98 \quad (9.4)$$

$$Y = -9.06 \cdot \log(-100 \cdot \psi) + 59.6;\ r^2 = 0.87 \quad (9.5)$$

where

Y = evolution rate of CO_2 [µl(CO_2) g^{-1}(soil) h^{-1}]

ψ = pressure potential of soil water [m H_2O]

The pressure potential range applied was from -1000 to -0.5 m H_2O and from -3.3 to -500 m H_2O in eq. (9.4) and (9.5), respectively. When extrapolating to $Y = 0$, a

pressure potential corresponding to pF equal to 6.5 and 6.6 is obtained for eq. (9.4) and (9.5) respectively.

Additionally, Stanford and Epstein (1974) and Miller and Johnson (1964) found that an optimum level of soil water content exists for net mineralization of nitrogen. Jenkinson et al. (1987) states that the decomposition rate of organic matter is slower under anaerobic conditions (likely to be present at very high water potentials) than under aerobic conditions.

In the present model it is assumed that turnover of soil organic matter approaches zero at pF=6.5, and that optimal conditions exist in the range 1.5<pF<2.5. Furthermore, it is assumed that the function to account for effect of water content on the turnover rate increases linearly from 0.6 (van Veen and Paul, 1981) at water saturation to 1.0 at pF 1.5 and that the function decreases linearly from 1.0 at pF 2.5 to zero at pF 6.5, eq. (9.6) (See Figure 9.3a).

$$F^{\psi}(\psi) = \begin{cases} 0.6 & \log(-\psi) \leq 0.0 \\ 0.6 + (1.0 - 0.6) \cdot \dfrac{\log(-\psi)}{1.5} & 0 > \log(-\psi) \leq 1.5 \\ 1 & 1.5 < \log(-\psi) \leq 2.5 \\ 1.0 - \dfrac{\log(-\psi) - 2.5}{6.5 - 2.5} & 2.5 < \log(-\psi) \leq 6.5 \\ 0 & 6.5 < \log(-\psi) \end{cases} \quad \text{Eq. (9.6)}$$

where

$F_{\psi}(\psi)$ = the modifier function for soil water [-],

ψ = pressure potential of soil water [cm H_2O].

9.4.3 Dependency on temperature

The turnover of organic matter is influenced considerably by temperature. The effect of temperature on net nitrogen mineralization has been considered by several authors. In Table 9.1, a number of references are listed, all of which apply an Arrhenius type equation to describe the temperature effect:

$$F^{T}(T) = A \cdot e^{-B/T}$$

$F_T(T)$ = function [-] to account for the effect of temperature T [K].

A and B = constants, A is dimensionless while B is in [K].

Table 9.1. Temperature effect on net mineralization of nitrogen described by an Arrhenius type equation as suggested in literature. The letter "d" is used to depict the Daisy function in Figure 9.4.

Reference	Temperature, °C	Comment	Legend[1)]
(Campbell et al., 1981)	5-40	5 soils, subsoil	a
(Campbell et al., 1981)	5-40	5 soils, topsoil	b
(Stanford et al., 1973)	5-35	11 soils	c
(Stanford et al., 1973)	15-35	11 soils	e
(Addiscott, 1983)	5-25	Mineral fertilizer	f
(Addiscott, 1983	5-25	Farmyard manure	g
(Nordmeyer and Richter, 1985)	10-35	Slowly decomposable fraction	h
(Nordmeyer and Richter, 1985)	10-35	Rapid decomposable fraction	i

[1)] Figure 9.4.

The various functions normalized to 1.0 at 10°C are shown in Figure 9.4. It is noted that good agreement exists between results obtained by Stanford et al. (1973) and Campbell et al. (1981) when measurements in the range of 5-40 °C are considered. Campbell et al. (1981) found that net mineralization of nitrogen was less affected by temperature in the subsoil than in the topsoil. Addiscott (1983) found greater temperature effect on net mineralization of nitrogen in arable soil which had received 35 tons ha^{-1} $year^{-1}$ of farmyard manure since 1843 than in arable soil which had received mineral nitrogen fertilizer in the same period. Nordmeyer and Richter (1985) found that turnover of the rapid decomposable fraction of added plant residues was affected much more by temperature than turnover of the more resistant fraction of the added plant residues. They also observed that turnover of the more resistant fraction of the added plant residues was depending considerably on the clay content of the soil.

Thus, the experimental evidence considered suggests that the temperature effect on the turnover rate is related to the nature of the organic matter in the soil. This may explain the considerable differences in experimental results obtained as illustrated in Figure 9.4. However, due to lack of sufficient quantitative information when the organic model was made, it was not possible to include the lability of the organic matter in modelling the temperature effect on the turnover rates. More recent work on temperature effects on mineralisation and immobilisation exists that can be included by the user by parameterising individual temperature functions for the different pools.

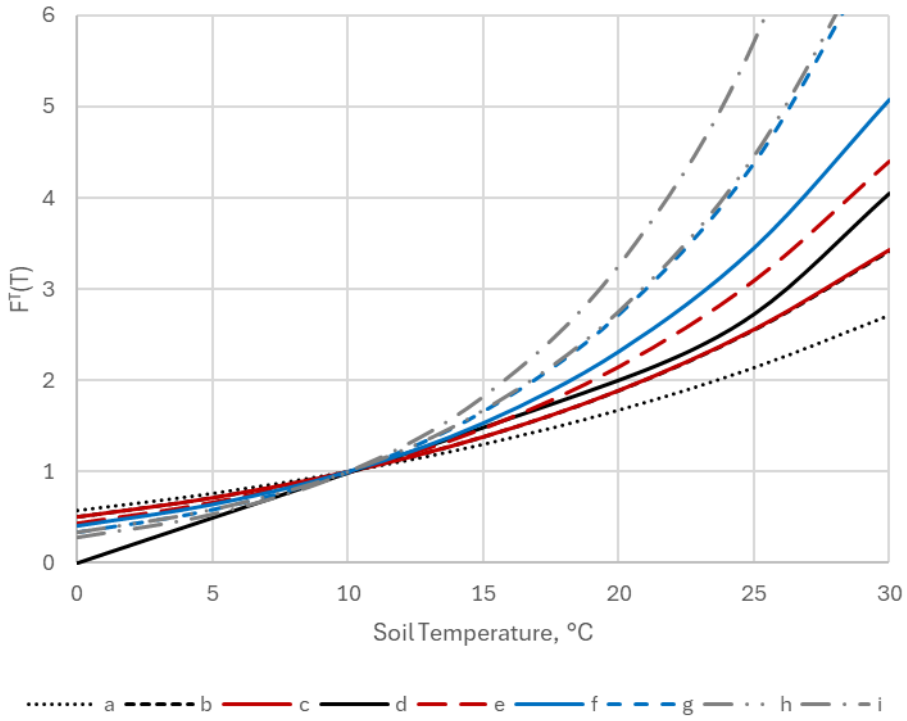

Figure 9.4. Several soil temperature functions for adjustment of the decomposition rate coefficient to actual soil temperature. Legend explanation, see Table 9.1. The letter "d" is used to depict the Daisy function.

Realizing the lack of experimental evidence for conditions below 5°C, it is assumed that the aerobic microbial decomposition rate of soil organic matter approaches zero at 0°C. Furthermore, in the present model it is assumed that the effect of soil temperature on the decomposition rate of organic matter increases linearly in the temperature range 0-20°C and exponentially at soil temperatures greater than 20°C. Above 37°C the mineralization is expected to decline, reaching a value of zero at 60°C (Van Veen and Frissel, 1981) (see Figure 9.3c). $F^T(T)$ is depicted as line "d" in Figure 9.4.

$$F^T(T) = \begin{cases} 0.0 & 0 \le T \\ 0.1 \cdot T & 0 < T < 20 \\ \exp\left(0.47 - 0.027 \cdot \mathrm{T} + 0.00193 \cdot \mathrm{T}^2\right) & 20 \le T < 37 \\ A \cdot \left(1.0 - \dfrac{(T - 37.0)}{(60.0 - 37.0)}\right) & 37 \le T < 60 \\ 0.0 & 60 \le T \end{cases} \tag{9.7}$$

$$A = e^{\left(0.47 - 0.027 \cdot 37.0 + 0.00193 \cdot 37.0^2\right)}$$

9.4.4 Other dependencies

Dependency on pH

As default, there is no relationship in Daisy, describing a link between organic matter turnover and pH. It is, however, possible to introduce a pH-factor ($F^{pH}(pH)$) as a plf, where pH and the required factors are given by the user. It is applied to all pools. It also requires that pH is defined for the column. By default,

the *column* parameter *SoilpH* is *neutral* (that is a constant pH of 7 is assumed). Alternatively, *SoilpH* can be defined pr. *year* with a plf of depth and pH.

Depth of the turn-over processes

As default, organic matter turn-over takes place in the root zone, which is also the soil volume where organic matter may be added. It is possible to activate the turn-over processes in the full column (active underground true), which could be relevant if the subsoil contains substantial amounts of organic matter and enough oxygen to sustain mineralisation. DOM is presently only included on an experimental basis (see section 9.10), and particulate movement of organic matter is not included at all, so organic matter does not move downwards in Daisy except by incorporation as described in section 9.3.

Dependency on mineral N

Lack of mineral N may limit the turnover, particularly of AOM to SMB2. This is described in section 9.5.

9.4.5 Generalised equations for the turn-over

The relationships and equation described in the previous chapters define the changes of the organic pools, and this is described in more detail below. The rate of change of the individual pools in the dynamic model is governed by the following equations:

$$\Delta AOM_i = pc_{AOMi} \cdot I_D + g_i \cdot AOM_i \;\; ; i = 1 \ldots N_{AOM} \tag{9.8}$$

$$\Delta SMB_i = \sum_{j=1}^{N_{SMB}} a_{i,j} SMB_j + \sum_{j=1}^{N_{SOM}} b_{i,j} SOM_j + \sum_{j=1}^{N_{AOM}} c_{i,j} AOM_j \;\; ; i = 1 \ldots N_{SMB} \tag{9.9}$$

$$\Delta SOM_i = \sum_{j=1}^{N_{SMB}} d_{i,j} SMB_j + \sum_{j=1}^{N_{SOM}} e_{i,j} SOM_j + \sum_{j=1}^{N_{AOM}} f_{i,j} AOM_j \;\; ; i = 1 \ldots N_{SOM} \tag{9.10}$$

Here, AOM_i, SMB_i and SOM_i denote the carbon content (mass) of the i'th SMB, SOM, or AOM pool, respectively. ΔAOM_i, ΔSMB_i, and ΔSOM_i denote the change of each pool (mass/time). N_{AOM}, N_{SMB} and N_{SOM} denote the number of the respective pools. The relationship between the mass of the pools and the change of the pools is assumed to be linear, and described by $a_{i,j}$, $b_{i,j}$, $c_{i,j}$, $e_{i,j}$, $f_{i,j}$, and g_i (fraction per time). These relationships are calculated based on the parameterization of the organic matter turnover model. I_D is an input function (Dirac's Delta function [kg cm^{-3} s^{-1}], defined as I_C, the organic carbon input [kg m^{-3}], divided by a time step (Δ) [s] and pc_{AOMi} is the partitioning coefficient, determining how much of the input goes to a specific AOM-pool.

Some examples of formulas for finding the linear multipliers are shown below:

$$a_{1,1} = (k_{SMB1}(X_{SMB1\rightarrow SMB1}E_{SMB1} - 1) - m_{SMB1}) \cdot F^T(T) \cdot F^{\psi}(\psi) \cdot F^{clay}(x_{clay})$$

$$a_{2,2} = (k_{SMB2}(X_{SMB2\rightarrow SMB2}E_{SMB2} - 1) - m_{SMB2}) \cdot F^T(T) \cdot F^{\psi}(\psi) \cdot F^{clay}_{SMB2}(x_{clay})$$

$$d_{2,2} = \left(k_{SMB2}(X_{SMB2\rightarrow SOM2}E_{SMB2})\right) \cdot F^T(T) \cdot F^{\psi}(\psi) \cdot F^{clay}_{SMB2}(x_{clay})$$

where k_{SMB1} and k_{SMB2} are turnover rates of SMB1 and SMB2, m_{SMB1} and m_{SMB2} are the maintenance rates of the SMB-pools. $X_{poolX\rightarrow poolY}$ is the carbon fraction going from the specified first pool to the specified second pool. E_{SMB1} and E_{SMB2} are the efficiency of which SMB1 and SMB2, respectively, are decomposed, while the remaining part is lost to the atmosphere as CO_2. The functions $F^T(T)$, $F^{\psi}(\psi)$ and $F^{clay}(x_{clay})$ are described above. $F^{clay}_{SMB2}(x_{clay})$ equals 1, as the clay function is not applied to the SMB2-pool.

9.5 Linking nitrogen to the carbon turn-over

Nitrogen follows carbon in the organic matter cycle. SMB and SOM-pools have defined C/N-relationships that do not change over time. AOM-pools differ, as the material allocated to the individual AOM pools can have any C/N-ratio. It is necessary to define the fractions of the carbon in AOM material allocated to "the number of AOM-pools minus 1" and the C/N-ratio of "the number of AOM-pools minus 1". The rest of the carbon is allocated to the last pool, and the N allocation can now be calculated, leaving the remaining N to the pool, where the C/N-ratio has not been specified.

Presently the default C/N-ratio of SMB-pools is 6.7 and the default C/N-ratio of SOM-pools is 11. The C/N-ratio of SOM pools is rather constant across the world and typically within the range of 8-14.

Be aware that some older articles describe the default C/N-ratio for the SMB-pools as 6 and 10 (e.g. Mueller et al. (1997)).

So, nitrogen enters the organic matter breakdown cycle with the added organic material together with carbon and is allocated to an AOM1 and AOM2-pool for the specified material. When AOM-material is broken down, half the C is lost as CO_2, while the rest of the C plus all the N is available for incorporation into the SMB2-pool. There may be a surplus or a deficiency of N, compared to the required C/N-ratio in the SMB2-pool. In case of a surplus, the N is released as ammonium. In case of deficiency, mineral N from the aqueous phase must be taken up (immobilisation). In this process, ammonium is preferred over nitrate, if available. Such immobilisation of nitrogen into the SMB2 pool may be observed after addition of organic materials with a high C/N-ratio, such as wheat- or barley straw. Maximum immobilization rates for ammonium and nitrate can be specified (default values for both are 0.020833 [h^{-1}], equal to 0.5 [d^{-1}]). If immobilisation is required to fulfil the C/N-ratios and mineral nitrogen is not available, the lack of mineral nitrogen will slow down/stop the AOM turnover process.

In principle, similar imbalances can take place at each step of the breakdown cycle but considering that the C/N-ratios are more similar among the SOM and SMB-pools and some carbon is lost as CO_2 in every step, immobilisation mainly happens when AOM pools are decomposed.

9.6 Parameterisation of AOM-pools

All material introduced into the organic matter cycle must be defined via the AOM-pools. It is important to realise that Figure 9.2 describes the system but different parameterisations of AOM1 and AOM2 exist for different materials, with different names. Those different names are used when building a simulation. The parameterisations shown in Figure 9.2 for AOM1, AOM2 and AOM3 are similar to the parameterisations *AOM-SLOW*, *AOM-FAST*, and *AOM-DIRECT*, respectively.

To know how much of the carbon from the added material that goes into a AOM pool, a total amount must be specified. For Daisy-calculated plant material, the amount is simulated by the crop model. As described above, it is necessary to define the fractions of the carbon in AOM material allocated to "the number of AOM-pools minus 1". and the C/N-ratio of "the number of AOM-pools minus 1". One pool should be left unspecified and will thus receive the amount not allocated elsewhere., and the N allocation can now be calculated, leaving the remaining N to the pool, where the C/N-ratio has not been specified. A negative C/N-ratio means that it is unspecified.

The description of an AOM-pool includes the type of information shown in Figure 9.2, that is the turnover rate (or half-time), and the substrate use efficiency, which equals (1- the fraction going to CO_2) when the material is converted into either CO_2 or SMB. In the present default model, all AOM1 and AOM2 material is broken down by SMB2, but in principle, the efficiency is a sequence, where an efficiency can be specified for each of the SMB-pools, see example below.

It is possible to specify how the digested material is divided into other pools as a sequence of fractions. The first numbers in the sequence correspond to SMB1 and SMB2, the next number to the SOM-buffer (see section 9.6.1) and any remaining numbers to each of the DOM pools (if such are in use, see section 9.10). The length of the sequence should thus be the number of SMB pools plus 1, plus optionally the number of DOM pools.

AOM-FAST	*AOM-SLOW*
	(C per N 90)
(turnover_rate 0.002 [h^{-1}])	(turnover_rate 0.0002 [h^{-1}])
(efficiency 0.5 0.5)	(efficiency 0.5 0.5)
(fractions 0 1 0)	(fractions 0 1 0)
	(initial_fraction 0.8)

Temperature and water functions for the AOM-pools can be defined by the user, but if not, the default functions are the ones described above (section 9.4.2 and 9.4.3).

Each addition of organic material is allocated to their own AOM pools, so many AOM1 and AOM2-pools are broken down in parallel. A minimal amount of C (by default 0.5 [g C m^{-2}]) and N (by default 0.05 [g N m^{-2}]) are specified, below which the pool is removed. Internally, the "leftovers" C and N are collected in a slow and a fast "clean-up"-pool with standard AOM parameters. If data are stored in a "checkpoint", AOM pool information will be stored in the submodel "initial".

A range of standard fertilizers and materials are parameterised under the *am*-component in Daisy. A few of them are further described in section 9.6.2, 9.6.3, and 9.6.4. In addition, pig slurry has been parameterised by ten Hoeve et al. (2016a and 2016b), sewage sludge by Bruun et al. (2016), garden waste by Nielsen et al. (2019), sludge and sludge biochar by Rydgård et al. (2024) and processed organic municipal solid waste by Bruun et al. (2006). The pig slurry, sewage sludge and garden waste parameters are available here.

9.6.1 From AOM to SOM

The buffer

In Figure 9.2, there is no arrow going directly from AOM to SOM pools. However, the code still allows transfer of material via the *buffer* sub-module under the *organic* component, with fully specified default values. It contains specifications of where the material allocated to the buffer should end up (0 for SOM1 and 1 for SOM2, the last is default), and a default turnover rate of 1 [h^{-1}]. The buffer is used when the material added has already been through transformations, such as compost or slurry, for an example see the definition of "slurry" in fertilizer.dai.

AOM-Direct

The pre-defined AOM3-pool *AOM-DIRECT* allocate material to the buffer. It is defined with *(fractions 0 0 1)*, meaning that all organic matter in this pool goes to the SOM-buffer with an efficiency of 1 and a turnover rate of 1 [h^{-1}]. Thus, the fraction of AOM material allocated to the buffer is transferred more or less immediately to the specified SOM-pool.

9.6.2 Definition of organic fertilizer

Content

All definitions of organic fertilizers must be given a name. Definition of organic fertilizer requires the dry matter fraction, the total C-fraction (of dry matter), the total N-fraction (of dry matter) and the fractions of NH_4^+ and NO_3^-. The N that is not mineral, is assumed to be organic. The fraction of ammonium that will volatilize should be specified. In practice, it will depend on the properties of the organic fertilizer and the method of application and even the weather at the time of application. The ALFAM2 model can be used to assess volatilization under different conditions. For examples, see fertilizer.dai in the lib-directory.

Distribution and turn-over

It is also necessary to specify how the organic material should be distributed between different AOM-pools, that is the name of each pools, the fraction of C allocated to the pools (total number of pools -1), the C/N-ratio governing the distribution of N for the (total number of pools -1), and the turn-over rate for each pool, see section 9.6. An example of such a definition is shown below:

```
(om (AOM-SLOW (initial_fraction 0.72 [])
        (C_per_N 100 [(g C/cm^3)/(g N/cm^3)])
        (turnover_rate 2.0e-4 [h^-1])
        (efficiency 0.60 0.60 []))
(AOM-FAST (initial_fraction 0.18 [])
        (turnover_rate 2.0e-3 [h^-1])
        (efficiency 0.60 0.60 []))
 (AOM-DIRECT (C_per_N 11 [(g C/cm^3)/(g N/cm^3)])
        (turnover_rate 1.0 [h^-1]))))
```

Special parameters

For organic fertilizers it is possible also to specify an expected 1st year and 2nd year utilization (mineral fertilizer equivalency). In Denmark, these values are specified in the legislation for different types of slurry and manure. The 1st year utilization can then be used to calculate "backwards" from the amount of effective N required on the soil for a specific crop to the total amount of organic fertilizer applied. 2nd year utilization can be used to calculate an expected contribution from organic fertilizer to N supply of next year's crop. The use of these specifications is described in Chapter 11, under management actions. When the action of application is defined, the amount of material [Mg wet weight/ha], or the equivalent weight [kg N/ha] may be specified.

A range of materials are described in the reference manual under "*am*". Some descriptions, supported by articles, can be found under "contributions" on the Daisy homepage.

9.6.3 AOM for crop materials

For crops, the amount of C and N in simulated plant material added as AOM is determined by the simulation, and this is the starting point for the distribution into pools.

The default definition for most crop residuals and rhizo-deposition are *AOM-FAST* and *AOM-SLOW*, which are defined with the parameters shown in Figure 9.2 and in section 9.6. The turnover rates are 0.002 corresponding to a half-life of 14 d and 0.0002 [h^{-1}] corresponding to a half-life of 144 days, respectively, the efficiency is 0.5 and the material only goes to SMB2 *(fractions 0 1 0)*. The allocation of the material is determined by an *initial fraction* for *AOM-SLOW* of 0.8, and a C/N-ratio of 90. The rates derived for *AOM-SLOW* and *AOM-FAST* stem from Hansen et al. (1990), where they were assessed based on short term incubation experiments.

For some crops, other parameters are defined. A *CROP-FAST* and a *CROP-SLOW* parameterisation with turnover rates of 0.002917 and 0.0002917 [h^{-1}] (half-lives 9.9 and 99 days) are pre-defined, and used for some crops, e.g. ryegrass (see ryegrass.dai under lib). These rates originates from Hansen et al. (1990)(p.111), and Jensen et al. (1997) refers to the parameterisation. *Ryegrass-SLOW* and *Wclover-SLOW* are defined directly in the respective crop files. The defined

parameterisations can be applied to different parts of the material at harvest. In the example below, each plant organ has been allocated breakdown parameters as part of the harvest definition in the format (material AOM1 AOM2):

```
(Harvest      (Dead  "Wclover-SLOW" "CROP-FAST")
              (Stem "Wclover-SLOW" "CROP-FAST")
              (Leaf "Wclover-SLOW" "CROP-FAST")
              (SOrg (Wclover-SLOW (initial_fraction 0.9)) "CROP-FAST")
              (Root  "Wclover-SLOW" "CROP-FAST"))
```

The existing parameterisations are not exhaustive and could be improved. Considerable work was done in the 90'es on parameterisation of crop materials. However, it was done with a different configuration of the organic matter model, where both SMB-pools participated in the breakdown of the AOM-material. To benefit from the data presented on this work, see Mueller et al. (1997) for oilseed rape straw incorporation, de Neergaard et al. (2002) on decomposition of white clover and ryegrass, Mueller et al. (1998a) and Mueller et al. (1998b) for turnover of chopped maize plants, barley straw and blue grass, Müller et al. (2003) on decomposition of plant residues of different quality, and Müller et al. (2006) on catch crop effects.

Daisy also includes a default model of initialization of old root remains, see "*root*" under "*am*" in the reference manual for details of the parameters.

9.6.4 AOM pools for bio-incorporation

The material that has been through the bio-incorporation process (section 9.3.2) is allocated to a set of AOM-pools, which by default are "*AOM-SLOW-BIOINCORPORATION*" and "*AOM-FAST*". By default, 80 % of the bio-incorporated material is allocated to the "*AOM-SLOW-BIOINCORPORATION*" pool. The "*AOM-SLOW-BIOINCORPORATION*" inherits most parameters from "*AOM-SLOW*" but has a C/N-ratio of 60. In case the amount of N in the original material is too small to fulfil this relationship, all pools receive the same C/N-ratio (>60).

The parameters and the pathways may be debated. Curry and Schmidt (2007) cite assimilation efficiencies of 43-55 % for dandelion leaves under favourable temperature and moisture conditions and of 30 and 70 % for L. rubellus when feeding on larch litter and alder leaves, respectively. Thus, the efficiency of 0.5 used in the two pools above is possible. However, they also write that these values may be unrealistically high, as the earthworms also consume mineral soil to a greater or lesser degree, and this will reduce the assimilation efficiency.

Zhang et al. (2013) reviewed CO_2-production and carbon sequestration with and without earthworms present and found that the presence of earthworms increased CO_2-formation over the first three weeks, while the net loss of soil organic carbon was similar after 8 weeks of observation. At the same time, the presence of earthworms resulted in more stabilized carbon in the soil. With the parameterization above, the CO_2-production will be higher with earthworms

present, as respiration will take place both by earthworms and by the SMB2-pool. By redirecting part of the carbon that goes through the earthworms to the SOM buffer, the respiration loss from the SMB2-pool will be avoided and the carbon stabilization effect will be higher. However, we do not yet have a calibrated description of these observations.

9.7 Parameterisation of SMB-pools

The definition of the SMB-pools is similar to the AOM-pools. Each pool is equipped with a C/N-ratio, a turnover rate or a halftime, an efficiency and a specification of fractions describing how the material is divided into other pools once decayed. The first numbers correspond to each of the SMB-pools, the next numbers to the SOM pools and the last numbers to each of the DOM-pools, if specified. The present parameterisation of turnover rates and maintenance respiration stem from Mueller et al. (1997). Water- and heat-functions for modification of the breakdown ratio can be user defined, but the functions described in section 9.4.2 and 9.4.3 are used as default. $F_{clay}(f_{clay})$ (Eq. 9.3) works on SMB1 only. As mentioned above the SMB-pools differ from the other pools by having maintenance respiration. The default parameters, describing the system shown in Figure 9.2, are listed below:

SMB-FAST (SMB2)		*SMB-SLOW* (SMB1)	
(C per N	6.7)	(C per N	6.7)
(turnover_rate	0.000416667 [h^{-1}])	(turnover_rate	7.708e-06 [h^{-1}])
(efficiency	0.6 0.6)	(efficiency	0.6 0.6)
(fractions	0 0.6 0 0.6 0)	(fractions	0 0.6 0 0.4 0)
(maintenance	0.000416667 [h^{-1}])	(maintenance	7.5e-05 [h^{-1}])

In connection with writing this documentation, it was discovered that an error in parameterisation of the pathway from SMB2 to SOM2 has been present in the model since the C++-version of Daisy was introduced. The consequences and actions taken as a result of this error is described in Section 9.11 and appendix 9.4.

Tillage influence

It is commonly observed that tillage can influence the turnover rate of organic matter. This is not included in Daisy as a default. However, it is possible to define a plf, linking the number of days after tillage with a factor to be multiplied onto the turnover rate. It is thus possible to increase the turnover rate for a period after tillage and then reduce it. It should be noted that the present turnover rates are calculated based on long-term experiments, and if turnover is increased for a period, it should probably be reduced for the remaining time, so the total mineralization stays the same.

9.8 Parameterisation of SOM-pools

The parameterisation of SOM-pools is quite similar to the SMB pools, except there is no maintenance loss. SOM1, SOM2 and SOM3 have default parameterisations, describing the system shown in Figure 9.2, see below:

SOM-FAST (SOM2)		*SOM-SLOW* (SOM1)	
(turnover_rate	5.83333e-06 [h^{-1}])	(turnover_rate	1.79167e-06 [h^{-1}])
(efficiency	0.5 0.5)	(efficiency	0.4 0.4)
(fractions	0.7 0 0.3 0 0)	(fractions	1 0 0 0 0)

SOM-Inert (SOM3)	
(turnover_rate	0 [h-1])
(efficiency	0.5 0.5)
(fractions	0 0 0 0 1)

For *fractions*, the first numbers correspond to each of the SMB-pools, the next numbers to the SOM pools and the last numbers to each of the DOM-pools, if specified.

The values above are documented in Bruun et al. (2003). The C/N-ratio can be specified for each pool, but generally the information comes from the definition of the horizon, where *SOM_C_per_N* has the default values "11 11 11", specifying the C/N-ratio for SOM1, SOM2 and SOM3, respectively. Optionally, the C/N-ratio of the horizon at initialization can be specified, including all organic pools. Then the C/N-ratio of the SOM pool is calculated, assuming that the C/N-ratios of the AOM and SMB-pools are known. In that case, the C/N ratio for the SOM pools will gradually move towards the values specified by *SOM_C_per_N*.

Water- and temperature functions for the breakdown rate can be user defined, but the functions described in section 9.4.2 and 9.4.3 are used as default, as is the modifier function for clay, Eq. (9.3).

SOM-FAST-OLD and SOM-SLOW-OLD are earlier default-parameterisations from before the structure of the model was changed, see Mueller et al. (1997).

Tillage influence

As for the SMB-pools, no effect of tillage on SOM turnover is included in Daisy as default. However, it is possible to define a plf, linking the number of days after tillage with a factor to be multiplied onto the turnover rate. It is thus possible to increase the turnover rate for a period after tillage and then reduce it. It should be noted that the present turnover rates are calculated based on long-term experiments, and if turnover is increased for a period, it should probably be reduced for the remaining time, so the total mineralization stays the same.

Special parameters

For scenario simulations, where the long-term change in organic matter content is not wanted, it is possible to store the SOM values after an initialization period and re-set the values when required. It is done through the commands *store_SOM* and *restore_SOM*. An example is shown below, where the rotation is run twice as initialization. SOM is then stored, and the SOM pools reset after each additional run of the rotation.

```
(manager activity
    Rotation1_Rotation1
    (store_SOM)
    (message "SOM stored")
    (repeat (activity Rotation1 restore_SOM))))
```

9.9 Initialization of organic pools

Initialisation of the organic matter pools is a major challenge because the status at a given point in time depends on the historical management. We can measure how much organic C there is in the soil we want to simulate but we do not know how much of this is in the SOM1 and SOM2 pools. This problem has been described by Bruun and Jensen (2002), but so far, there are no perfect solutions. Appendix 9.2 contains a sensitivity analysis describing the challenges of initialization as well as a calculation of sensitivity of nitrate leaching to the initial SOM1/SOM-fraction. Appendix 9.3 is an unpublished article, elaborating on the initialization options described below.

Initialisation of the pools are based on the equations in section 9.4.5, but assuming that temperature and soil moisture conditions are constant and known. In that case, the a_{ij}-f_{ij} and g_i will also be known constants. That leaves us with one equation and two unknowns (content and change) for each pool in our system. To find a solution, further assumptions are needed to either increase the number of equations or decrease the number of unknowns.

Daisy includes six methods for initialization. Each of these will result in a linear equation system that can be solved using a standard technique (in this case, Gauss-Jordan elimination). All the methods rely on the assumption that the SMB pools are at equilibrium, meaning that ΔSMBi are all zero (Eq. (9.11)). This is reasonable, as the SMB pools tend to adjust to input levels relatively fast (a few years at most).

$$\Delta SMB_i = 0;\ i = 1 \ldots\ldots N_{SMB} \tag{9.11}$$

All but one of the initialization options require the user to specify the total organic matter (*TOM*) in the soil. This adds one more equation to the system without increasing the number of unknowns:

$$TOM = \sum_{i=1}^{N_{SMB}} SMB_i + \sum_{i=1}^{N_{SOM}} SOM_i + \sum_{i=1}^{N_{AOM}} AOM_i \tag{9.12}$$

The final common assumption is that the carbon input is known. In this case, the size of AOM_i can be found from eq. (9.8) (if $\Delta AOM = 0$, $AOM_i = I_C/g_i$). These pools can thus be eliminated as unknowns from the equation system. However, $(N_{SOM} - 1)$ equations are still missing before the system can be solved.

The six methods of initialization are selected using the "*init*"-function under "*organic*". The *"init"*-function has default parameters limiting the possible fraction-values of SOM1 and SOM2 (*SOM_limit_where, SOM_limit_lower, and*

SOM_limit_upper). It also has default settings for the pressure at which equilibrium is calculated (h = -100 [cm]) and for root biomass (*root* = 800 [kg/C/ha/y]). If the parameter "*input*" is set, it represents the total yearly input of carbon, including from roots. Bioincorporation is set to 0 as default in the "*init*" function.

Method 1: Explicit SOM partitioning

The original method of initializing the SOM pools was to require the user to explicitly specify the fraction of the total SOM allocated to each pool, as in eq. (9.13):

$$SOM_i = f_{SOMi} \sum_{j=1}^{N_{SOM}} SOM_j \;\; ; \;\; i = 1 \ldots N_{SOM} \tag{9.13}$$

where f_{SOMi} are user supplied fractions. This results in N_{SOM} additional equations. However, since $\sum_{i=1}^{N_{SOM}} f_{SOMi} = 1$, the system is over-specified, and one equation can be left out. Thus, for a system with two SOM-pools, we only specify one equation: $SOM_1 = f_{SOMi}(SOM_1 + SOM_2)$. Now Eqs. (9.8), (9.11), (9.12), and (9.13) provides enough equations to find a solution. The SOM fractions are defined in the sub-model "*horizon*".

The explicit SOM partitioning gives the user good control over the simulation with a manageable number of parameters. However, the SOM partitioning model is specific, and does not correspond to measurable quantities.

Method 2: Background mineralisation

Background mineralisation is the mineralization from all SMB and SOM pools but not from the AOM pools. Daisy allows the user to specify desired background mineralisation levels. The background mineralization is defined as the decrease over time of nitrogen stored in the SOM pools. Assuming a constant C/N ratio for each pool (C/N_{SOMi}), equation (9.14) can be added:

$$background = \sum_{i=1}^{N_{SOM}} \frac{\Delta SOM_i}{C/N_{SOMi}} \tag{9.14}$$

With this extra equation, the system can be solved in case of two SOM-pools. Using background mineralization for initializing the system has the advantage of being model independent and even indirectly measurable but requires a good understanding of the nitrogen dynamics of the system. An example of the use of background mineralization for initialization is shown below:

(OrganicMatter original (init (background_mineralization 50 [kg N/ha/y]) (end -25 [cm])))

"end" specifies to which depth the mineralization should be considered, by default it is the depth of the topmost horizon.

Equilibrium assumptions

If the system is in equilibrium, none of the pools will change, so Eq. (9.15) can be added:

$$\Delta SOM_i = 0 \quad ; i = 1 \ldots . N_{SOM} \tag{9.15}$$

Together with Eqs. (9.8), (9.11), and (9.12), this results in one more equation than needed, so it is possible to relax some other assumptions. This leads to three different variants, discussed below.

Method 3: Size of the inert pool

If we have an inert pool like SOM3 in Figure 9.2, no additional information is added by stating that ΔSOM3 = 0. This is already part of Eq. (9.15) and Eq. (9.10), where $d_{3,j}$, $e_{3,j}$, and $f_{3,j}$ will be 0 for all j. This is the case for the default initialization of the subsoil, where we assume that the active pools are in equilibrium with the input and let the equation system find the size of the inert pool. This method can only be specified for the topsoil indirectly, by defining an extremely small topsoil:

(OrganicMatter original (init (end -0.001 [cm])))

Method 4: Total organic matter

This method allows the user to leave out Eq. (9.13), so the total amount of (active) soil organic matter is estimated from the input levels. This is rarely useful, as the total amount of organic material is easy to measure but may be relevant for special applications.

(OrganicMatter original (init (variable_pool -1) (variable_pool_2 -1) (end -25 [cm])))

Method 5: Unknown input

The last and most common equilibrium initialization is to let the user specify the size of the inert pool (usually to zero) and leave out the AOM-calculation based on Eq. (9.8). This is useful for cases where the user has no idea of what the input levels for the field used to be.

This method requires a column definition with specification of "MaxRootingDepth" and SOM_fractions for the top horizon to be considered.

(OrganicMatter original (init (end -25 [cm])))

Method 6: Quasi equilibrium

The default initialization for organic matter in the plough layer is to weaken the equilibrium assumption and allow the pool with the lowest (non-zero) turn-over rate to change. That is, we remove one of the equations added by Eq. (9.15), namely for the slowest active pool (typically SOM1) and keep all the Eqs. (9.11), (9.12), and (9.8). The idea is that all the fast pools will quickly adapt to the input and to the size of the slow pool. This initialization requires specification of the average input of carbon (found from a long-term simulation). If this is not specified, it will use the input rate from the initial AOM-pools. The depth of the upmost horizon will be used for the calculation, if a different depth is not specified, as show below:

(OrganicMatter original (init (input 3000 [kg C/ha/y]) (end -25 [cm])))

However, an unpublished study showed that the quasi-equilibrium estimate is strongly dependent on the selected abiotic factors, and the difference in half-lives between the two SOM-pools may not be enough to get a good starting point for the simulations, using this method.

Conclusions

The best recommendations for initialisation of the organic matter pools are to 1) work with background mineralisation estimated from non-fertilized plots (or fertilized at a low rate) and 2) test the sensitivity of the simulations with SOM1- and 2-fractions from [0.3-0.7] (see Appendix 9.2 for the ranges obtained). For the first case, the field must have been treated uniformly until the experiment is carried out. The other methods can help provide estimates to test. Plots of changes in total SOM and SOM1/(Total SOM) will show how far the simulated system is from equilibrium. If we trust the time to obtain equilibrium estimated from the graphs in Appendix 9.2, few systems are in equilibrium, as the farming practice seldom is constant for sufficiently long periods of time.

9.10 Dissolved organic matter (DOM)

Dissolved Organic matter (DOM) has been included in Daisy twice on an experimental basis. However, the descriptions are not fully compatible, and the functions are not default and should be used with caution. In the first project, DOM was generated by de-sorption from SOM, in the second project, it was generated from the turn-over of mulch (plant residue organic matter decomposing on the soil surface if not tilled). The two components "*dom*" and "*domsorp*" under "*organic*" stem from the first project (Gjettermann, 2004), (Gjettermann et al., 2004 and 2008). "*dom*" uses the fixed component *DOM* that also stems from the first project and defines a single DOM-pool and its turnover pathway and rates. The domsorp-function describes the sorption/desorption of DOM on SOM. The mulch module (App. 3.1) does not use these entries.

The mulch module (App. 3.1) creates DOM that is broken down with the parameters specified in the *reaction DOM_turnover*. In this case, DOM is internally described as a DOC and a DON-pool (with corresponding names). DOM is, by default, converted to SMB2 with an efficiency of 62% and a rate of 0.04125 [h^{-1}] (Garnier et al., 2003, Table 1). The target for the C/N-ratio of the DOM-pool should be 10 (Garnier et al., 2003, Table 2). To achieve this, mineral N will be added or removed. The *max_N_depletion* (default 0.1 [h^{-1}]) determines the amount of mineral N that can be included in the DOM-pool.

DOC and DON are also defined under *chemical* as *nutrient (C)*, with shared canopy dissipation rate and wash off coefficient, but individual litter diffusion rates and diffusion coefficients. These are used for tracing of these components, see also Ch. 6 and 8.

It is recommended that these functions are used only in consultation with the Daisy group.

9.11 Re-parameterisation of the SMB2 to SOM2 pathway and bio-incorporation respiration

The error in the parameterisation of the pathway from SMB2 to SOM2 discovered in connection with writing this documentation, has led to changes in the parameterization of the default SMB-FAST (SMB2) pool so the default fractions now are (0 0.6 0 0.4 0) and an optional SMB-FAST-2000 pool is implemented defined with the earlier default fractions (0 0.4 0 0.6 0).

In addition, the default parameterization of the bio-incorporation respiration changed from 0.5 to 0 (from daisy 6.47 to Daisy 7.0.7).

If the SMB-FAST-2000 parameterization is combined with a bio-incorporation respiration of 0.5 it will correspond to the default parameterization of the SMB2 to SOM2 pathway and bio incorporation respiration in Daisy C++ before version 7.

The current default (Daisy 7.0.7) with SMB-FAST fractions (0 0.6 0 0.4 0) and a bio-incorporation-rate of 0 correspond to the parameterization in the original Fortran version (Hansen et al. (1990); Hansen et al. (1991)) and thus the parameterization used for the calibration of the pool in Bruun et al. (2003). For future studies we would therefore recommend using the SOM2025 parameterization.

We tested the two parameterizations for two test set ups run for 25 years:

- Test 1: A sandy loam (sandy clay loam below 50 cm) and a coarse sandy soil with conventional tillage and continuous spring barley.
- Test 2: A sandy loam (sandy clay loam below 50 cm) with conventional tillage and crop rotation, and with no tillage, mulching and crop rotation.

For simulations with conventional tillage the two parameterization produces similar C and N. However, for the simulation with no tillage (e.g. the C incorporation is completely dominated by bio-incorporation) the C and N dynamics differs between the two parameterizations. See appendix 9.4.

In the Daisy group we wish to do additional test of the SOM parameterizations and in the future re-calibrate the SOM-module. Until then, we recommend to use the new default parameterization for future studies, in particular when simulating no-till systems, as it resembles the parameterization used in Bruun et al. (2003) and because we do not find it reasonable that 50 % of the bio-incorporated material should be lost twice (in the bio-incorporation process and by the AOM pool).

9.12 Parameter overview

Table 9.2. Related Parameter names in Daisy.

Name and explanation		Model (in Daisy)	Parameter name (Daisy reference manual)	Default	Default unit
Soil organic matter	fraction of organic matter in a horizon	horizon	*humus*	user defined	[ ]
R_{max}	The rate of bio-incorporation, Eq. (9.1).	Bioincorporation	*R_max*	0.5	[g DM m^{-2} h^{-1}]
k_{half}	The half-saturation constant for bio-incorporation, Eq. (9.1).	Bioincorporation	*K_half*	1	[g DM m^{-2}]
f(C/N)	The dependency of the rate on the C/N-ratio, Eq. (9.1).	Bioincorporation	*C_per_N_factor*	plf: (C_per_N_factor (50 1) (100 0.1) (120 0.01))	[(g C cm^{-2})/(g N cm^{-2}) [ ]]
f(T)	Temperature function for bio-incorporation, Eq. (9.1)	Bioincorporation	*T_factor*	plf-function, default values (T_factor (4 0) (6 1))	[°C [ ]]
respiration	Fraction of C lost in respiration	Bioincorporation	*respiration*	0.5	[ ]
distribution	Distribution of incorporated matter in soil, see Figure 9.1. plf of (X, Y), where X is depth (negative) and Y is relative weight in that depth.	Bioincorporation	*distribution*	(distribution (-80 0) (-18 100) (0 100)	[cm [ ]]
Incorporated material	AOM-pool turnover parameters	Bioincorporation	*AOM*	(AOM "AOM-SLOW-BIOINCORPORATION" "AOM-FAST")	

Name and explanation		Model (in Daisy)	Parameter name (Daisy reference manual)	Default	Default unit
k	First order turnover rate, Eq. (9.2)	AOM, SMB, SOM	*Turnover_rate*	See Figure 9.2 and Section 9.6, 9.7, and 9.8.	[h^{-1}]
Half-life	ln(2)/k	AOM, SMB, SOM	*Turnover_halftime*	As above	[h]
turnover factor	Multiplied with all the pool turnover rates in the horizon	horizon	*turnover_factor*	1	[ ]
C/N-ratio (soil)	The carbon/nitrogen ratio in the soil cells.	AOM, SMB, SOM	*C_per_N*	Optional state variable.	[(g C cm^{-3})/g N cm^{-3})]
efficiency	The efficiency by which this pool can be digested by each of the SMB pools (sequence)	AOM, SMB, SOM	*efficiency*	See Figure 9.2 and Section 9.6, 9.7, and 9.8. Efficiency is (1- the fraction of CO_2 released).	[ ]
fractions	A sequence describing how the digested material from this pool is divided between other pools.		*fractions*	See Figure 9.2 and the description in:	[ ]
	First numbers represent each of the SMB-pools, then the SOM buffer, and any remaining numbers are DOM pools (if present)	AOM	*fractions*	Section 9.6	
	First numbers represent each of the SMB-pools, then the SOM pools, and	SMB and SOM	*fractions*	Section 9.7 and 9.8	

Name and explanation		Model (in Daisy)	Parameter name (Daisy reference manual)	Default	Default unit
	any remaining numbers are DOM pools (if present)				
$F^T(T)$	Temperature factor on organic matter turnover, Eq. (9.7).	AOM, SMB, SOM and organic (code in abiotic.C)	*heat_factor*	Default function in Eq. (9.7) for all pools but can be individually specified by user.	[ ]
$F^\psi(\psi)$	Water factor on organic matter turnover, Eq. (9.6).	AOM, SMB, SOM and organic	*water_factor*	Default function in Eq. (9.6) for all pools but can be individually specified by user.	[ ]
Neutral	A soil with a constant pH of 7.	soilph	*neutral*	7	[pH]
Year	pH as a function of year and soil depth. A submodel to soilph that take the parameters:	soilph year	*year* *pH_depth*	User defined Plf of depth and pH	[calender year] [cm → pH]
(initial) C/N-ratio (pools)	The initial C/N ratio when this pool was created.	AOM, SMB, SOM	*initial_C_per_N*	Optional state variable. Default for SMB-pools: 6.7 and for SOM-pools: 11. Negative numbers means unspecified	[g C g^{-1} N]
Initial fraction	The initial fraction of total carbon in added material allocated to this AOM pool. One pool	AOM	*initial_fraction*	See section 9.6.2, 9.6.3 and the definitions under AOM in the reference manual.	[ ]

Name and explanation		Model (in Daisy)	Parameter name (Daisy reference manual)	Default	Default unit
	should be left unspecified.				
Maintenance respiration	The respiration rate of the SMB pools	SMB	*maintenance*	See Figure 9.2 and Section 9.7.	[h^{-1}]
$F^{clay}(f_{clay})$	The clay factor multiplied onto the organic matter turnover og SOM1, 2 and SMB2.	organic, code in ClayOM.C	*ClayOM*	Default "old", as described as the standard model in Section 9.4.1.	[ ]
$F^{pH}(pH)$	Influence of pH on turnover	organic	*pH_factor*	Default: not defined. plf can be user defined (pH value)	[ ]
Depth of turnover processes	Part of the soil column involved in organic matter turnover.	organic	*Active_underground*	By default, organic matter turnover takes place in the root zone (*false*), but the whole column can be included (*true*).	
Maximum immobilisation rates	Maximum rates by which NH_4^+ and NO_3^- can be built into organic matter.	organic	*K_NH4* *K_NO3*	(default values for both are 0.020833 [h^{-1}], equal to 0.5 [d^{-1}]	[h^{-1}]
CO_2-threshold	Turnover rate that determines the limit between fast and slow processes	organic	*CO2_threshold*	0.0001 (approximately 289 days)	[h^{-1}]
The buffer	Submodel that describes transformation from AOM to SOM	organic	*buffer*	(where 1); [SOM2] (turnover_rate 1)	[h^{-1}]

Name and explanation		Model (in Daisy)	Parameter name (Daisy reference manual)	Default	Default unit
AOM	Added organic matter pools. Most of these pools will be added as part of management.	organic	*am*	(am root) [used for initialization of root remains]. See am (root) in reference manual for detailed parameterisation.	
SMB-pools	Choice of SMB pool descriptions.	organic	*smb*	(smb "SMB-SLOW" "SMB-FAST")	
SOM-pools	Choice of SOM pool descriptions.	organic	*som*	(som "SOM-SLOW" "SOM-FAST" "SOM-INERT")	
	Layered initialization of the soil SOM content, specifying a sequence of depths (bottom of layers) and corresponding organic carbon content for each layer.	organic	*Initial_SOM*	Optional submodel.	[cm, negative] [kg C m^{-2}]
Tillage influence, SMB	Distribution of turnover rates of SMB-pools over time after tillage. Sequence of plf's.	organic	*smb_tillage_factor*	Default: no effect	[d [ ]]
Tillage influence, SOM	Distribution of turnover rates of SMB-pools over time after tillage. Sequence of plf's.	organic	*som_tillage_factor*	Default: no effect	[d [ ]]

Name and explanation		Model (in Daisy)	Parameter name (Daisy reference manual)	Default	Default unit
Minimum C in AOM	The minimum amount of C present in an AOM-pool. If below, the pool is removed.	organic	*Min_AM_C*	Default: 0.5	[g C m^{-2}]
Minimum N in AOM	The minimum amount of N present in an AOM-pool. If below, the pool is removed.	organic	*Min_AM_N*	Default: 0.05	[g N m^{-2}]
Initialization	Submodel providing parameters for initialization of the SOM and SMB pools.	organic	*init*	If the C-content of all pools have been specified explicitly, those values are used. Otherwise, the total C-content from either the "initial SOM" parameter (if specified) or else from the humus content of each soil horizon will be used. If SOM_fractions have been specified, the pools will be initialized assuming the SMB pools are in equilibrium. Otherwise, it will be assumed that at least SOM 1 is in equilibrium too, see section 9.9.	

Name and explanation		Model (in Daisy)	Parameter name (Daisy reference manual)	Default	Default unit
Parameters of the init function					
	Pressure used for equilibrium calculations	init	*h*	100	[cm]
	Carbon added to the organic matter system from dead roots. It is part of the total amount specified by the "input" parameter.	init	*root*	800	[kg C ha^{-1} y^{-1}]
	Temperature used for the equilibrium calculation	init	*T*	By default, the yearly average from the weather component will be used.	[°C]
	Depth of non-root input. The input will be distributed uniformly till this depth, after subtracting the root-input.	init	*end*	By default, the end of the first horizon will be used.	[cm]
	The efficiency by which the input can be digested by each or the SMB-pools. Only used if "*input*" is specified.	init	*efficiency*	(0.5 0.5)	[ ]
	Destinations of AOM from "*input*".	init	*fractions*	(0 1 0)	[ ]

Name and explanation		Model (in Daisy)	Parameter name (Daisy reference manual)	Default	Default unit
	Distance downwards to reduce the root density to half the original value.	init	*dist*	7	[cm]
	Amount of carbon added (in average) to the organic matter system, typically found from initial simulations.	init	*input*	Default: none, but user specified for the quasi-equilibrium method. If unspecified, the input rate from the initially added organic matter pools will be used.	[kg C ha^{-1} y^{-1}]
	Amount of carbon added to the organic matter system from bioincorporation.	Init	*bioinc*	Default: 0. This is part of the total amount specified by the "input" parameter	[kg C ha^{-1} y^{-1}]
	Pool allowed not to be in equilibrium if neither the C-content nor "SOM_fractions" are specified.	init	*variable_pool*	Optional parameter. By default, the slowest active pool will be used. "0" equals SOM 1, "1"=SOM2, etc. If set to (-1), equilibrium will be assumed for all pools and the humus content will be ignored.	
	If "background mineralisation" is specified, two pools can	init	*variable_pool_2*	By default, the second slowest active pool will be	

Name and explanation		Model (in Daisy)	Parameter name (Daisy reference manual)	Default	Default unit
	be in non-equilibrium. This is the second.			used. “0” equals SOM 1, “1”=SOM2, etc.	
	Mineralization from all SMB and SOM pools, but not from the AOM pools.	init	*Background_mineralization*	If neither the C content of individual pools nor ’SOM fractions’ are specified, the SOM and SMB pools will be initialized so all pools in the topsoil (above ’end’, usually the first horizon) are in equilibrium except those specified by ’variable pool’ and ’variable pool 2’, usually SOM1 and SOM2. These two will be initialized so the background mineralization will be the specified number. The subsoil is not affected by this parameter. If unspecified, “variable_pool_2” will be assumed in equilibrium.	
	The SOM pool that must be within the limits specified by	init	*SOM_limit_where*	Default: 0	

Name and explanation		Model (in Daisy)	Parameter name (Daisy reference manual)	Default	Default unit
	"*SOM_limit_lower*" and "*SOM_limit_upper*".			0=SOM1, negative numbers disable the function.	
	Lower limit for automatic SOM partitioning, defined by the "*SOM_limit_where*" selected.	init	*SOM_limit_lower*	(SOM_limit_lower 0.3 0.7 0) Values must be adjusted if the SOM_limit_where is changed. If the fraction is below the lower limit, the default values are used. The values are ignored if SOM partitioning is specified in the horizons or as C content of each pool. The limit is ignored for depth below "end".	[ ]
	Upper limit for automatic SOM partitioning, defined by the "*SOM_limit_where*" selected.	init	*SOM_limit_upper*	(SOM_limit_upper 0.7 0.3 0) Values must be adjusted if the SOM_limit_where is changed. Works as the limit above.	[ ]
Parameters of the am organic function					
Weight	Amount of organic fertilizer (wet weight) applied.	am organic	*weight*	User specified	[Mg wet weight ha^{-1}]

Name and explanation		Model (in Daisy)	Parameter name (Daisy reference manual)	Default	Default unit
C-fraction	Carbon fraction of dry matter	am organic	*total_C_fraction*	User specified	[ ]
N-fraction	Nitrogen fraction of dry matter	am organic	*total_N_fraction*	User specified	[ ]
1st year utilization	Estimated useful N-fraction for the first year. Used to calculate total application from "equivalent weight" of N applied.	am organic	*first_year_utilization*	User specified	[ ]
2nd year utilization	Estimated useful N-fraction for the second year.	am organic	*second_year_utilization*	User specified	[ ]
Dry matter fraction	Dry matter fraction of total (wet) weight.	am organic	*dry matter fraction*	User specified	[ ]
NO_3-N fraction	Nitrate-N fraction of total N in (organic) fertilizer	am organic	*NO3_fraction*	User specified (default 0)	[ ]
NH_4-N fraction	Ammonium-N fraction of total N in (organic) fertilizer	am organic	*NH4_fraction*	User specified (default 0)	[ ]
Volatilization	Fraction of ammonium-N that evaporates on application.	am organic	*volatiliztion*	User specified (default 0)	[ ]
DOM-processes					
	Diffusion coefficient of DOM	Fixed component, DOM	*diffusion_coefficient*		[$cm^2\ s^{-1}$]

Name and explanation		Model (in Daisy)	Parameter name (Daisy reference manual)	Default	Default unit
	plf-function describing the dependency of the rate on temperature	Fixed component, DOM	*heat_factor*	default from organic matter	[°C [ ]]
	plf-function describing the dependency of the rate on soil moisture	Fixed component, DOM	*water_factor*	default from organic matter	[cm [ ]]
turnover-rate		Fixed component, DOM	*turnover_rate*	user specified (either rate or halftime)	[h^{-1}]
turnover halftime		Fixed component, DOM	*turnover_halftime*	user specified (either rate or halftime)	[h]
efficiency	The efficiency by which this pool can be digested by each of the SMB-pools	Fixed component, DOM	*efficiency*	user specified	[ ]
fractions	Fraction of this pool that ends up in each of the SMB-pools.	Fixed component, DOM		user specified	[ ]
	Target for DOM turnover. 0=SMB1, 1=SMB2. If there are 2 SMB-pools, 2=soil buffer.	reaction DOM_turnover	*where*	1	[ ]
efficiency	The efficiency by which this pool can be digested by the selected SMB-pool	reaction DOM_turnover	*efficiency*	0.62	
	Name of the DOC-pool allocated to DOM	reaction DOM_turnover	*DOC_name*	DOC	string

Name and explanation		Model (in Daisy)	Parameter name (Daisy reference manual)	Default	Default unit
	Name of the DON-pool allocated to DOM	reaction DOM_turnover	*DON_name*	DON	string
turnover	turnover-rate of DOM	reaction DOM_turnover	*turnover*	0.04125	[h^{-1}]
max N-depletion rate	The rate by which mineral N can be allocated to the DOM-pool to fulfil the C/N-goal.	reaction DOM_turnover	*max_N_depletion*	0.1	[h^{-1}]
C/N-goal for DOM pool	A C/N-ratios that determines uptake of mineral N from the soil	reaction DOM_turnover	*C_per_N_goal*	10	[g C (g N)$^{-1}$]

Original text from	A10, Daisy Description, Abrahamsen et al. (2010)*	
Updated by	date	For Daisy version
Styczen, M and Holbak, M.	2025-04-10	7.0.7

*Abrahamsen, P., Gjettermann, B. and Hansen, S. (2010- but unpublished): Initializing organic matter pools.

9.13 Appendices

Appendix 9.1: The BIOMOD model and clay dependency.

Appendix 9.2: Sensitivity analysis describing challenges of initialization of OM-pools.

Appendix 9.3: Abrahamsen, P., Gjettermann, B. and Hansen, S. (2010- but unpublished): Initializing organic matter pools.

Appendix 9.4: Test of different SOM parameterizations (SMB2 to SOM2 fractions and respiration from bio incorporation)

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