C-TOOL

A simple tool for simulation of soil carbon turnover

Technical report

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Part 1:

1. Introduction

The C-TOOL model enables simulations of the medium to long-term changes in soil organic carbon (SOC) to using a much reduced number of parameters and input data. Such a model would be of particular value for wide-area applications, where satisfying the data demands of more complex models is difficult or impossible. The model was inspired by contemporary soil organic matter (SOM) models (Petersen et al. 2002, Saffih-Hdadia and Mary 2008), and hence has many principles in common with a range of other contemporary SOM models, including Century (Parton et al. 1987), CN-SIM (Petersen et al. 2005), the DAISY SOM model (Hansen et al. 1991), ICBM (Andrén and Kätterer 1997) and RothC (Coleman and Jenkinson 1996). The C-TOOL framework was initially constructed as a flexible SOC model system and tested for a SOM model structure corresponding to that of the Daisy model (Petersen et al., 2002).

C-TOOL considers three conceptual SOC pools. These pools are fresh organic matter (FOM), humified organic matter (HUM), and resilient organic matter (ROM); C inputs to and turnover in topsoil and subsoil, C transport from topsoil to subsoil, and CO_2 emissions. Simulation of carbon isotope ^{14}C is also facilitated, and it is possible to simulate a specific isotope tagging to investigate carbon flow properties. The current C-TOOL version is parameterised with data on soil carbon and radiocarbon contents covering different crop and soil management in United Kingdom, Sweden and Denmark.

2. Model description

A scientific manuscript about C-TOOL is provided by Taghizadeh-Toosi *et al.*, 2014.

2.1. C-TOOL structure

The structure of the current version C-TOOL is shown in Figure 1. The organic matter decomposition starts with addition of FOM to the soil in the form of plant aboveground and belowground tissues, and the organic matter in animal manure.

The second pool is HUM. This organic material has been physically and/or biochemically transformed, mainly as a result of catabolism. The organic matter in animal manure will often have undergone a degree of decomposition in the animal gut or in manure storage, so that a proportion of the manure C is assumed to contribute directly to the HUM pool, in contrast to plant residues which are assumed only to contribute to FOM. The degree of humification is modelled through the f_{HUM} factor (Figure 1), which is > 0 for manure and 0 for plant residues. Radiocarbon measurements combined with measurements of mineralisation rates clearly indicate that the active humus pools are defined as having a half-life measured in decades (The third pool is called ROM, and this contains organic matter that may be several millennia old.

2.2. Transformations

Carbon turnover in C-TOOL consists of C in soil, C transport into deeper layers, and CO_2 emissions (Jenny 1941). The SOC is distributed between pools of different degradability and different depth (Figure 1).

The decomposition of carbon in each pool is described by first-order reaction kinetics:

$$\frac{dC_i}{dt} = -k_i C_i F_T(T) \qquad Equation\ 1$$

where k_i is decomposition rate coefficient (y^{-1}) for pool i at standard conditions (10°C), C_i is carbon content in pool i (Mg C ha^{-1}) and $F_T(T)$ is a temperature coefficient.

The temperature coefficient is modified to obtain unity at 10°C in the following manner (Kirschbaum 1995):

$$F_T(T) = 7.24 \exp\left[-3.432 + 0.168T\left(1 - \frac{0.5T}{36.9}\right)\right] \qquad Equation\ 2$$

where T is temperature (°C).

Soil temperature is a function of position and time. The boundary condition which describes an harmonic oscillation in monthly temperature at various depth is expressed as (Monteith and Unsworth 1990):

$$T(z,t) = \overline{T} + A(0)\exp\left(-\frac{z}{D}\right)\sin\left(\omega t - \frac{z}{D}\right) \qquad Equation\ 3$$

where $\overline{T}$ is the average monthly air temperature, A(0) is amplitude in air temperature at the surface on a monthly basis, z is depth, D is damping depth, and ω is angular frequency of the oscillation which is $2\pi/P$, i. e. for secondly cycles $\omega = \left(\frac{2\pi}{365\times24\times3600}\right)s^{-1}$.

After simulating the decomposition of FOM, two steps are assumed in C-TOOL: (1) a proportion of the resulting SOM (t_F) is transported to the deeper layer, and (2) the remaining of SOM is going through a humification process (Figure 1).

The clay content is assumed to influence the “humification coefficient”, h, which is the proportion of C that is directed to the HUM pool (Figure 1). The clay response on h is taken from Coleman and Jenkinson (1996), who fitted the following equation to data from Sørensen (1975):

$$R = 1.67(1.85 + 1.6\exp(-7.86X)) \qquad Equation\ 4$$

where R is ratio (C lost as CO_2)/(C directed to HUM), and X is clay fraction in the soil (kg kg^{-1})
The constant 1.67 is used to adjust to observed values of R in the field (Coleman and Jenkinson 1996).

The humification coefficient (h) is thus calculated as:

$$h = \frac{1}{R+1} \qquad Equation\ 5$$

With the equation above, the humification coefficient ranges from 0.148 at zero clay fraction (kg kg^{-1}) to 0.244 for pure clay.

The amount of SOC that is removed either with transport to the subsoil or emission as CO_2 from HUM pool is calculated simultaneously in C-TOOL after the decomposition process (Figure 1). The same procedure happens in ROM pool. The proportion of SOC present as ROM depends in part on the history of the soil. For example, soils that have developed from heathland that was regularly burnt for improving regrowth appear to have a larger proportion of SOC in the form ROM (Thomsen et al. 2008b). Previous studies indicate that the SOC turnover rate is related to the C:N ratio of the native soil organic matter (Thomsen et al. 2008b), suggesting that the C:N ratio can be used as an indicator of SOC partitioning between pools . The function used in C-TOOL is:

$$f(cn) = \min(56.2cn^{-1.69}, 1) \qquad Equation\ 6$$

where *cn* is the C:N ratio. This function is only used when the C:N ratio is above a threshold of 10.8; and it was developed from an independent dataset from Danish soils (Thomsen et al. 2008b). If the C:N ratio is above the threshold of 10.8, the initial content of C in HUM is adjusted downwards by multiplying *f(cn)* by the amount of C in HUM pool, subsequently the initial content of C in ROM is adjusted upwards to reflect a higher content of resilient organic matter (including charred material) with a high C:N ratio, so that the relative turnover rate is adjusted to the level determined by Equation 6.

The C-TOOL model uses a one-way, convection type transport model for simulating vertical transport of C in the soil as also utilised by Jenkinson & Coleman (2008). This assumption can be considered a simplification of the transport patterns reported by Dörr and Münnich (1989) and Bruun *et al*. (2007). In the present model, the convection is a fraction of the pool turnover (Figure 1), assumed to occur from the topsoil pool (0-25 cm depth) to the corresponding subsoil pool (25-100 cm). In the subsoil, the amount of SOC vertical transport is calculated but since no modelling of SOC below 100 cm is attempted, that amount is returned to the relevant pool (Figure 1).

The water function as a result of precipitation and potential evaporation within the other models such as RothC would have fitted well into the philosophy of simplicity and transparency underpinning the C-TOOL modelling concept. However, the data available for parameterisation were solely from temperate areas of Europe, with relatively similar climates for soil water content. This was considered a poor basis for parameterising a water function, so no function was included. In addition, the model does not simulate carbon turnover under excessively wet conditions that with low redox potentials may be restricting SOM degradation.

2.3. Isotope simulation

The carbon isotopes (^{14}C) can be simulated by C-TOOL, and the flows of these isotopes are assumed to follow that of ^{12}C without any discrimination. Radiocarbon measurements (^{14}C) are described here, as percent modern (*pM*) or as the difference in ^{14}C content relative to a defined standard ($\Delta^{14}C$) (Petersen et al. 2002).

$$pM = 100\frac{\sum_{i=1}^{n}\lambda_i}{\sum_{i=1}^{n}C_i} \qquad Equation\ 7$$

where λ_i is directly proportional to the amount of the isotope (^{14}C) in pool *i* and C_i is total C content in pool *i*.

$$\Delta^{14}C = 10(pM) - 1000 \qquad Equation\ 8$$

Annual atmospheric concentrations of ^{14}C during the period 1840-1899 were obtained by calculation from the expected size of the Suess effect (Baxter and Walton 1971). Before 1860, the model assumes that the radiocarbon age of the plant material entering the soil each year is zero which resulted in the values of 0 and 100 for $\Delta^{14}C$ and *pM*; respectively. Annual atmospheric concentrations during the period 1900-1949 were achieved from measured ^{14}C concentration of stored and dated malt whiskies, wines and flax seeds (Baxter and Walton 1971). Hence, for the period 1860-1949, the model simulates soil radiocarbon content using the dataset from Baxter and Walton (1971). For the period 1950-1984, measured atmospheric ^{14}C concentrations at U.K. latitudes were used (Harkness et al. 1986). For the period 1985-1996 and 1997-2013, the datasets from Levin *et al.* (1994) and Levin and Kromer (1997) were utilised; respectively (Figure 2).

In C-TOOL, the ^{14}C concentration of the plant material and manure entering the soil in a specific year is taken to be the same as the concentration in atmospheric CO_2, in that year. The values of the radiocarbon are in units of "absolute" percent modern (*sensu* Stuiver and Polach, 1977) in C-TOOL.

Hence, the radiocarbon activity of the input for a particular year is expresses as (*PM*/100) or (Δ^{14}C+1000)/1000, i.e. taking the value for 1859 as 1.

2.4. Implementation

The C-TOOL components were assembled in MATLAB (MathWorks Inc, 2012). The program can utilise a range of time-steps for SOC contents. The program can use any time step between one day and one year, and can be run for a predefined period. We used a monthly time step for simulations, applying mean monthly air temperature. All crop residues and root deposition were assumed to be partitioned over the year with 8% in April, 12% in May, 16% in June and 64% in July for all datasets. The manure application was assumed to be performed in March each year for relevant treatments (Petersen *et al.*, 2005a). All first-order relationships were integrated using the 4th order Runge-Kutta method (Abramowitz and Stegun 1964). The C-TOOL executable program is available at Agroecology department, Aarhus University, Denmark.

3. Data requirements

The required data to run the model are:

1. Average monthly mean air temperature ($^{\circ}$C)
2. Clay content of the soil (as a percentage
3. Soil C:N ratio
4. Yearly input of plant residues (Mg C ha^{-1})
5. Yearly input of FYM manure (Mg C ha^{-1})
6. Optional atmospheric ^{14}C content

4. C-TOOL parameters and values

The C-TOOL model parameters and values are shown in Table 1. For simplicity, we assumed that the initial SOC averaged 47% and 53% relative to the first meter SOC content in topsoil (0-25 cm) and subsoil (25-100 cm); respectively (Batjes 1996). The values for most of the C-TOOL fractions and parameters were extracted from literature. The decomposition rate of FOM pool (k_{FOM}, 1.44 yr^{-1}) was taken from Petersen *et al.* (2005a). The initial fraction of topsoil SOC in ROM pool of 0.405 was taken from Petersen *et al.* (2005a). The decomposition rate of HUM pool was obtained through optimisation of various long term trials in North Europe (k_{HUM}, 0.0192 yr^{-1}). The decomposition rate of ROM pool (k_{ROM}) was set to 4.63×10^{-4} yr^{-1}. Furthermore, the fraction of FOM topsoil which was going to ROM pool (f_{ROM}) is set to 0.012, so that under steady state the value for the topsoil inert organic matter fraction remains at 0.405 which had been recognized in the other studies (e.g. Petersen *et al.* (2005a)).

The fraction of C outflow from the topsoil FOM pool going to the equivalent subsoil pool was expressed by the parameter t_F. In a study on ^{14}C labelled ryegrass, Jenkinson (1977) found a leaching of 0.40-0.75% of labelled C applied, over a period of two years. In another study on ^{14}C labelled barley straw, Sørensen (1987) found an amount of 9-10% of retained labelled C after 8 years to be residing in the subsoil (below 20 cm). On the basis of this span, we set a value of $t_F = 0.03$. The fraction of outflux from HUM and ROM can be assumed to be lost as CO_2, and the remaining fraction is transported to the similar pool in subsoil. This was done by the simplifying assumption that the SOC in topsoil and subsoil in samples from agricultural fields from Danish nationwide square grid net (7 × 7 km) on average was in a “steady state” (Heidmann et al. 2002). Then according the above criterion, A fraction of C which emitted as CO_2 (f_{CO2}) to the atmosphere was set to 0.628.

The initial distribution of SOC between three pools in topsoil and subsoil were estimated using data from a network of soil carbon samplings to 1 m depth on agricultural land across Denmark. In brief, a Danish nation-wide square grid monitoring net with 830 sampling areas (each 50 × 50 m) spaced at a distance of 7 km was established in 1986, and was sampled 3 times with approximately 10-year intervals in 1986, 1997, and 2009 (Taghizadeh-Toosi *et al.*, 2014a). The 600 measured SOC values were available from those sampling areas in 1986. The distribution of those measured SOC contents followed the log normal distribution. Therefore, geometric mean and geometric standard deviation were calculated for SOC contents of three main soil types in Jutland and Islands in 1986 (Table 2).

We used 277 of the 830 sampling areas where we had all the measured SOC values for 3 sampling occasions on agricultural land and where management history allowed us do the comparison between SOC in 1986, 1997 and 2009. The topsoil SOC content was set to the measured SOC for 0-25 cm depth and subsoil SOC to that measured for 25-100 cm in 1986. These initial SOC contents (t C ha^{-}

^{1}) were calculated from the analysed SOC concentration and bulk densities. To estimate the different pool fractions, we ran the model for 100 years prior to 1986 assuming constant management and C inputs over this period. For this purpose, the C input was optimised for each grid area to minimise the sum of the squared error of the difference between simulated and measured SOC in 1986. The optimisation was performed using nonlinear curve-fitting function in MATLAB (Math-Works Inc., 2012). The average fraction of OC in the pools across three main soil types (FOM, HUM, and ROM) was shown in Table 1.

5. Calculations of total C (Mg ha^{-1}) deposited in top and sub soil

5.1. Carbon input from plants

The annual input of organic C to a soil is difficult to measure since it stems from many sources, including litter-fall, stubble, root exudates, dead roots, etc. Here, we assumed allometric relationships between crop yields and plant C input to the soil. For cereals, dry matter yield was reported separately for grain and straw, whereas for other crops, only total above-ground mass was reported. Even when straw is harvested, there will be a substantial amount of crop residues going back to the soil, e.g. 50% of stems, leaves and awns may be going back, partly because these are scattered as small particles or left in stubble and thus not harvestable with current technologies (Jørgensen et al. 2007). If the total aboveground biomass is cut close to the soil surface, or if the harvestable straw is removed from the field; the substantial amount of crop residues going back to the soil can be less than 50%. The belowground C inputs was assumed to include dead root biomass and rhizodeposition (Berntsen et al. 2005). Values for carbon allocation to roots are crop specific and were derived from various studies (Table 2). It was assumed that the plant dry matter C content was 45% for all crop parts. The procedure for the allometric calculations of total C deposited from plants is shown in Table 3 and uses the parameters shown in Table 2.

5.2. Carbon input from animal manure, faeces, digested faeces and digested feed

Specified amounts of animal manure may also be added in some treatments. The composition of farmyard manure was not measured, thus this was assumed to contain 9% C (Berntsen et al. 2005). It was also assumed that the manure dry matter C content was 45%. A fraction of animal manure (f_{HUM}) is transferred directly to the active humus pool (Figure 1). This fraction was calculated on the basis of Stemmer *et al.* (2000). In their long-term field experiment, they applied ^{14}C labelled straw and animal manure to two crop rotations and a bare fallow treatment; respectively. Then, the ratio of "*^{14}C content:organic C content*" averaged over the three treatments was "*1:1.358*" after 30 years (Stemmer et al. 2000). Also, they determined that the distribution of labelled C within the soil size fractions still differed significantly from the distribution of native organic C after 30 years. The silt size fraction was enriched with labelled C whereas the clay fraction containing highest amount of native C indicating the humification of applied C was weak or just starting. Considering the clay content dependent value of h (Equations 4 and 5), the f_{HUM} for animal manure was calculated based on Stemmer et al.'s study (2000); $f_{HUM}=1.358-1-h$. The f_{HUM} for pure plant origin was set to 0.

The f_{HUM} value for faeces, digested faeces and digested feed were extracted from (Thomsen et al. 2013); and were as below:

Faeces: fHUM= 0.1

Digested faeces: fHUM=0.63

Digested feed: fHUM=0.39

6. C-TOOL initialisation

The total initial soil C content for long-term experiments and also the distribution of the initial C content of topsoil and subsoil in SOC pools are estimated utilising a Marquard-Levenberg algorithm (Marquard 1963). The optimisation was performed with a weighted squared error sum as target function using available measured data (Soil C and *pM* from selected sites) and simulated data (Soil C and *pM*). In order to simulate SOC content, the C-TOOL was assembled in MATLAB (MathWorks Inc, 2012) and individually compared against data sets obtained from the long-term experiments. The initial distribution of SOM between HUM and ROM pool influences C-TOOL simulations (Bruun and Jensen 2002). This distribution of SOM cannot be corresponded to any measurable entities (Christensen 1996). In C-TOOL, a 30 year long of the pre-experimental management history was used to initialise C in each pool in order to generate the input required to match the initial stock of soil organic C. The weighted target function, as well as the other procedures for optimisation, was taken from Petersen *et al*. (2005a). The target function T was calculated as:

$$T = \sqrt{\frac{\sum_{i}^{m}\sum_{j}^{n_i}\sum_{k}^{l_{ij}}\frac{(O_{ijk}-S_{ijk})^2}{l_{ij}O_{\overline{J\ldots}}^{2}}}{n}} \qquad Equation\ 9$$

where i is the sums over all measurement types, j is the sums over all data series within each type, O_{ijk} is observation k in experiment j of type i, S_{ijk} is simulation k in experiment j of type i, $O_{\overline{J\ldots}}$ is average of all observation of type i and l_{ij} is total number of observations of type i in data series j.

Optimisation was performed using a lsqcurvefit function according to *Equation 9* in Matlab (2012b). A lower and upper bound for each parameter or fraction was defined prior to the start of optimisation from previous studies (Jenkinson and Rayner 1977, Petersen et al. 2005, Kätterer et al. 2011). Then, lsqcurvefit optimisation was run iteratively until all parameters stabilised by minimising the sum of root mean squared errors (RMSE) locally. The C-TOOL model parameters and their default and optimised values are shown in Table 1.

7. Definition of abbreviation used

SOC: soil organic carbon

FOM: Fresh Organic Matter

HUM: Humified organic matter

ROM: Resilient Organic Matter

f_{HUM}: fraction of input going to humified organic matter

k_{FOM}: decomposition rate of fresh organic matter

k_{HUM}: decomposition rate of humified organic matter

f_{ROM}: fraction of fresh organic matter going to resilient organic matter

k_{ROM}: deccomposition rate of resilient organic matter

t_F: The fraction of downward transport of C from fresh organic matter pool

X: soil clay fraction

R: (C lost as CO_2) to (C directed to humified organic matter) ratio

h: Humification coefficient

cn: carbon to nitrogen ratio

f_{CO2}: fraction of released CO_2

FYM: farm yard manure

T: temperature

t: time

$F_T(T)$: temperature coefficient

$\overline{T}$: the average monthly air temperature

A(0): amplitude in air temperature at the surface

z: depth

D: damping depth

ω: is angular frequency of the oscillation

^{14}C: carbon isotope

pM: percent modern

$\Delta^{14}C$: the difference in ^{14}C content relative to a defined standard

C_i: carbon content in pool i

λ_i: directly proportional to the amount of the isotope (^{14}C) in pool i

Part 2:

1. Input files

The parameters and values are required to run C-TOOL located in the input directory. The order of parameters in the input.txt file must be exactly as specified. An example of input file is shown in Part 3.

2. Data files

The data file specifies date, amount and optionally isotope content of carbon inputs. For each data file, data must be in the below column order from left to right: Year, carbon deposited from plant materials to top soil, carbon deposited from plant materials to subsoil, carbon deposited from manure to topsoil, plant radiocarbon content of atmospheric CO_2, and manure radiocarbon content of atmospheric CO_2. Data must be separated with space(s) or tab(s). An example of data file is shown in Part 3.

3. Temperature file

The temperature file contained the monthly temperature for whole simulation period. The temperature file starts with temperature data from January to December of the relevant years in the data file.

4. Running the C-TOOL

C-TOOL provides a simple interface, which is purely file-driven. If the execution file "Ctool2AsExe" is called (clicking on CTOOL.exe), it will search for the available input, data, and temperature file in the folder. It is convenient to place related files to run C-TOOL in the main folder, and place the other files in other directions.

5. Output files

C-TOOL provides two output files: total amount, transport and CO_2. The output files contain tabular-separated data.

The "*total amount*" file consists of the monthly data in the following order:

- C content from plant materials in topsoil FOM (Mg $ha^{-1}m^{-1}$)
- C content from plant materials in topsoil HUM (Mg $ha^{-1}m^{-1}$)
- C content from plant materials in topsoil ROM (Mg $ha^{-1}m^{-1}$)

- C content from manure in topsoil FOM (Mg $ha^{-1}m^{-1}$)
- C content from manure in topsoil HUM (Mg $ha^{-1}m^{-1}$)
- C content from manure in topsoil ROM (Mg $ha^{-1}m^{-1}$)
- ^{14}C (*pM*) from plant materials in topsoil FOM
- ^{14}C (*pM*) from plant materials in topsoil HUM
- ^{14}C (*pM*) from plant materials in topsoil ROM
- ^{14}C (*pM*) from manure in topsoil FOM
- ^{14}C (*pM*) from manure in topsoil HUM
- ^{14}C (*pM*) from manure in topsoil ROM,
- Total ^{14}C (*pM*) from manure and plant in topsoil
- Total amount of C (Mg $ha^{-1}m^{-1}$) in topsoil
- C content from plant materials in subsoil FOM (Mg $ha^{-1}m^{-1}$)
- C content from plant materials in subsoil HUM (Mg $ha^{-1}m^{-1}$)
- C content from plant materials in subsoil ROM (Mg $ha^{-1}m^{-1}$)
- C content from manure in subsoil FOM (Mg $ha^{-1}m^{-1}$)
- C content from manure in subsoil HUM (Mg $ha^{-1}m^{-1}$)
- C content from manure in subsoil ROM (Mg $ha^{-1}m^{-1}$)
- ^{14}C (*pM*) from plant materials in subsoil FOM
- ^{14}C (*pM*) from plant materials in subsoil HUM
- ^{14}C (*pM*) from plant materials in subsoil ROM
- ^{14}C (*pM*) from manure in subsoil FOM
- ^{14}C (*pM*) from manure in subsoil HUM
- ^{14}C (*pM*) from manure in subsoil ROM,
- Total ^{14}C (*pM*) from manure and plant in subsoil
- Total amount of C (Mg $ha^{-1}m^{-1}$) in subsoil

The “CO_2” file consists of the monthly data in the following order:

- Topsoil CO_2 emission (Mg $ha^{-1}m^{-1}$) from FOM decomposition
- Subsoil CO_2 emission (Mg $ha^{-1}m^{-1}$) from FOM decomposition

- Topsoil CO_2 emission (Mg $ha^{-1}m^{-1}$) from HUM decomposition
- Subsoil CO_2 emission (Mg $ha^{-1}m^{-1}$) from HUM decomposition
- Topsoil CO_2 emission (Mg $ha^{-1}m^{-1}$) from ROM decomposition
- Subsoil CO_2 emission (Mg $ha^{-1}m^{-1}$) from ROM decomposition

The "*transport*" file consists of the monthly data in the following order:

- Topsoil vertical transported C (Mg $ha^{-1}m^{-1}$) from FOM
- Topsoil vertical transported C (Mg $ha^{-1}m^{-1}$) from HUM
- Topsoil vertical transported C (Mg $ha^{-1}m^{-1}$) from ROM

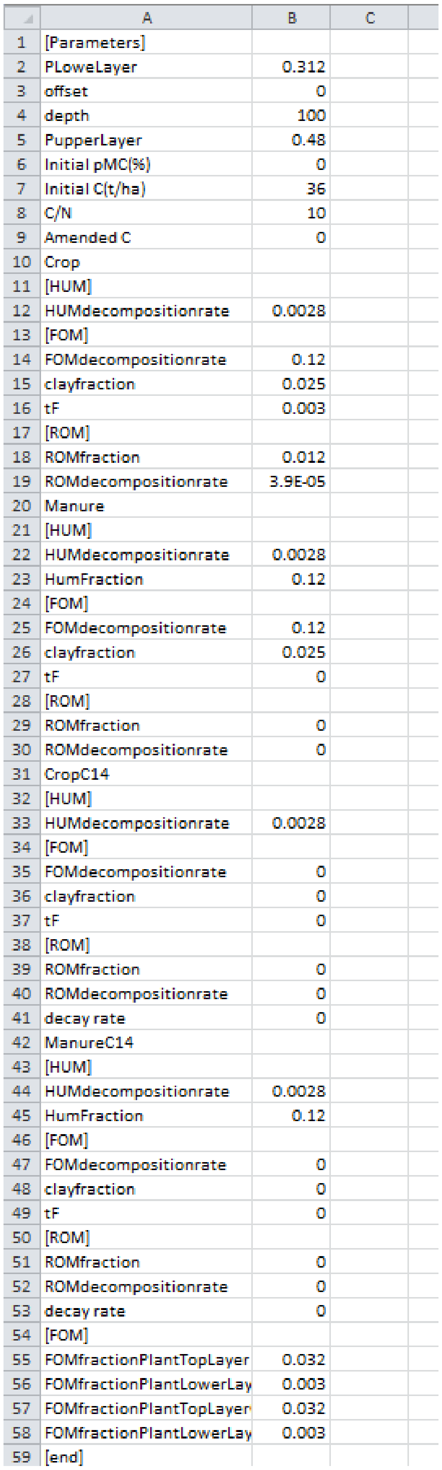
Part 3:

An example of the use of C-TOOL

An example was made with the simple assumption of having spring barley with the same yield every year, in order to show the input and out put files of C-TOOL.

1. **Input file**

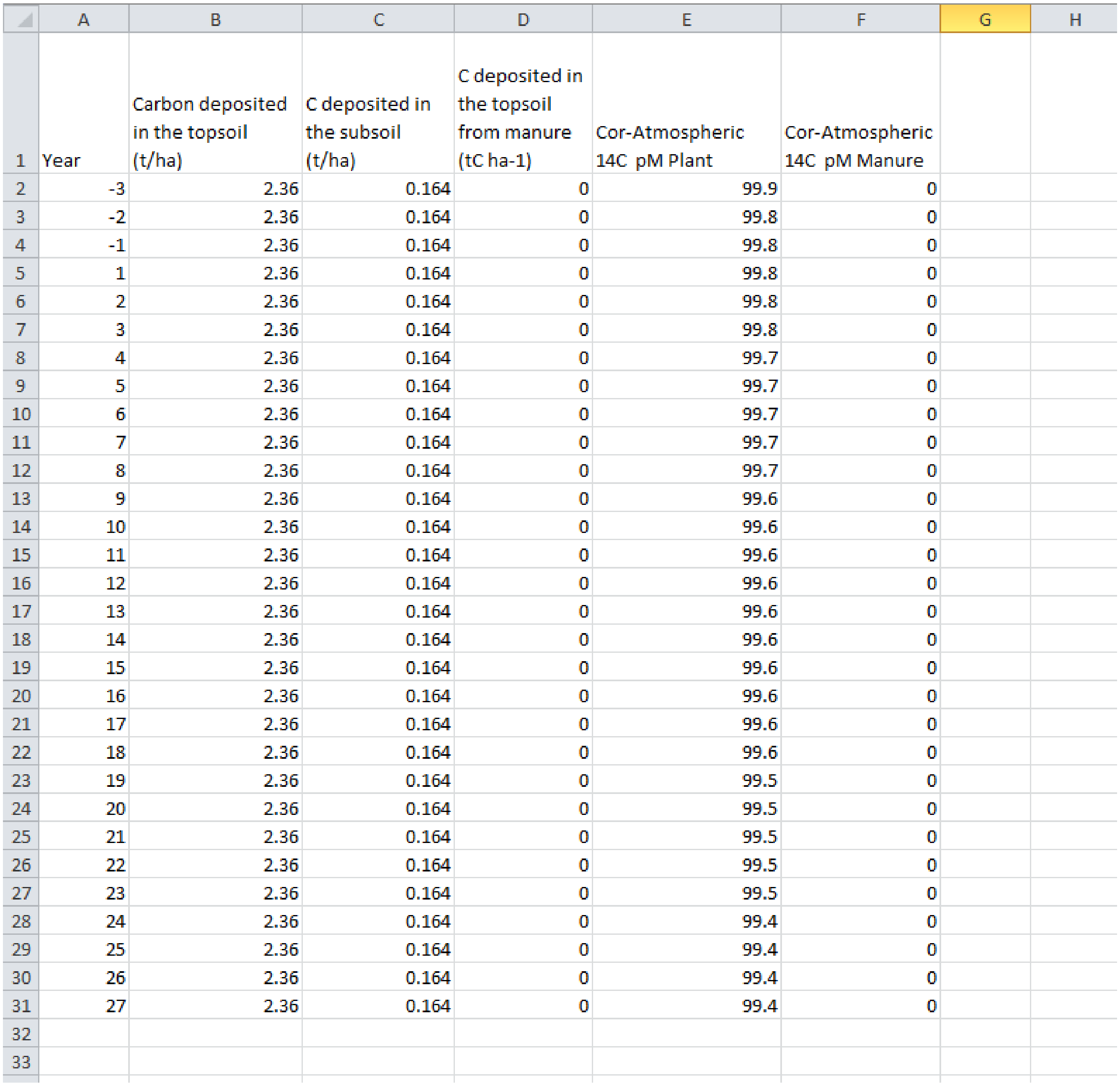
Treatment with Spring Barley:



	A	B	C
1	[Parameters]		
2	PLoweLayer	0.312	
3	offset	0	
4	depth	100	
5	PupperLayer	0.48	
6	Initial pMC(%)	0	
7	Initial C(t/ha)	36	
8	C/N	10	
9	Amended C	0	
10	Crop		
11	[HUM]		
12	HUMdecompositionrate	0.0028	
13	[FOM]		
14	FOMdecompositionrate	0.12	
15	clayfraction	0.025	
16	tF	0.003	
17	[ROM]		
18	ROMfraction	0.012	
19	ROMdecompositionrate	3.9E-05	
20	Manure		
21	[HUM]		
22	HUMdecompositionrate	0.0028	
23	HumFraction	0.12	
24	[FOM]		
25	FOMdecompositionrate	0.12	
26	clayfraction	0.025	
27	tF	0	
28	[ROM]		
29	ROMfraction	0	
30	ROMdecompositionrate	0	
31	CropC14		
32	[HUM]		
33	HUMdecompositionrate	0.0028	
34	[FOM]		
35	FOMdecompositionrate	0	
36	clayfraction	0	
37	tF	0	
38	[ROM]		
39	ROMfraction	0	
40	ROMdecompositionrate	0	
41	decay rate	0	
42	ManureC14		
43	[HUM]		
44	HUMdecompositionrate	0.0028	
45	HumFraction	0.12	
46	[FOM]		
47	FOMdecompositionrate	0	
48	clayfraction	0	
49	tF	0	
50	[ROM]		
51	ROMfraction	0	
52	ROMdecompositionrate	0	
53	decay rate	0	
54	[FOM]		
55	FOMfractionPlantTopLayer	0.032	
56	FOMfractionPlantLowerLay	0.003	
57	FOMfractionPlantTopLayer	0.032	
58	FOMfractionPlantLowerLay	0.003	
59	[end]		

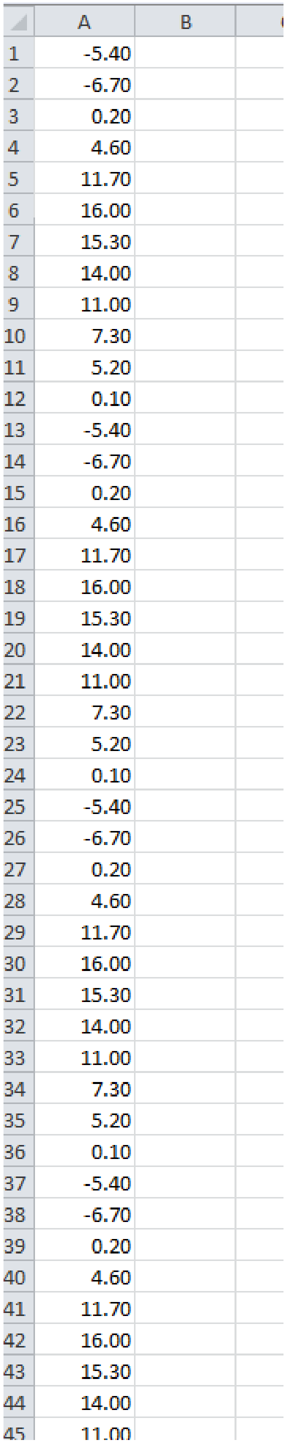
2. **Data files**

3. Treatment with Spring Barley:



Year	Carbon deposited in the topsoil (t/ha)	C deposited in the subsoil (t/ha)	C deposited in the topsoil from manure (tC ha-1)	Cor-Atmospheric 14C pM Plant	Cor-Atmospheric 14C pM Manure
-3	2.36	0.164	0	99.9	0
-2	2.36	0.164	0	99.8	0
-1	2.36	0.164	0	99.8	0
1	2.36	0.164	0	99.8	0
2	2.36	0.164	0	99.8	0
3	2.36	0.164	0	99.8	0
4	2.36	0.164	0	99.7	0
5	2.36	0.164	0	99.7	0
6	2.36	0.164	0	99.7	0
7	2.36	0.164	0	99.7	0
8	2.36	0.164	0	99.7	0
9	2.36	0.164	0	99.6	0
10	2.36	0.164	0	99.6	0
11	2.36	0.164	0	99.6	0
12	2.36	0.164	0	99.6	0
13	2.36	0.164	0	99.6	0
14	2.36	0.164	0	99.6	0
15	2.36	0.164	0	99.6	0
16	2.36	0.164	0	99.6	0
17	2.36	0.164	0	99.6	0
18	2.36	0.164	0	99.6	0
19	2.36	0.164	0	99.5	0
20	2.36	0.164	0	99.5	0
21	2.36	0.164	0	99.5	0
22	2.36	0.164	0	99.5	0
23	2.36	0.164	0	99.5	0
24	2.36	0.164	0	99.4	0
25	2.36	0.164	0	99.4	0
26	2.36	0.164	0	99.4	0
27	2.36	0.164	0	99.4	0

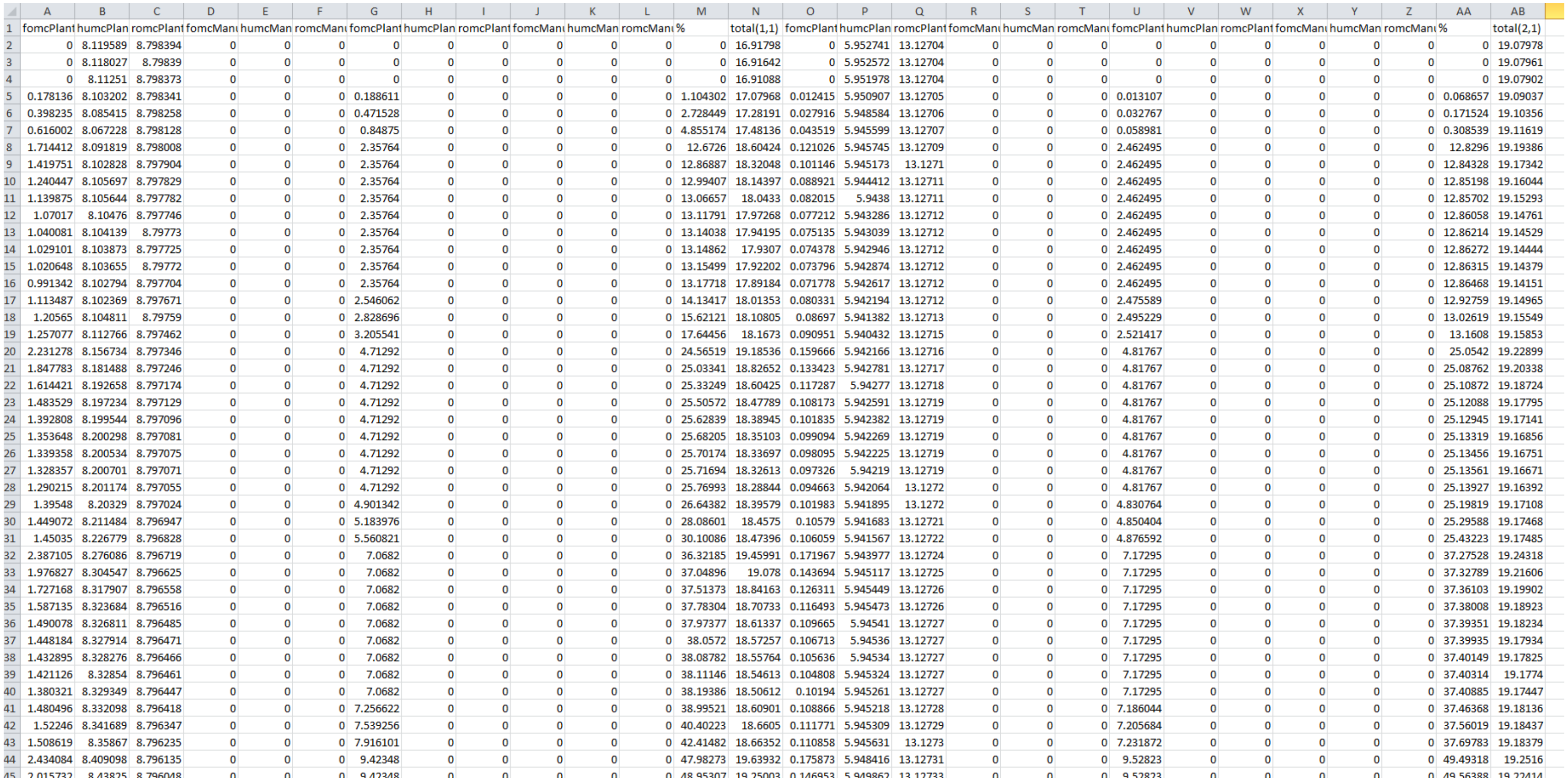
4. Temperature file



	A	B
1	-5.40	
2	-6.70	
3	0.20	
4	4.60	
5	11.70	
6	16.00	
7	15.30	
8	14.00	
9	11.00	
10	7.30	
11	5.20	
12	0.10	
13	-5.40	
14	-6.70	
15	0.20	
16	4.60	
17	11.70	
18	16.00	
19	15.30	
20	14.00	
21	11.00	
22	7.30	
23	5.20	
24	0.10	
25	-5.40	
26	-6.70	
27	0.20	
28	4.60	
29	11.70	
30	16.00	
31	15.30	
32	14.00	
33	11.00	
34	7.30	
35	5.20	
36	0.10	
37	-5.40	
38	-6.70	
39	0.20	
40	4.60	
41	11.70	
42	16.00	
43	15.30	
44	14.00	
45	11.00	

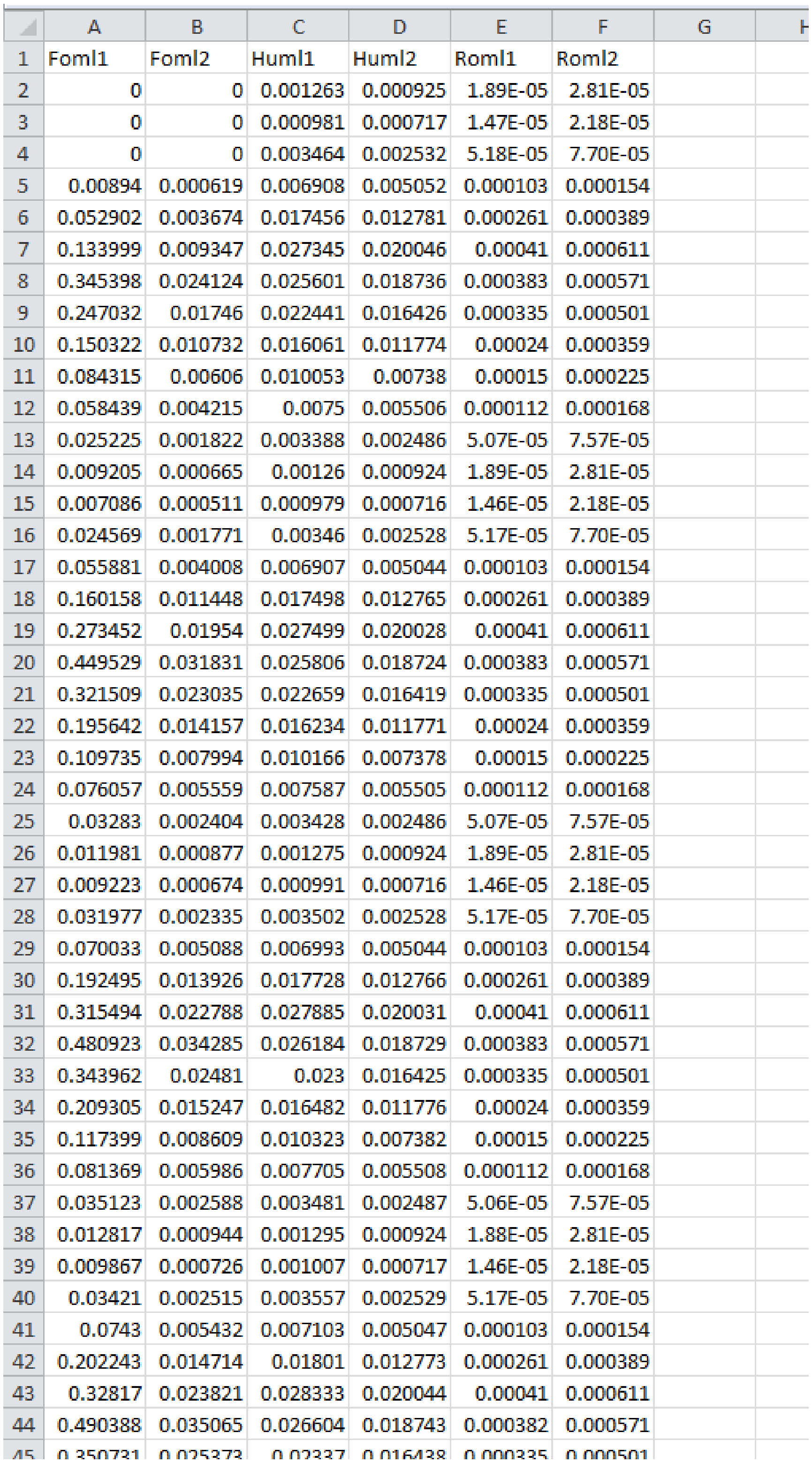
5. Output files

5.1. Total amount



	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W	X	Y	Z	AA	AB
1	fomcPlant	humcPlan	romcPlant	fomcMan	humcMan	romcMan	fomcPlant	humcPlan	romcPlant	fomcMan	humcMan	romcMan	%	total(1,1)	fomcPlant	humcPlan	romcPlant	fomcMan	humcMan	romcMan	fomcPlant	humcPlan	romcPlant	fomcMan	humcMan	romcMan	%	total(2,1)
2	0	8.119589	8.798394	0	0	0	0	0	0	0	0	0	0	16.91798	0	5.952741	13.12704	0	0	0	0	0	0	0	0	0	0	19.07978
3	0	8.118027	8.79839	0	0	0	0	0	0	0	0	0	0	16.91642	0	5.952572	13.12704	0	0	0	0	0	0	0	0	0	0	19.07961
4	0	8.11251	8.798373	0	0	0	0	0	0	0	0	0	0	16.91088	0	5.951978	13.12704	0	0	0	0	0	0	0	0	0	0	19.07902
5	0.178136	8.103202	8.798341	0	0	0	0.188611	0	0	0	0	0	1.104302	17.07968	0.012415	5.950907	13.12705	0	0	0	0.013107	0	0	0	0	0	0.068657	19.09037
6	0.398235	8.085415	8.798258	0	0	0	0.471528	0	0	0	0	0	2.728449	17.28191	0.027916	5.948584	13.12706	0	0	0	0.032767	0	0	0	0	0	0.171524	19.10356
7	0.616002	8.067228	8.798128	0	0	0	0.84875	0	0	0	0	0	4.855174	17.48136	0.043519	5.945599	13.12707	0	0	0	0.058981	0	0	0	0	0	0.308539	19.11619
8	1.714412	8.091819	8.798008	0	0	0	2.35764	0	0	0	0	0	12.6726	18.60424	0.121026	5.945745	13.12709	0	0	0	2.462495	0	0	0	0	0	12.8296	19.19386
9	1.419751	8.102828	8.797904	0	0	0	2.35764	0	0	0	0	0	12.86887	18.32048	0.101146	5.945173	13.1271	0	0	0	2.462495	0	0	0	0	0	12.84328	19.17342
10	1.240447	8.105697	8.797829	0	0	0	2.35764	0	0	0	0	0	12.99407	18.14397	0.088921	5.944412	13.12711	0	0	0	2.462495	0	0	0	0	0	12.85198	19.16044
11	1.139875	8.105644	8.797782	0	0	0	2.35764	0	0	0	0	0	13.06657	18.0433	0.082015	5.9438	13.12711	0	0	0	2.462495	0	0	0	0	0	12.85702	19.15293
12	1.07017	8.10476	8.797746	0	0	0	2.35764	0	0	0	0	0	13.11791	17.97268	0.077212	5.943286	13.12712	0	0	0	2.462495	0	0	0	0	0	12.86058	19.14761
13	1.040081	8.104139	8.79773	0	0	0	2.35764	0	0	0	0	0	13.14038	17.94195	0.075135	5.943039	13.12712	0	0	0	2.462495	0	0	0	0	0	12.86214	19.14529
14	1.029101	8.103873	8.797725	0	0	0	2.35764	0	0	0	0	0	13.14862	17.9307	0.074378	5.942946	13.12712	0	0	0	2.462495	0	0	0	0	0	12.86272	19.14444
15	1.020648	8.103655	8.79772	0	0	0	2.35764	0	0	0	0	0	13.15499	17.92202	0.073796	5.942874	13.12712	0	0	0	2.462495	0	0	0	0	0	12.86315	19.14379
16	0.991342	8.102794	8.797704	0	0	0	2.35764	0	0	0	0	0	13.17718	17.89184	0.071778	5.942617	13.12712	0	0	0	2.462495	0	0	0	0	0	12.86468	19.14151
17	1.113487	8.102369	8.797671	0	0	0	2.546062	0	0	0	0	0	14.13417	18.01353	0.080331	5.942194	13.12712	0	0	0	2.475589	0	0	0	0	0	12.92759	19.14965
18	1.20565	8.104811	8.79759	0	0	0	2.828696	0	0	0	0	0	15.62121	18.10805	0.08697	5.941382	13.12713	0	0	0	2.495229	0	0	0	0	0	13.02619	19.15549
19	1.257077	8.112766	8.797462	0	0	0	3.205541	0	0	0	0	0	17.64456	18.1673	0.090951	5.940432	13.12715	0	0	0	2.521417	0	0	0	0	0	13.1608	19.15853
20	2.231278	8.156734	8.797346	0	0	0	4.71292	0	0	0	0	0	24.56519	19.18536	0.159666	5.942166	13.12716	0	0	0	4.81767	0	0	0	0	0	25.0542	19.22899
21	1.847783	8.181488	8.797246	0	0	0	4.71292	0	0	0	0	0	25.03341	18.82652	0.133423	5.942781	13.12717	0	0	0	4.81767	0	0	0	0	0	25.08762	19.20338
22	1.614421	8.192658	8.797174	0	0	0	4.71292	0	0	0	0	0	25.33249	18.60425	0.117287	5.94277	13.12718	0	0	0	4.81767	0	0	0	0	0	25.10872	19.18724
23	1.483529	8.197234	8.797129	0	0	0	4.71292	0	0	0	0	0	25.50572	18.47789	0.108173	5.942591	13.12719	0	0	0	4.81767	0	0	0	0	0	25.12088	19.17795
24	1.392808	8.199544	8.797096	0	0	0	4.71292	0	0	0	0	0	25.62839	18.38945	0.101835	5.942382	13.12719	0	0	0	4.81767	0	0	0	0	0	25.12945	19.17141
25	1.353648	8.200298	8.797081	0	0	0	4.71292	0	0	0	0	0	25.68205	18.35103	0.099094	5.942269	13.12719	0	0	0	4.81767	0	0	0	0	0	25.13319	19.16856
26	1.339358	8.200534	8.797075	0	0	0	4.71292	0	0	0	0	0	25.70174	18.33697	0.098095	5.942225	13.12719	0	0	0	4.81767	0	0	0	0	0	25.13456	19.16751
27	1.328357	8.200701	8.797071	0	0	0	4.71292	0	0	0	0	0	25.71694	18.32613	0.097326	5.94219	13.12719	0	0	0	4.81767	0	0	0	0	0	25.13561	19.16671
28	1.290215	8.201174	8.797055	0	0	0	4.71292	0	0	0	0	0	25.76993	18.28844	0.094663	5.942064	13.1272	0	0	0	4.81767	0	0	0	0	0	25.13927	19.16392
29	1.39548	8.20329	8.797024	0	0	0	4.901342	0	0	0	0	0	26.64382	18.39579	0.101983	5.941895	13.1272	0	0	0	4.830764	0	0	0	0	0	25.19819	19.17108
30	1.449072	8.211484	8.796947	0	0	0	5.183976	0	0	0	0	0	28.08601	18.4575	0.10579	5.941683	13.12721	0	0	0	4.850404	0	0	0	0	0	25.29588	19.17468
31	1.45035	8.226779	8.796828	0	0	0	5.560821	0	0	0	0	0	30.10086	18.47396	0.106059	5.941567	13.12722	0	0	0	4.876592	0	0	0	0	0	25.43223	19.17485
32	2.387105	8.276086	8.796719	0	0	0	7.0682	0	0	0	0	0	36.32185	19.45991	0.171967	5.943977	13.12724	0	0	0	7.17295	0	0	0	0	0	37.27528	19.24318
33	1.976827	8.304547	8.796625	0	0	0	7.0682	0	0	0	0	0	37.04896	19.078	0.143694	5.945117	13.12725	0	0	0	7.17295	0	0	0	0	0	37.32789	19.21606
34	1.727168	8.317907	8.796558	0	0	0	7.0682	0	0	0	0	0	37.51373	18.84163	0.126311	5.945449	13.12726	0	0	0	7.17295	0	0	0	0	0	37.36103	19.19902
35	1.587135	8.323684	8.796516	0	0	0	7.0682	0	0	0	0	0	37.78304	18.70733	0.116493	5.945473	13.12726	0	0	0	7.17295	0	0	0	0	0	37.38008	19.18923
36	1.490078	8.326811	8.796485	0	0	0	7.0682	0	0	0	0	0	37.97377	18.61337	0.109665	5.94541	13.12727	0	0	0	7.17295	0	0	0	0	0	37.39351	19.18234
37	1.448184	8.327914	8.796471	0	0	0	7.0682	0	0	0	0	0	38.0572	18.57257	0.106713	5.94536	13.12727	0	0	0	7.17295	0	0	0	0	0	37.39935	19.17934
38	1.432895	8.328276	8.796466	0	0	0	7.0682	0	0	0	0	0	38.08782	18.55764	0.105636	5.94534	13.12727	0	0	0	7.17295	0	0	0	0	0	37.40149	19.17825
39	1.421126	8.32854	8.796461	0	0	0	7.0682	0	0	0	0	0	38.11146	18.54613	0.104808	5.945324	13.12727	0	0	0	7.17295	0	0	0	0	0	37.40314	19.1774
40	1.380321	8.329349	8.796447	0	0	0	7.0682	0	0	0	0	0	38.19386	18.50612	0.10194	5.945261	13.12727	0	0	0	7.17295	0	0	0	0	0	37.40885	19.17447
41	1.480496	8.332098	8.796418	0	0	0	7.256622	0	0	0	0	0	38.99521	18.60901	0.108866	5.945218	13.12728	0	0	0	7.186044	0	0	0	0	0	37.46368	19.18136
42	1.52246	8.341689	8.796347	0	0	0	7.539256	0	0	0	0	0	40.40223	18.6605	0.111771	5.945309	13.12729	0	0	0	7.205684	0	0	0	0	0	37.56019	19.18437
43	1.508619	8.35867	8.796235	0	0	0	7.916101	0	0	0	0	0	42.41482	18.66352	0.110858	5.945631	13.1273	0	0	0	7.231872	0	0	0	0	0	37.69783	19.18379
44	2.434084	8.409098	8.796135	0	0	0	9.42348	0	0	0	0	0	47.98273	19.63932	0.175873	5.948416	13.12731	0	0	0	9.52823	0	0	0	0	0	49.49318	19.2516
45	2.015732	8.43825	8.796048	0	0	0	9.42348	0	0	0	0	0	48.95307	19.25003	0.146953	5.949862	13.12733	0	0	0	9.52823	0	0	0	0	0	49.56388	19.22414

5.2.CO_2



	A	B	C	D	E	F	G
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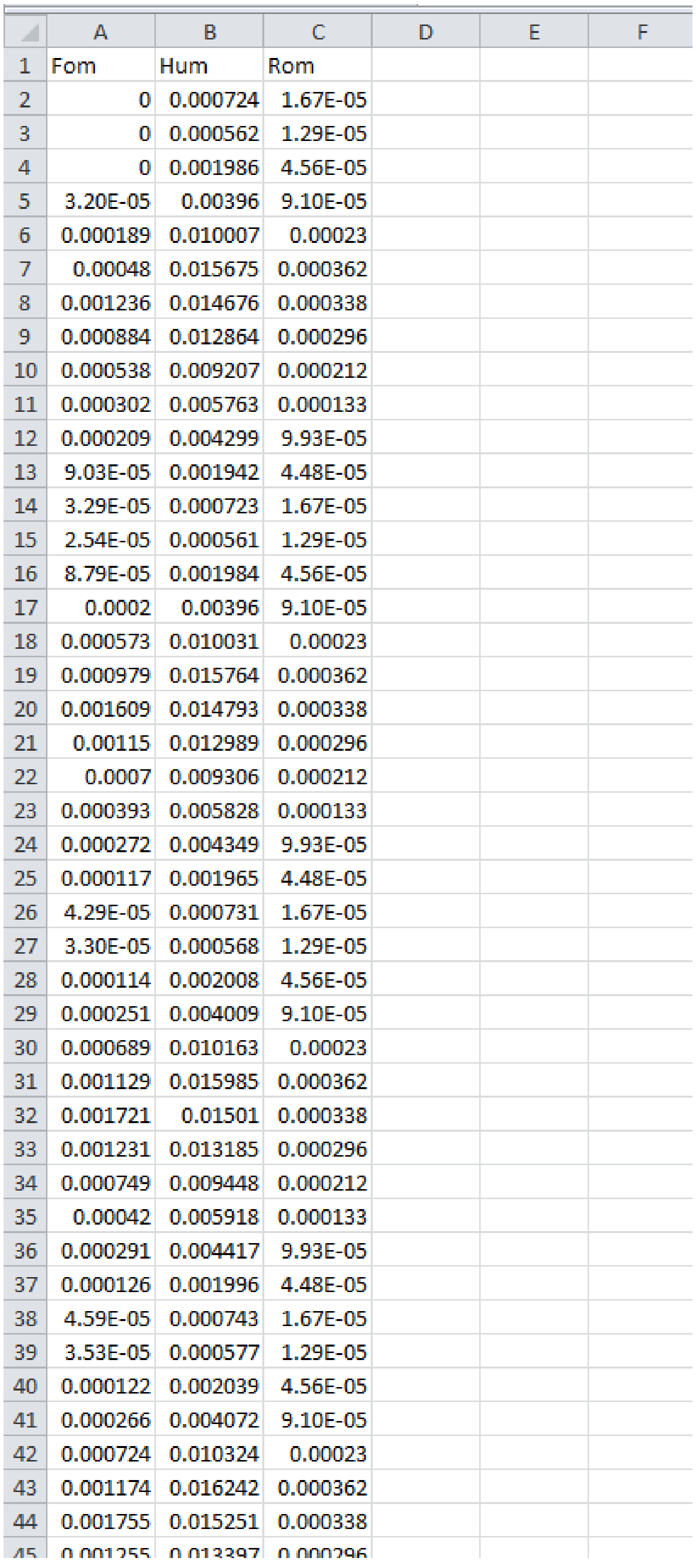
3	0	0	0.000981	0.000717	1.47E-05	2.18E-05	
4	0	0	0.003464	0.002532	5.18E-05	7.70E-05	
5	0.00894	0.000619	0.006908	0.005052	0.000103	0.000154	
6	0.052902	0.003674	0.017456	0.012781	0.000261	0.000389	
7	0.133999	0.009347	0.027345	0.020046	0.00041	0.000611	
8	0.345398	0.024124	0.025601	0.018736	0.000383	0.000571	
9	0.247032	0.01746	0.022441	0.016426	0.000335	0.000501	
10	0.150322	0.010732	0.016061	0.011774	0.00024	0.000359	
11	0.084315	0.00606	0.010053	0.00738	0.00015	0.000225	
12	0.058439	0.004215	0.0075	0.005506	0.000112	0.000168	
13	0.025225	0.001822	0.003388	0.002486	5.07E-05	7.57E-05	
14	0.009205	0.000665	0.00126	0.000924	1.89E-05	2.81E-05	
15	0.007086	0.000511	0.000979	0.000716	1.46E-05	2.18E-05	
16	0.024569	0.001771	0.00346	0.002528	5.17E-05	7.70E-05	
17	0.055881	0.004008	0.006907	0.005044	0.000103	0.000154	
18	0.160158	0.011448	0.017498	0.012765	0.000261	0.000389	
19	0.273452	0.01954	0.027499	0.020028	0.00041	0.000611	
20	0.449529	0.031831	0.025806	0.018724	0.000383	0.000571	
21	0.321509	0.023035	0.022659	0.016419	0.000335	0.000501	
22	0.195642	0.014157	0.016234	0.011771	0.00024	0.000359	
23	0.109735	0.007994	0.010166	0.007378	0.00015	0.000225	
24	0.076057	0.005559	0.007587	0.005505	0.000112	0.000168	
25	0.03283	0.002404	0.003428	0.002486	5.07E-05	7.57E-05	
26	0.011981	0.000877	0.001275	0.000924	1.89E-05	2.81E-05	
27	0.009223	0.000674	0.000991	0.000716	1.46E-05	2.18E-05	
28	0.031977	0.002335	0.003502	0.002528	5.17E-05	7.70E-05	
29	0.070033	0.005088	0.006993	0.005044	0.000103	0.000154	
30	0.192495	0.013926	0.017728	0.012766	0.000261	0.000389	
31	0.315494	0.022788	0.027885	0.020031	0.00041	0.000611	
32	0.480923	0.034285	0.026184	0.018729	0.000383	0.000571	
33	0.343962	0.02481	0.023	0.016425	0.000335	0.000501	
34	0.209305	0.015247	0.016482	0.011776	0.00024	0.000359	
35	0.117399	0.008609	0.010323	0.007382	0.00015	0.000225	
36	0.081369	0.005986	0.007705	0.005508	0.000112	0.000168	
37	0.035123	0.002588	0.003481	0.002487	5.06E-05	7.57E-05	
38	0.012817	0.000944	0.001295	0.000924	1.88E-05	2.81E-05	
39	0.009867	0.000726	0.001007	0.000717	1.46E-05	2.18E-05	
40	0.03421	0.002515	0.003557	0.002529	5.17E-05	7.70E-05	
41	0.0743	0.005432	0.007103	0.005047	0.000103	0.000154	
42	0.202243	0.014714	0.01801	0.012773	0.000261	0.000389	
43	0.32817	0.023821	0.028333	0.020044	0.00041	0.000611	
44	0.490388	0.035065	0.026604	0.018743	0.000382	0.000571	
45	0.350731	0.025373	0.02337	0.016438	0.000335	0.000501	

5.3. Transport



	A	B	C	D	E	F
1	Fom	Hum	Rom			
2	0	0.000724	1.67E-05			
3	0	0.000562	1.29E-05			
4	0	0.001986	4.56E-05			
5	3.20E-05	0.00396	9.10E-05			
6	0.000189	0.010007	0.00023			
7	0.00048	0.015675	0.000362			
8	0.001236	0.014676	0.000338			
9	0.000884	0.012864	0.000296			
10	0.000538	0.009207	0.000212			
11	0.000302	0.005763	0.000133			
12	0.000209	0.004299	9.93E-05			
13	9.03E-05	0.001942	4.48E-05			
14	3.29E-05	0.000723	1.67E-05			
15	2.54E-05	0.000561	1.29E-05			
16	8.79E-05	0.001984	4.56E-05			
17	0.0002	0.00396	9.10E-05			
18	0.000573	0.010031	0.00023			
19	0.000979	0.015764	0.000362			
20	0.001609	0.014793	0.000338			
21	0.00115	0.012989	0.000296			
22	0.0007	0.009306	0.000212			
23	0.000393	0.005828	0.000133			
24	0.000272	0.004349	9.93E-05			
25	0.000117	0.001965	4.48E-05			
26	4.29E-05	0.000731	1.67E-05			
27	3.30E-05	0.000568	1.29E-05			
28	0.000114	0.002008	4.56E-05			
29	0.000251	0.004009	9.10E-05			
30	0.000689	0.010163	0.00023			
31	0.001129	0.015985	0.000362			
32	0.001721	0.01501	0.000338			
33	0.001231	0.013185	0.000296			
34	0.000749	0.009448	0.000212			
35	0.00042	0.005918	0.000133			
36	0.000291	0.004417	9.93E-05			
37	0.000126	0.001996	4.48E-05			
38	4.59E-05	0.000743	1.67E-05			
39	3.53E-05	0.000577	1.29E-05			
40	0.000122	0.002039	4.56E-05			
41	0.000266	0.004072	9.10E-05			
42	0.000724	0.010324	0.00023			
43	0.001174	0.016242	0.000362			
44	0.001755	0.015251	0.000338			
45	0.001255	0.013397	0.000296			

List of Tables

Table 1. C-TOOL parameters and values.

Table 2. Geometric mean SOC content (t C ha^{-1}) for three main Danish soil type.

Table 3. Values of carbon allocation to harvest (main and secondary products) and roots.

Table 4. Calculations of total C (Mg ha^{-1}) deposited from plant materials in topsoil and subsoil.

Figure captions

Figure 1. C-TOOL model structure for topsoil and subsoil.

Figure 2. Atmospheric content of ^{14}C in the Northern Hemisphere (Coleman and Jenkinson 2008).

Table 1. C-TOOL parameters and values.

C-TOOL Parameter	**Value**
Initial C content (Mg ha^{-1})	Optimised for each treatment
Initial f_{FOM} (Jutland-CC1-Topsoil-for the beginning of 1986)	0.026
Initial f_{FOM} (Jutland-CC1-Subsoil-for the beginning of 1986)	0.003
Initial f_{HUM} (Jutland-CC1-Topsoil-for the beginning of 1986)	0.277
Initial f_{HUM} (Jutland-CC1-Subsoil-for the beginning of 1986)	0.190
Initial f_{ROM} (Jutland-CC1-Topsoil-for the beginning of 1986)	0.697
Initial f_{ROM} (Jutland-CC1-Subsoil-for the beginning of 1986)	0.808
Initial f_{FOM} (Jutland-CC2&3-Topsoil-for the beginning of 1986)	0.029
Initial f_{FOM} (Jutland-CC2&3-Subsoil-for the beginning of 1986)	0.003
Initial f_{HUM} (Jutland-CC2&3-Topsoil-for the beginning of 1986)	0.390
Initial f_{HUM} (Jutland-CC2&3-Subsoil-for the beginning of 1986)	0.287
Initial f_{ROM} (Jutland-CC2&3-Topsoil-for the beginning of 1986)	0.582
Initial f_{ROM} (Jutland-CC2&3-Subsoil-for the beginning of 1986)	0.710
Initial f_{FOM} (Jutland-CC4&5-Topsoil-for the beginning of 1986)	0.034
Initial f_{FOM} (Jutland- CC4&5-Subsoil-for the beginning of 1986)	0.003
Initial f_{HUM} (Jutland- CC4&5-Topsoil-for the beginning of 1986)	0.549
Initial f_{HUM} (Jutland- CC4&5-Subsoil-for the beginning of 1986)	0.334
Initial f_{ROM} (Jutland- CC4&5-Topsoil-for the beginning of 1986)	0.417
Initial f_{ROM} (Jutland- CC4&5-Subsoil-for the beginning of 1986)	0.662
Initial f_{FOM} (Islands-CC3-Topsoil-for the beginning of 1986)	0.040
Initial f_{FOM} (Islands -CC3-Subsoil-for the beginning of 1986)	0.004
Initial f_{HUM} (Islands -CC3-Topsoil-for the beginning of 1986)	0.512
Initial f_{HUM} (Islands -CC3-Subsoil-for the beginning of 1986)	0.324
Initial f_{ROM} (Islands -CC2&3-Topsoil-for the beginning of 1986)	0.448
Initial f_{ROM} (Islands -CC2&3-Subsoil-for the beginning of 1986)	0.672
Initial f_{FOM} (Islands -CC4&5&6-Topsoil-for the beginning of 1986)	0.031
Initial f_{FOM} (Islands - CC4&5&6-Subsoil-for the beginning of 1986)	0.003
Initial f_{HUM} (Islands - CC4&5&6-Topsoil-for the beginning of 1986)	0.552
Initial f_{HUM} (Islands - CC4&5&6-Subsoil-for the beginning of 1986)	0.351
Initial f_{ROM} (Islands - CC4&5&6-Topsoil-for the beginning of 1986)	0.417
Initial f_{ROM} (Islands - CC4&5&6-Subsoil-for the beginning of 1986)	0.647
f_{HUM} (Crop)	0
f_{HUM} (Manure)	1.358-1-h
f_{ROM}	0.012
k_{FOM} (yr^{-1})	1.44
k_{HUM} (yr^{-1})	0.0336 ± 0.002
k_{ROM} (yr^{-1})	4.63×10^{-4}
t_F	0.03
f_{CO2}	0.628

Table 2. Geometric mean SOC content (t C ha^{-1}) for three main Danish soil type.

Region	**Color Code**	**Topsoil Number of the points**	**Topsoil Geometric Mean (t C ha^{-1})**	**Topsoil Geometric Standard deviation**	**Subsoil Number of the points**	**Subsoil Geometric Mean (t C ha^{-1})**	**Subsoil Geometric Standard deviation**
Jutland	1	98	62.2	1.5	98	62.0	1.7
Jutland	2 & 3	206	62.7	1.6	206	61.9	1.6
Jutland	4 & 5 & 6	116	58.1	1.4	114	77.7	1.6
Islands	1	2	43.4	1.3	2	52.6	1.8
Islands	2 & 3	35	46.4	1.3	35	62.9	1.6
Islands	4 & 5 & 6	143	51.9	1.5	142	70.4	1.6

Table 3. Values of carbon allocation to harvest (main and secondary products) and roots.

Crop	**Harvest index of main crop relative to aboveground biomass (α)**	**Biomass of secondary crop product as proportion of yield of main crop product (δ)**	**Root and exudate C as proportion of total C assimilation (β)**
Winter wheat (Kuzyakov and Domanski 2000, Olesen et al. 2000, Danmarks-Statistik 2004)	0.45	0.55	0.25
Spring barley (Kuzyakov and Domanski 2000, Danmarks-Statistik 2004)	0.45	0.55	0.17
Winter barley (Kuzyakov and Domanski 2000, Danmarks-Statistik 2004)	0.39	0.55	0.17
Rye (Kuzyakov and Domanski 2000, Danmarks-Statistik 2004, Kätterer et al. 2004)	0.38	0.80	0.25
Oat (Kuzyakov and Domanski 2000, Danmarks-Statistik 2004)	0.40	0.60	0.17
Cereals for whole-crop silage (Lindroth and Båth 1999, Kuzyakov and Domanski 2000, Danmarks-Statistik 2004)	0.75	0.00	0.17
Other cereals, mainly triticale (Kuzyakov and Domanski 2000, Danmarks-Statistik 2004, Kätterer et al. 2004)	0.38	0.80	0.25
Oilseed rape (Danmarks-Statistik 2004, Kätterer et al. 2004)	0.37	0.90	0.25
Grass and grass clover (Estimated from (Christensen et al. 2009))	0.70	0.00	0.45
Potatoes (Andrén et al. 2004, Danmarks-Statistik 2004)	0.70	0.00	0.11
Sugar beets (Andrén et al. 2004, Danmarks-Statistik 2004)	0.70	0.00	0.12
Fodder beets (Andrén et al. 2004, Danmarks-Statistik 2004)	0.70	0.34	0.12
Swedish turnip (Estimated from (Andrén et al. 2004, Danmarks-Statistik 2004))	0.70	0.00	0.12

Table 4. Calculations of total C (Mg ha^{-1}) deposited in top and sub soil.

Parameters

α = Harvest index of main crop product relative to aboveground biomass

β = Root biomass and exudate C (below-ground C) as proportion of total net C assimilation

δ = Biomass of secondary crop product (e.g. straw) as proportion of yield of main crop product

ζ = Proportion of secondary crop product that is harvested

ε = Concentration of C in biomass DM (kg Mg^{-1})

ξ = Proportion of root and exudate C deposited in top soil (0-25cm)

Input

Y_{main} = DM yield of main crop product (Mg DM ha^{-1})

C partitioning

C_{main} = C yield of main crop product = εY_{main}

C_{tot} = total C assimilation = $1/((1 - \beta)\,\alpha)\,C_{main}$

The above-ground carbon in crop residues (C_{resid}) is calculated as:

If there is only one crop product or if the secondary product is not harvested:

$$C_{resid} = (1/\alpha - 1)\,C_{main}$$

If the secondary product is harvested:

$$C_{resid} = (1/\alpha - 1 - \delta\,\zeta)\,C_{main}$$

The below-ground carbon in root residues and exudates (C_{resid}) are calculated as:

$$C_{below} = \beta\,C_{tot} = \beta\,/((1 - \beta)\,\alpha)\,C_{main}$$

The C in residues, roots and exudates deposited in topsoil ($C_{rootTop}$) is calculated as

$$C_{rootTop} = C_{resid} + \xi\,C_{below}$$

The C in residues, roots and exudates deposited in subsoil ($C_{rootSub}$) is calculated as

$$C_{rootSub} = (1 - \xi)\,C_{below}$$

α, β and δ are defined in Table 2, $\varepsilon = 0.45$, $\xi = 0.7$ (winter crops), 0.8 (spring crops) or 0.9 (grassland).

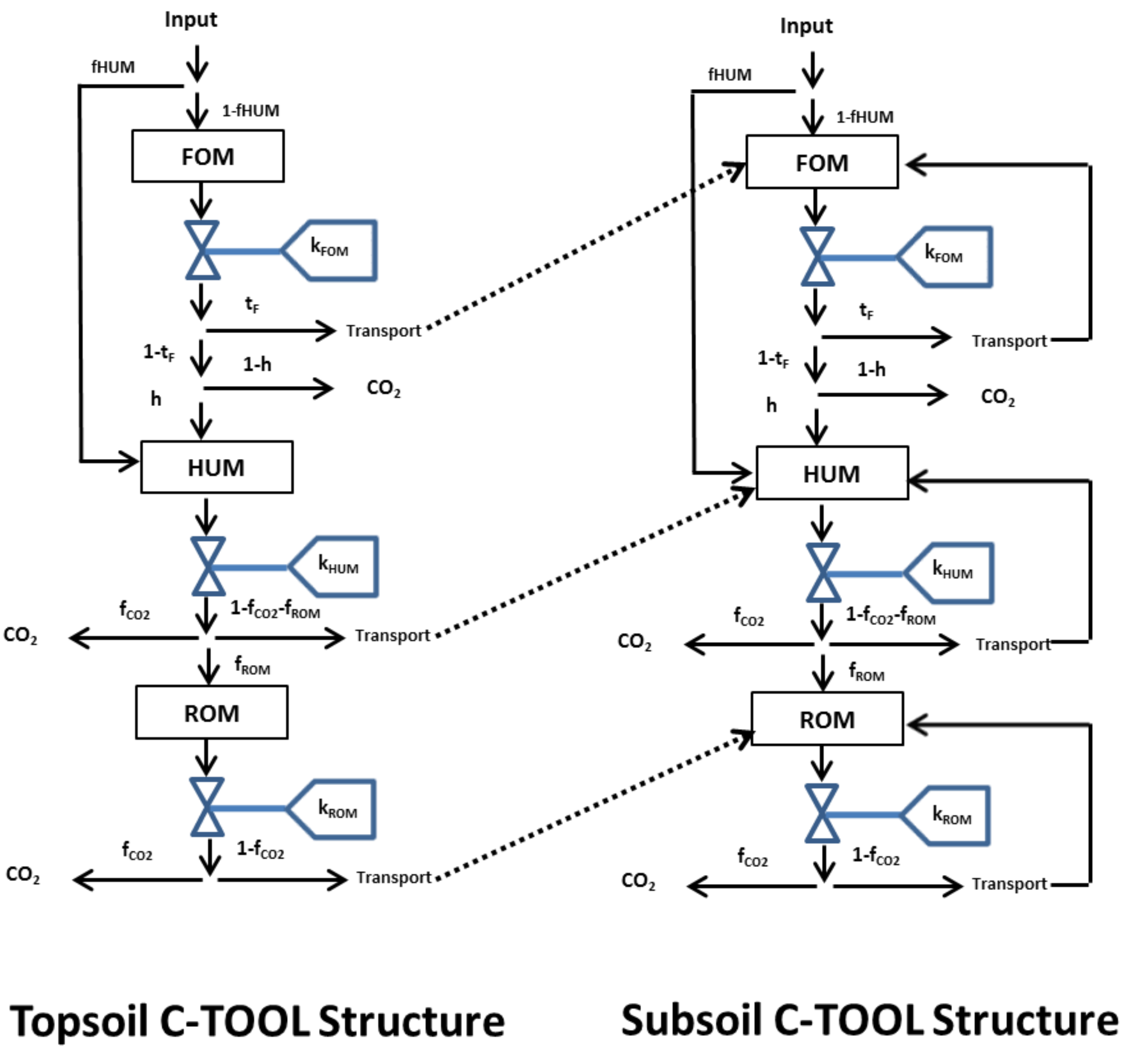


Figure 1. C-TOOL model structure for top and subsoil

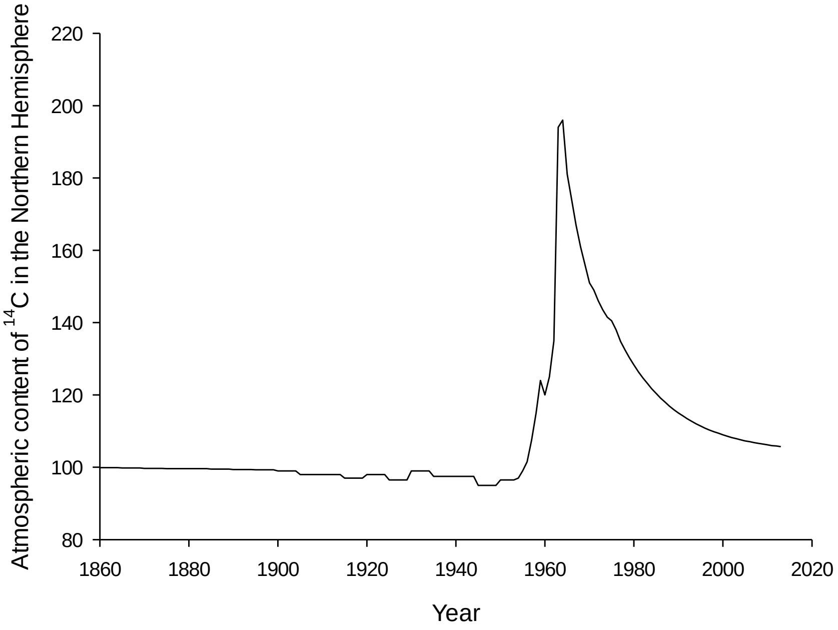


Figure 2. Atmospheric content of ^{14}C in the Northern Hemisphere (Coleman and Jenkinson 2008).

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