ROTHC-26.3

A model for the turnover

of carbon in soil

Model description and users guide

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This documentation is split into three parts: Part 1 describes the structure of the model and defines the abbreviations used. Part 2 lists the system requirements, describes how to run the model on an IBM-compatible personal computer and how to use command files. Part 3 gives an example run of the model. For further information I can be contacted at the above address (EMail or Fax preferred).

Note that ROTHC-26.3 was originally developed and parameterized to model the turnover of organic carbon in arable soils under a range of soil and climatic conditions. It has been extended to model turnover in temperate grassland and forest sites. It should be used cautiously outside this range.

Contents

Part 1

1.1 Introduction

Rothc-26.3 is a model of the turnover of organic carbon in non-waterlogged soils that allows for the effects of soil type, temperature, moisture content and plant cover on the turnover process. It uses a monthly time step to calculate total organic carbon (t ha^{-1}), microbial biomass carbon (t ha^{-1}) and $\Delta^{14}C$ (from which the radiocarbon age of the soil can be calculated) on a years to centuries timescale. (Jenkinson *et al*. 1987; Jenkinson, 1990; Jenkinson *et al.* 1991; Jenkinson *et al.* 1992; Jenkinson and Coleman, 1994) It needs few inputs and those it needs are easily obtainable. It is an extension of the earlier model described by Jenkinson and Rayner, 1977 and by Hart, 1984.

1.2 Data requirements

The only data required to run the model are: -

1)   Monthly rainfall (mm).

2)   Monthly open pan evaporation (mm).

> Rainfall and open pan evaporation are used to calculate topsoil moisture deficit (TSMD), as it is easier to obtain rainfall and pan evaporation data, from which the TSMD is calculated, than monthly measurements of the actual topsoil water deficit.

3)   Average monthly air temperature (^{o}C).

> Air temperature is used rather than soil temperature because it is more easily obtainable for most sites. For Rothamsted, monthly air temperature satisfactorily represents the monthly mean soil temperature in the surface 20 cm, showing a difference of only $+1^{o}$C of the annual minimum and -1°C of the annual maximum.

4)   Clay content of the soil (as a percentage).

>   Clay content is used to calculate how much plant available water the
>   topsoil can hold; it also affects the way organic matter decomposes.

5)   An estimate of the decomposability of the incoming plant material - the
DPM/RPM ratio.

6)   Soil cover - Is the soil bare or vegetated in a particular month ?.

>   It is necessary to indicate whether or not the soil is vegetated because
>   decomposition has been found to be faster in fallow soil than in cropped
>   soil, even when the cropped soil is not allowed to dry out (Jenkinson *et al*
>   1987; Sommers *et al*, 1981; Sparling *et al* 1982).

7)   Monthly input of plant residues (t C ha^{-1}).

>   The plant residue input is the amount of carbon that is put into the soil per
>   month (t C ha^{-1}), including carbon released from roots during crop
>   growth. As this input is rarely known, the model is most often run 'in
>   reverse', generating input from known soil, site and weather data.

8)   Monthly input of farmyard manure (FYM) (t C ha^{-1}), if any.

>   The amount of FYM (t C ha^{-1}) put on the soil, if any, is inputed
>   separately, because FYM is treated slightly differently from inputs of
>   fresh plant residues.

9) Depth of soil sample (cm)

1.3 Model Structure

Soil organic carbon is split into four active compartments and a small amount of inert organic
matter (IOM). The four active compartments are Decomposable Plant Material (DPM), Resistant

Plant Material (RPM), Microbial Biomass (BIO) and Humified Organic Matter (HUM). Each compartment decomposes by a first-order process with its own characteristic rate. The IOM compartment is resistant to decomposition. The structure of the model is shown in Figure 1.

Incoming plant carbon is split between DPM and RPM, depending on the DPM/RPM ratio of the particular incoming plant material. For example, for most agricultural and improved grassland, we use a DPM/RPM ratio of 1.44, i.e. 59% of the plant material is DPM and 41% is RPM. For a deciduous or tropical woodland a DPM/RPM ratio of 0.25 is used, so 20% is DPM and 80% is RPM. All incoming plant material passes through these two compartments once, but only once.

Both DPM and RPM decompose to form CO_2 (lost from the system), BIO and HUM. The proportion that goes to CO_2 and to BIO + HUM is determined by the clay content of the soil - see section 1.7. The BIO + HUM is then split into 46% BIO and 54% HUM. BIO and HUM both decompose to form more CO_2, BIO and HUM.

FYM is assumed to be more decomposed than normal plant material. It is split in the following way : DPM 49%, RPM 49% and HUM 2%.

1.4 Decomposition of an active compartment

If an active compartment contains Y t C ha^{-1}, this declines to Y e^{-abckt} t C ha^{-1} at the end of the month.

where a is the rate modifying factor for temperature

b is the rate modifying factor for moisture

c is the plant retainment rate modifying factor

k is the decomposition rate constant for that compartment

t is 1 / 12, since k is based on a yearly decomposition rate.

So Y (1 - e^{-abckt}) is the amount of the material in a compartment that decomposes in a particular month.

1.5 Decomposition rate constants

The decomposition rate constants (k), in years^{-1}, for each compartment are set at: -

DPM : 10.0

RPM : 0.3

BIO : 0.66

HUM : 0.02

These values were originally set by tuning the model to data from some of the long-term field experiments at Rothamsted (Jenkinson *et al* 1987; Jenkinson *et al* 1992) : they are not normally altered when using the model.

1.6 Calculation of the rate modifying factors

Temperature : the rate modifying factor (a) for temperature is given by: -

$$a \; = \; \frac{47.9}{1 \; + \; e^{(\frac{106}{tm \, + \, 18.3})}}$$

where *tm* is the average monthly air temperature (^{o}C). Figure 2 illustrates this relationship.

Moisture : the soil moisture deficit (SMD) rate modifying factor (b) is calculated in the following way:-

The maximum SMD for the 0-23 cm layer of a particular soil is first calculated from

Maximum SMD = -(20.0 + 1.3 (%clay) - 0.01 (%clay)^2)

So for Rothamsted (%clay = 23.4), the maximum SMD = - 44.94

The maximum SMD thus obtained is that under actively growing vegetation : if the soil is bare during a particular month, this maximum is divided by 1.8, to allow for the reduced evaporation

from a bare soil.

Next, the accumulated SMD is calculated from the first month when 0.75 (evaporation) exceeds rainfall until it reaches the max. SMD, where it stays until the rainfall starts to exceed 0.75 (evaporation) and the soil wets up again. The factor 0.75 is conventional for converting open pan evaporation to evapotranspiration from a growing crop.

An example of this calculation for Rothamsted is shown below.

Accumulated Soil Moisture Deficit (Acc. SMD) for Rothamsted

	Rainfall	Evaporation	0.75*E	R - 0.75*E	Acc. SMD
	(MM)				
Jan	74.0	8.0	6.00	68.00	0.00
Feb	59.0	10.0	7.50	51.50	0.00
Mar	62.0	27.0	20.25	41.75	0.00
Apr	51.0	49.0	36.75	14.25	0.00
May	52.0	83.0	62.25	-10.25	-10.25[*]
Jun	57.0	99.0	74.25	-17.25	-27.50
Jul	34.0	103.0	77.25	-43.25	-44.94[**]
Aug	55.0	91.0	68.25	-13.25	-44.94
Sep	58.0	69.0	51.75	6.25	-38.69
Oct	56.0	34.0	25.50	30.50	-8.19
Nov	75.0	16.0	12.00	63.00	0.00
Dec	71.0	8.0	6.00	65.00	0.00

Finally, the rate modifying factor (*b*) used each month is calculated from :-

$$if\ acc.\ SMD\ <\ 0.444\ max.\ SMD,$$

$$b\ =\ 1.0$$

$$otherwise,$$

$$b\ =\ 0.2\ +\ (1.0\ -\ 0.2)\ *\ \frac{(max.\ SMD\ -\ acc.\ SMD)}{(max.\ SMD\ -\ 0.444\ max.\ SMD)}$$

This is shown in Figure 3.

Plant retainment factor : The plant retainment factor (*c*) slows decomposition if growing plants are present.

If soil is vegetated   *c*=0.6

If soil is bare   *c*=1.0

1.7 Partitioning of carbon between that lost from the soil and that remaining : the CO_2 / (BIO+HUM) ratio

The model adjusts for soil texture by altering the partitioning between CO_2 evolved and (BIO+HUM) formed during decomposition, rather than by using a rate modifying factor, such as that used for temperature. The ratio CO_2 / (BIO + HUM) is calculated from the clay content of the soil using the following equation: -

$$x = 1.67\ (1.85 + 1.60\ \exp(-0.0786\ \%clay))$$

where x is the ratio CO_2 / (BIO+HUM)

Then $x / (x + 1)$ is evolved as CO_2

and $1 / (x + 1)$ is formed as BIO + HUM

The scaling factor 1.67 is used to set the CO_2 / (BIO+HUM) ratio in Rothamsted soils (23.4% clay) to 3.51 : the same scaling factor is used for all soils.

Figure 4 shows how the % clay content of the soil affects the soil texture factor, ie the CO_2 / (BIO+HUM) ratio.

Note that the above equation relating the CO_2 / (BIO+HUM) ratio to %clay is not the same as that given by Jenkinson *et al* (1987) or Jenkinson, (1990).

1.8 Calculation of the radiocarbon age

Radiocarbon measurements are commonly expressed in one of two ways, as % modern,
i.e. 100 (specific activity of the sample) / (specific activity of the standard)

or as the $\Delta^{14}C$ value,
i.e. 1000 (specific activity of the sample - specific activity of the standard) / (specific activity of the standard).

So $\Delta^{14}C = 10$ (% Modern) - 1000

Radiocarbon age is related to $\Delta^{14}C$ in the model by the following equation

$$\Delta^{14}C = 1000 \exp(-\text{radiocarbon age} / 8035) - 1000$$

using the conventional half-life for ^{14}C (5568 years)

Before 1860, the model assumes that the radiocarbon age of the plant material entering the soil each year is zero, ie its Δ^{14}C value is zero and it is 100 % modern. After 1860 the radiocarbon content of the incoming plant carbon (expressed as % modern) in a particular year is set from an internal table - illustrated graphically in Figure 5. This input Table was constructed from data on the radiocarbon content of atmospheric CO_2 : for the 1860 - 1949 period from Baxter & Walton (1971), for 1950 - 1984 from Harkness *et al* (1986) and for 1987 - 1993 from Levin *et al* (1994). The radiocarbon content of each year's input of plant carbon is taken to be the same as that of atmospheric CO_2 for the same year. The 'radiocarbon activity scaling factor' in the model print-out is the radiocarbon activity of the input for a particular year, expressed as either (%modern) / 100 or (Δ^{14}C + 1000) / 1000, i.e. taking the value for 1859 as 1.

The age of the IOM fraction is set by default to 50,000 years, implying that it contains virtually no ^{14}C (Δ^{14}C = -998.0) and that it is of geological age rather than pedological age.

1.9 Definitions of abbreviations used

a	:	Rate modifying factor for temperature
b	:	Rate modifying factor for moisture
BIO	:	Microbial biomass
c	:	Rate modifying factor for plant retainment
DPM	:	Decomposable plant material
FYM	:	Farm yard manure
HUM	:	Humified organic matter
IOM	:	Inert organic matter
k	:	Decomposition rate constant
RPM	:	Resistant plant material
SMD	:	Soil moisture deficit
t	:	time
tm	:	Temperature
TSMD:		Top soil moisture deficit

Part 2

2.1 System requirements

The program, written in FORTRAN 77, will run on any IBM or IBM compatible 286 P.C. or higher. No other system requirements are needed to run the program.

2.2 Input files

All the data, needed to run the program, apart from the DPM / RPM ratio, is read into the program from two files, one containing the meteorological data and the percent clay content, and the other containing the plant residue input, FYM input, if any, and the soil cover i.e. whether the soil is vegetated in a particular month or not. The DPM / RPM ratio is read in separately. Examples of the data files needed are given below:

Meteorological data - ROTH.DAT

Description of data in file

3.4	74.0	8.0
4.4	59.0	10.0
5.1	62.0	27.0
7.3	51.0	49.0
11.0	52.0	83.0
13.9	57.0	99.0
16.0	34.0	103.0
16.0	55.0	91.0
13.5	58.0	69.0
10.2	56.0	34.0
6.1	75.0	16.0
4.6	71.0	8.0
23.4	23.0	

Row 1   **Description of data in the file**

Row 2-13   **Months Jan ... Dec.**

       Column 1   **Temperature (^{o}C)**

       Column 2   **Rainfall (mm)**

       Column 3   **Evaporation (mm)**

Row 14 Col 1   **% clay content of the soil**

Row 14 Col 2   **Depth soil sample was taken (cm)**

Land Management data - LMHFEQ.DAT

Description of data in file

0.00	0.0	0
0.00	0.0	0
0.00	0.0	0
0.10	0.0	1
0.22	0.0	1
0.33	0.0	1
0.98	0.0	1
0.00	0.0	0
0.00	0.0	0
0.00	0.0	0
0.00	0.0	0
0.00	0.0	0

Row 1   **Description of data in the file**

Row 2 - 13   **Months Jan ... Dec**

       Column 1 Plant Residues (t C ha^{-1})

       Column 2 FYM (t C ha^{-1})

       Column 3 Soil cover   0 = bare

                     1 = vegetated

2.3 Running the program

The program is installed on to the c: drive by typing A: <rtn> (or B: <rtn>) at the c:\> prompt and then INSTALL <rtn>. The installation file creates two sub-directories C:\MODEL26 and C:\MODEL26\DATA. It is advisable to edit your autoexec.bat file to include the path C:\MODEL26

So,   SET PATH = C:\; C:\DOS

Becomes,   SET PATH = C:\; C:\DOS; C:\MODEL26

The program is run by typing **MOD26_3** <rtn> at the dos prompt and answering the questions as they come up. (If you have not included the path C:\MODEL26 in your autoexec.bat file you have to **type C:\MODEL26\MOD26_3** <rtn> at the dos prompt).

> *Two things that you must remember are firstly that the meteorological and land management data files must exist before the program is run and secondly that the full name of the land management file must be typed including the '.dat'*

The program creates two output files the first called '**XXXX.out**', where XXXX is the four characters of the output file name (see below) and the second called '**graph.dat**', which contains the DPM, RPM, BIO, HUM, IOM, TOTAL C, CO2 and DELTA VALUE in columns. This file can be imported into any graphics packages.

Below is an example run of the program, with the **Bold** type being the replies to the questions.

MOD26_3 <rtn>
Please type the four characters for the output file name
hf01

Input file name
roth.dat

Do you want:-

(1) Short term carbon model

(2) Equilibrium carbon model (10,000 years)

Reply 1 or 2

2

Input initial soil state (tonnes / ha) for :-

DPM **0**

RPM **0**

BIO **0**

HUM **0**

IOM **3.8**

Input initial radiocarbon ages of :-

DPM **0**

RPM **0**

BIO **0**

HUM **0**

Quality factor for incoming plant debris (DPM/RPM ratio) ?

Suggested values

(1) Most agricultural crops and improved grassland   1.44

(2) Unimproved grassland and scrub   0.67

(3) Deciduous and tropical woodland   0.25

(4) Other

Reply 1, 2, 3 or 4

1

Input name of file containing land management information

lmhfeq.dat

Do you want output produced :-

（1）Every year

（2）Final year only

Reply 1 or 2

2

Input number of start month (Jan = 1, etc.)

1

Please wait for a short while

Steady state conditions have now been reached

Do you want to :-

（1）Continue with the same conditions

（2）Continue with different conditions

（3）stop

3

2.4 Running the program with command files

If you have to run the program many times it is often easier to use command files, which are simply text files that contain the information needed to run the program. The example above is given below in a command file format. The file is called **example.com**

hf01

roth.dat

2

0

0

0

0

3.8

0

0

0

0

1

lmhfeq.dat

2

1

3

To run the program with a command file type **mod26_3 < 'setup file name' <rtn>** at the dos prompt. In the above example type **mod26_3 < example.set <rtn>**

Part 3

3.1 An example of the use of the model

The use of the model will be illustrated using data from one of the Rothamsted long-term field experiments, on the continuous cultivation of spring barley. This experiment was started on Hoosfield in 1852 and was designed to study the effects of fertilizers and FYM on the yield of barley. A detailed account can be found in the booklet *Guide to the classical field experiments.* Rothamsted Experimental Station (1991). None of the data from this experiment were used in setting the model parameters, so the fit obtained between model and data is an objective test of the model.

In modelling the Hoosfield data, it is first necessary to run the model to produce a starting soil organic C content that is the same as that originally present in the soil (33.8 t C ha^{-1} in 1852, which includes 3.8 t C ha^{-1} in IOM). This is done by assuming that the soil organic C had reached equilibrium in 1852 and running the model iteratively with different annual inputs of plant C from a spring barley crop until the value of 33.8 t C ha^{-1} is reached (within $\pm$ 0.5 t C ha^{-1}). Land management file LMHFEQ.DAT (see page 13) is used in this run : weather data file is ROTH.DAT (see page 12) and a DPM / RPM ratio of 1.44 is used.

It should be noted that the annual input finally chosen (1.63 t C ha^{-1} year^{-1} : see LMHFEQ.dat file on page 13) is distributed between April, May, June and July, with no inputs in other months. This distribution is no more than an educated guess for a particular crop, spring barley, sown in February or March and harvested in early August. It makes little difference to the calculated equilibrium value for total organic C or to radiocarbon age how the annual input is distributed, or even if it is all added in a single pulse. Only if the model is being used to predict annual changes in fractions with short turnover times (notably biomass and DPM) will the input distribution appreciably affect the results.

The IOM content of the Hoosfield soil was set at 3.8 t C ha^{-1} throughout the run to establish the equilibrium state. The same value for IOM was used in all the subsequent runs with this soil. This value gives a radiocarbon age of 1055 years for the whole soil organic C in 1852, a little less than the mean (1290 years) for all the pre-1900 Rothamsted topsoils (0 - 23 cm) analysed for

radiocarbon (Jenkinson *et al* 1992). No measurements of radiocarbon are available from the Hoosfield experiment : had they been, the IOM content of the soil *and* the annual inputs of plant C would have been iteratively adjusted to give both the correct organic C content and the correct radiocarbon age for a particular sampling date.

Once the starting C content has been established, land management files are created for each of the three treatments modelled in Figure 6; these are plot 7-2 (farmyard manure annually), plot 7-1 (farmyard manure annually 1852-1871, nothing thereafter) and a mean of plots 6-1 and 6-2 (both unmanured).

For the unmanured treatment, 1.76 t C ha^{-1} of plant residues was used (distributed, again arbitrarily, with 0.16 t C ha^{-1} in April, 0.16 in May, 0.32 in June and 1.12 in July). A soil cover factor of one was used in April, May, June and July, zero in the other months. These input figures were used from 1852 to 2000, except in the years which were fallow (1912, 1933, 1943 and 1967). For the fallow years the plant input was set at zero (bare cultivated fallow) and a soil cover factor of 0 was used in all twelve months.

For the treatment receiving farmyard manure annually (plot 7-2), the annual input of plant residues from the barley was taken to be 2.6 t C ha^{-1} (0.21 t C ha^{-1} in April, 0.37 in May, 0.53 in June and 1.49 in July) Again a soil cover factor of one was used in April, May, June and July, zero in the other months. As with the unmanured treatment, this input was used from 1852 to 2000, except in the four fallow years (1912, 1933, 1943 and 1967). The FYM (containing 3.0 t C ha^{-1}) was applied in February each year from 1852-1911 and from 1913-1930. In 1931 FYM containing 6.0 t C ha^{-1} was applied (3.0 in Feb and 3.0 in Nov). From 1932 to 2000, FYM containing 3.0 t C ha^{-1} was applied in November each year.

The third treatment received FYM (3 t C ha^{-1}) every February from 1852 to 1871 and nothing thereafter (plot 7-1). From 1852 to 1876, plant residues were set at 2.6 t C ha^{-1} (split in the same way as plot 7-2), with the same soil cover factor of one in April, May, June and July, zero in the other months. From 1877 to 2000, plant residues were set at 1.76 t C ha^{-1} (split in the same way as the unmanured plot), with the same soil cover factor, except in the four fallow years of 1912, 1933, 1943 and 1967.

3.2 How the model calculates the carbon content of the soil and its radiocarbon age

To see how carbon content, age and $\Delta^{14}C$ values are calculated, we will examine the first month (January 1852) of the simulation for the unmanured plot on the Hoosfield spring barley experiment (Fig. 6). First consider the position at the end of this preliminary run to equilibrium on 31st December 1851, after the model had run for 10,000 years using the Rothamsted weather file (ROTH.DAT : see page 9) the Hoosfield Land Management file (LMHFEQ.DAT, with an annual input of 1.63 t C ha^{-1} year^{-1} : see page 10), a DPM/RPM ratio of 1.44 and an IOM of 3.8 t C ha^{-1}. On 31st December 1851 the state of the model is :

Radiocarbon activity scaling factor = 1.0000

	Carbon (t C ha^{-1})	Radio age (years)	Delta Value
DPM	0.0620	0.46	-0.06
RPM	4.3755	6.59	-0.82
BIO	0.6611	21.04	-2.60
HUM	24.8750	116.76	-14.43
IOM	3.8000	50000.00	-998.02
Total	33.7736	1055.01	-123.05

Now consider the state on the 31st January 1852 for the unmanured plot which, under land management information file LMHF4.DAT, does not receive any input of plant C or FYM in January. The temperature, moisture and plant cover during January give a combined rate modifying factor, *abc*, of 0.3561. Using the rate constants given in section 1.5

DPM becomes 0.0620 * exp[- 10 * 0.3561 / 12] = 0.0461
RPM becomes 4.3755 * exp[- 0.3 * 0.3561 / 12] = 4.3367
BIO becomes 0.6611 * exp[- 0.66 * 0.3561 / 12] = 0.6483
HUM becomes 24.8750 * exp[- 0.02 * 0.3561 / 12] = 24.8602

The difference between one month and the next for each compartment is

DPM   0.0159

RPM   0.0388

BIO   0.0128

HUM   0.0148

These differences represents the material that decomposes during the month in each compartment. This material is split (see section 1.7) between (BIO+HUM) and CO_2 in the following way:

(3.51 / 4.51) * (difference) is CO_2

(1 / 4.51) * (difference) is (BIO+HUM)

The (BIO+HUM) thus formed is split as 46% BIO and 54% HUM

This is shown in the following table:

	Diff	BIO	HUM	CO_2
DPM	0.0159	0.0016	0.0019	0.0124
RPM	0.0388	0.0040	0.0046	0.0302
BIO	0.0128	0.0013	0.0015	0.0100
HUM	0.0148	0.0015	0.0018	0.0115

The carbon content of each compartment is now made up in the following way

DPM = 0.0461	= 0.0461
RPM = 4.3367	= 4.3367
BIO = 0.6483 + 0.0016 + 0.0040 + 0.0013 + 0.0015	= 0.6567
HUM = 24.8602 + 0.0019 + 0.0046 + 0.0015 + 0.0018	= 24.8700

Each month all the radiocarbon in a compartment ages by 1/12 years (_ 0.08 years). The

radiocarbon age at the end of the month is weighted by the amount of carbon in each compartment:

So the radiocarbon age of each compartment is:

DPM = 0.0461*(0.46+0.08) / 0.0461   = 0.54

RPM = 4.3755*(6.59+0.08) / 4.3755   = 6.67

BIO = [0.6483*(21.04+0.08) + 0.0016*(0.46+0.08)

       + 0.0040*(6.59+0.08) + 0.0013*(21.04+0.08)

       + 0.0015*(116.76+0.08)] / 0.6567   = 21.20

HUM = [24.8602*(116.76+0.08) + 0.0019*(0.46+0.08)

       + 0.0046*(6.59+0.08)+ 0.0015*(21.04+0.08)

       + 0.0018*(116.76+0.08)] / 24.8700   = 116.81

and the delta value of each compartment is:

DPM   = -0.07

RPM   = -0.83

BIO   =-2.62

HUM   =-14.43

A similar procedure is followed if there is an input of fresh plant residue during a particular month. This input is given the appropriate radiocarbon scaling factor for the year in which it occurs and distributed between DPM and RPM in the specified proportions at the end of the month in question.

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Sparling GP, Cheshire MV and Mundie CM (1982). Effect of barley plants on the decomposition of ^{14}C-labelled soil organic matter. *Journal of Soil Science* **33**, 89-100

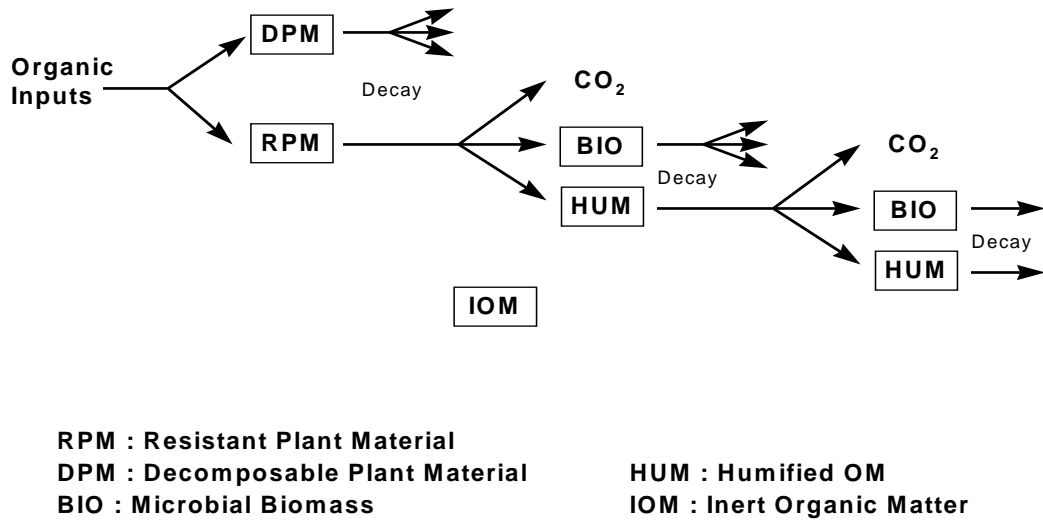Figure 1 - Structure of the Rothamsted Carbon Model

Organic Inputs

DPM

RPM

Decay

CO$_2$

BIO

HUM

Decay

CO$_2$

BIO

HUM

Decay

IOM

RPM : Resistant Plant Material
DPM : Decomposable Plant Material   HUM : Humified OM
BIO : Microbial Biomass   IOM : Inert Organic Matter

Figure 2 - The rate modifying factor for temperature

Rate modifying factor

Mean annual
temperature
at Rothamsted

Temperature ^{o}C
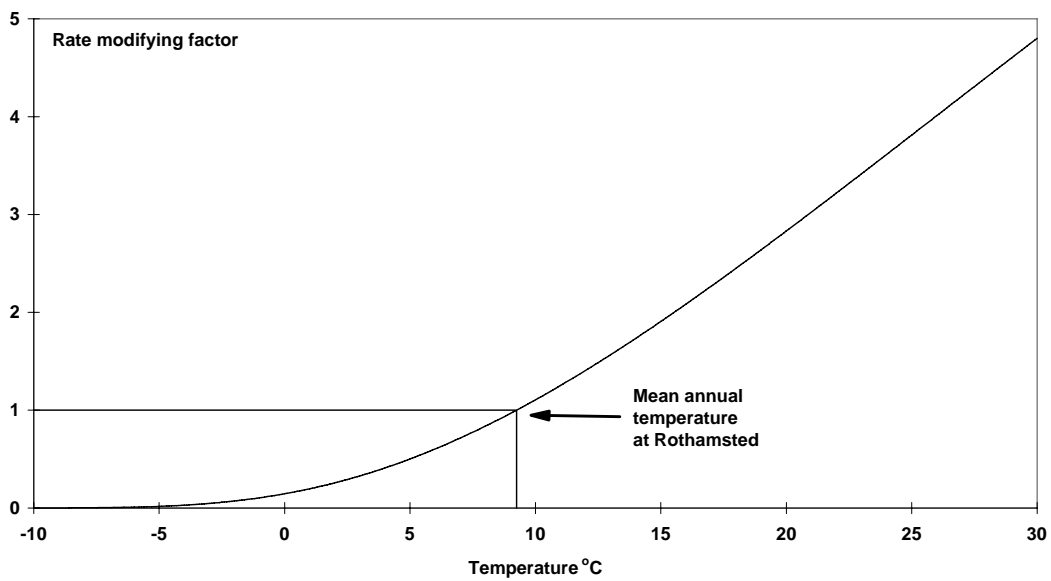
Figure 3 - The rate modifying factor for moisture

Rate modifying factor

Topsoil moisture deficit (mm)
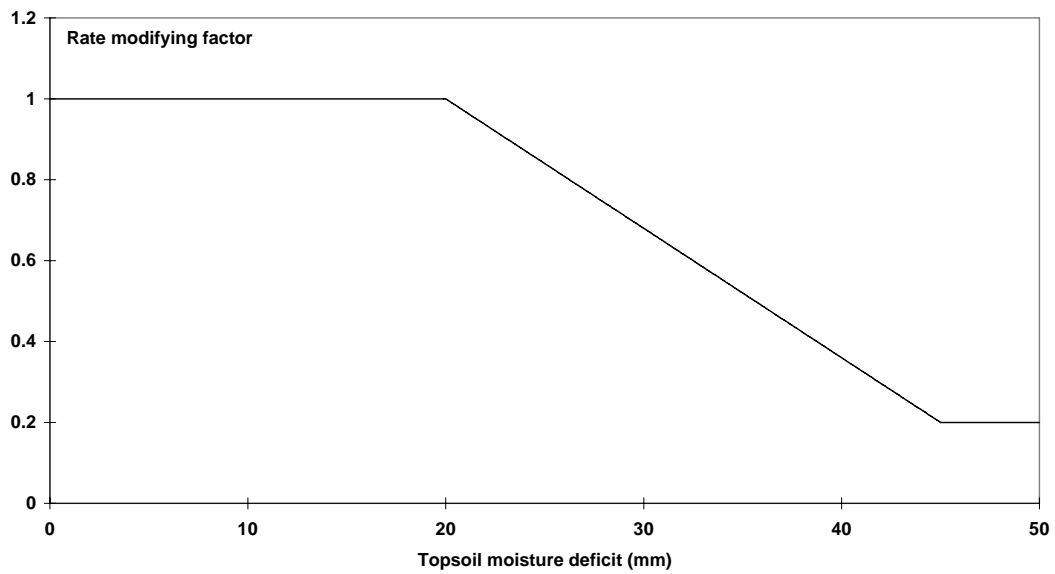
Figure 4 - The effect of clay on the ratio of CO_2 released to (BIO + HUM) formed

CO_2 / (BIO + HUM) ratio
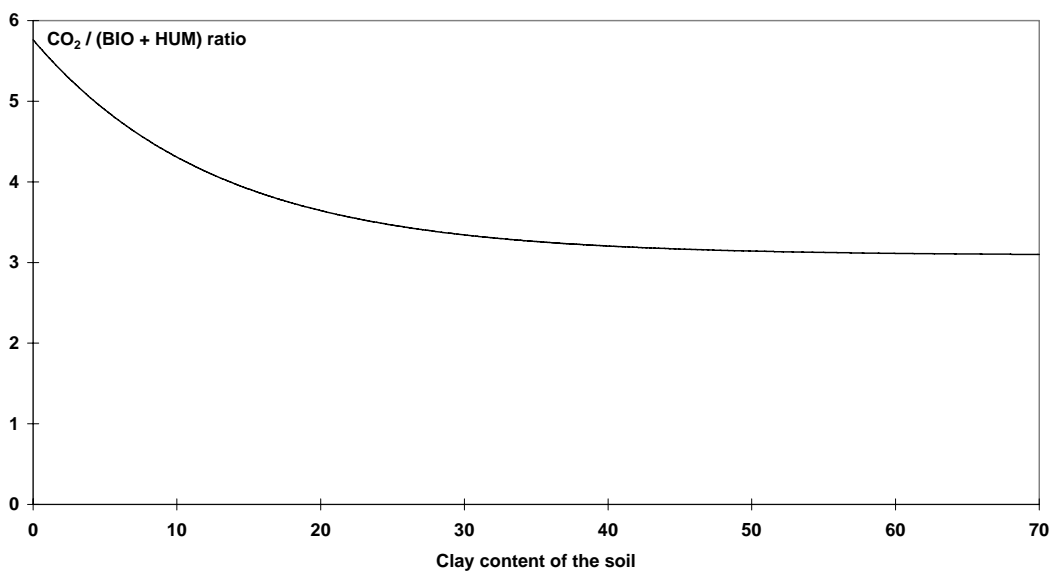
Clay content of the soil

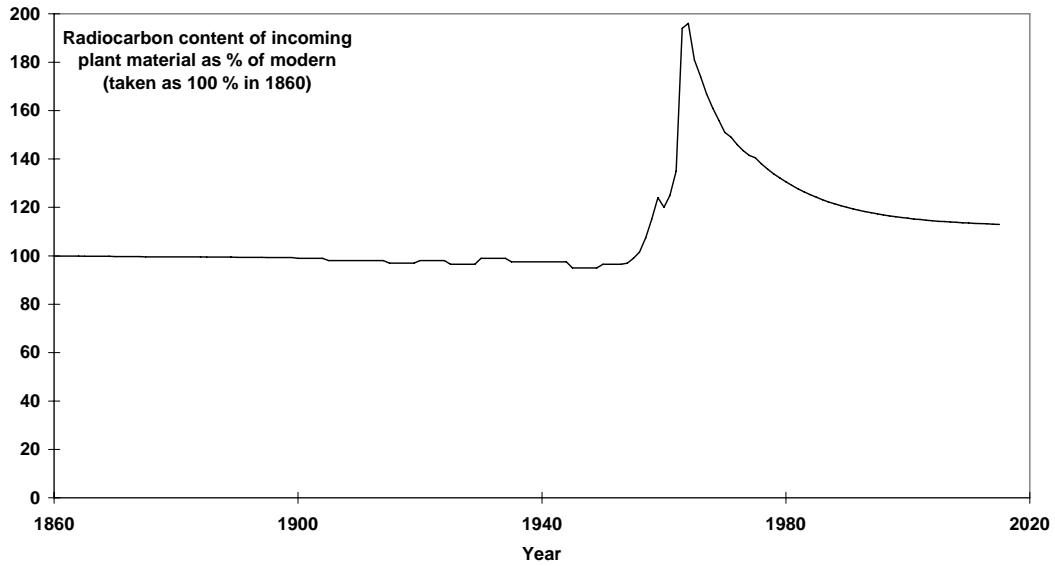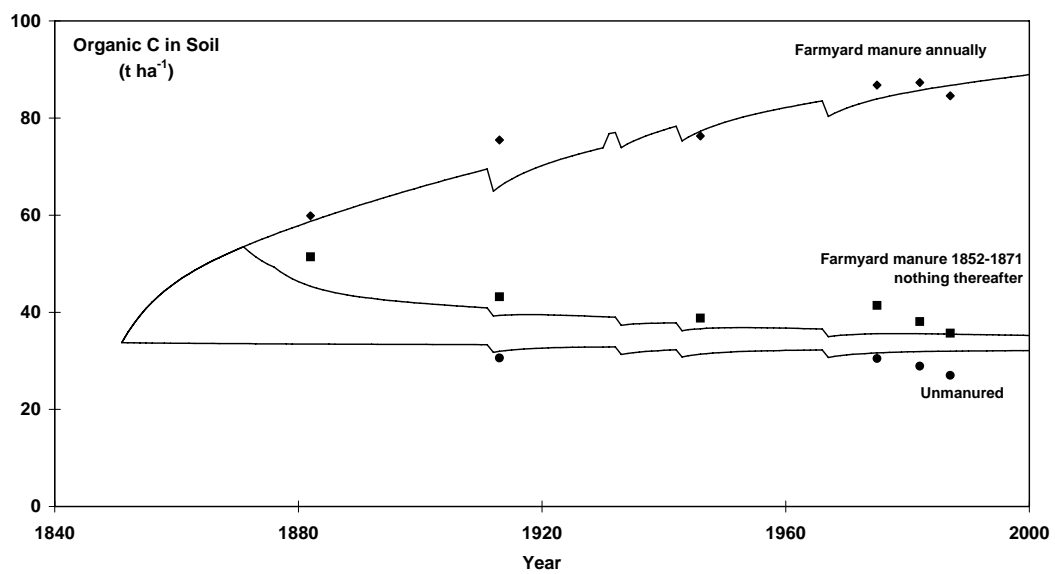# Figure 5 - Postulated radiocarbon content of incoming plant material 1860 - 2013

Figure 6 - Hoosfield continuous barley experiment
Data modelled by RothC-26.3 (Solid lines)