

**RothC - A model for the turnover
of carbon in soil**

Model description and users guide

(Windows version)

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Part 1

1.1 Introduction

RothC-26.3 is a model for the turnover of organic carbon in non-waterlogged topsoils 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 $\Delta^{14}\text{C}$ (from which the equivalent 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).

A version replacing the monthly time steps by continuous processes has been published by Parshotam (1995). King *et al* (1997) have incorporated RothC into a much larger model for global C cycling. A comparative study of C turnover models, including RothC-26.3, has recently been published (Smith *et al*, 1997).

RothC-26.3 is designed to run in two modes: ‘forward’ in which known inputs are used to calculate changes in soil organic matter and ‘inverse’, when inputs are calculated from known changes in soil organic matter.

RothC-26.3 was originally developed and parameterized to model the turnover of organic C in arable topsoils from the Rothamsted Long Term Field Experiments - hence the name. Later, it was extended to model turnover in grassland and in woodland and to operate in different soils and under different climates. It should be used cautiously on subsoils, soils developed on recent volcanic ash (but see Parshotam *et al* 1995, Tate *et al* 1996 and Sagggar *et al* 1996), soils from the tundra and taiga and not at all on soils that are permanently waterlogged.

1.2 Data requirements

The 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 do this than obtain monthly measurements of the actual topsoil water deficit. If open-pan evaporation is not available, monthly potential evapotranspiration can be calculated with adequate accuracy from Müller's (1982) collection of meteorological data for sites around the world. Sites should be selected from Müller's collection that are as similar climatically as possible to the site under investigation. Column 14 in Müller's Tables is headed 'Mean potential evaporation', but in fact this column gives calculated mean monthly potential evapotranspiration. If Müller's 'Mean potential transpiration' is used, you must remember to convert his values to open-pan evaporation by dividing them by 0.75. This is most important because the model is presently primed to run on open-pan evaporation data, which is then multiplied internally by 0.75 to give evapotranspiration.

i.e. if Müller's data are used as an input for the model, Open-pan evaporation = 'Mean potential transpiration' / 0.75

- 3) Average monthly mean air temperature (°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 topsoil, the soil temperature at 20 cm showing a difference of only +1°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 'inverse' mode, generating input from known soil, site and weather data.

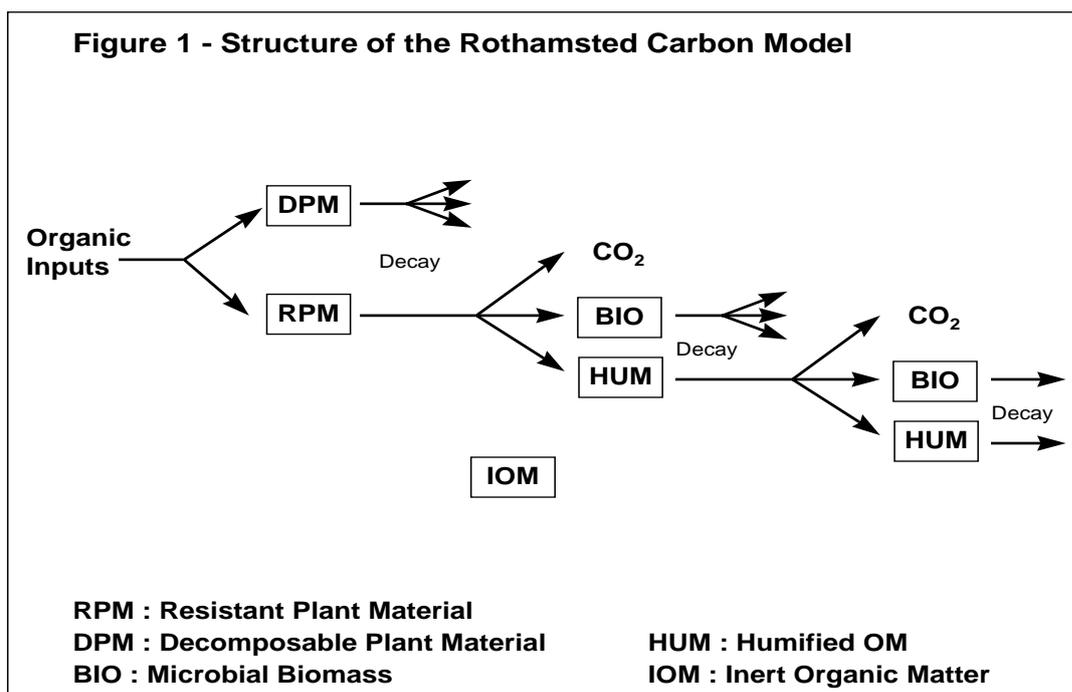
- 8) Monthly input of farmyard manure (FYM) (t C ha⁻¹), if any.

The amount of FYM (t C ha⁻¹) put on the soil, if any, is inputted separately, because FYM is treated slightly differently from inputs of fresh plant residues.

- 9) Depth of soil layer sampled (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 most agricultural crops 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 unimproved grassland and scrub (including Savanna) a ratio of 0.67 is used. 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 CO₂, BIO and HUM. The proportion that goes to CO₂ 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 CO₂, BIO and HUM.

FYM is assumed to be more decomposed than normal crop 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 $Y \text{ t C ha}^{-1}$, this declines to $Y e^{-abckt} \text{ t C ha}^{-1}$ 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 soil cover 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.

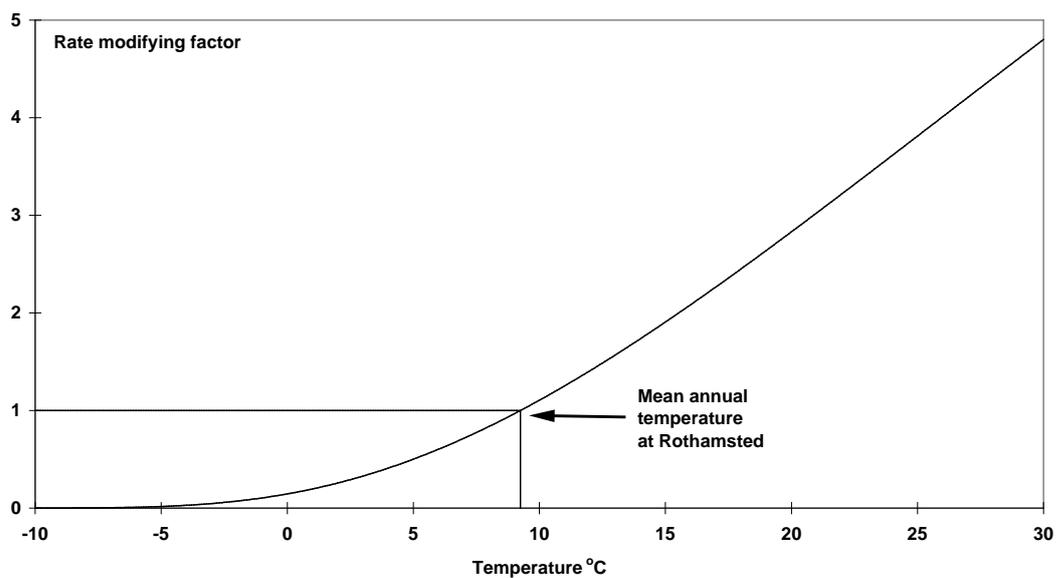
1.6 Calculation of the rate modifying factors

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

$$a = \frac{47.91}{1 + e^{\left(\frac{106.06}{T+18.27}\right)}}$$

where T is the average monthly air temperature (°C). (Figure 2)

Figure 2 - The rate modifying factor for temperature



Moisture : the topsoil moisture deficit (TSMD) rate modifying factor (*b*) is calculated in the following way:-

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

$$\text{Maximum TSMD} = -(20.0 + 1.3 (\% \text{clay}) - 0.01 (\% \text{clay})^2)$$

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

For a soil layer of different thickness, the maximum TSMD thus calculated is divided by 23 and multiplied by the actual thickness, in cm.

Next, the accumulated TSMD for the specified layer of soil is calculated from the first month when $0.75 \times (\text{open pan evaporation})$ exceeds rainfall until it reaches the max. TSMD, where it stays until the rainfall starts to exceed $0.75 \times (\text{open pan evaporation})$ and the soil wets up again. If open pan evaporation is not known, potential evapotranspiration from Müller (1982) can be used by selecting sites from his compilation that are as similar climatically to the sampling site as possible. Note that the model is presently primed to run on open-pan evaporation data, which is multiplied internally by 0.75 to give evapotranspiration. Data from Müller's tables should therefore be divided by 0.75 before entering : this is **most** important.

Bare soil moisture deficit (BareSMD)

The maximum TSMD obtained above is that under actively growing vegetation : if the soil is bare during a particular month, this maximum is divided by 1.8 to give BareSMD, to allow for the reduced evaporation from a bare soil. When the soil is bare it is not allowed to dry out further than BareSMD, unless the accumulated TSMD is already less than BareSMD in which case it cannot dry out any further.

An example of this calculation for Rothamsted is shown below.

Accumulated Topsoil Moisture Deficit (Acc. TSMD) for Rothamsted

	Rainfall	Open pan evaporation	0.75*E	R - 0.75*E	Acc. TSMD
(mm water)					
Jan	74	8	6.00	68.00	0.00
Feb	59	10	7.50	51.50	0.00
Mar	62	27	20.25	41.75	0.00
Apr	51	49	36.75	14.25	0.00
May	52	83	62.25	-10.25	-10.25*
Jun	57	99	74.25	-17.25	-27.50
Jul	34	103	77.25	-43.25	-44.94**
Aug	55	91	68.25	-13.25	-44.94
Sep	58	69	51.75	6.25	-38.69
Oct	56	34	25.50	30.50	-8.19
Nov	75	16	12.00	63.00	0.00
Dec	71	8	6.00	65.00	0.00

*First month when 0.75 (evaporation) is greater than the rainfall

**Max. TSMD

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

if acc. TSMD < 0.444 max. TSMD,

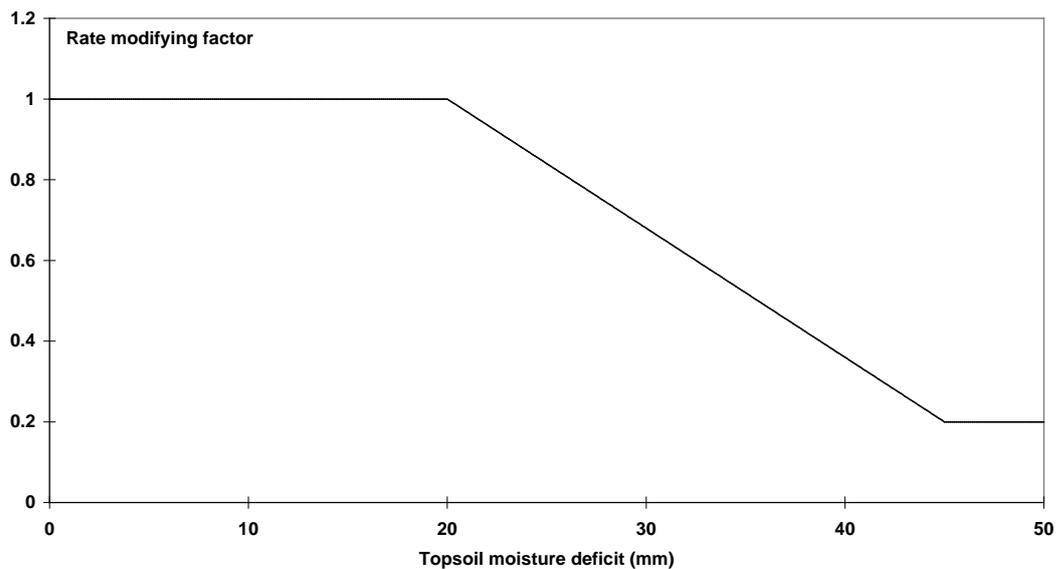
$$b = 1.0$$

otherwise,

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

This is shown in Figure 3.

Figure 3 - The rate modifying factor for moisture



Note that the calculation in the above table starts from the 1st January, when the soil is assumed to be at field capacity. For situations where this is not so, the weather data input should be displaced by a whole number of months, so that the soil is at field capacity at the start of the model run. Thus, in the Southern Hemisphere, the weather data file should start in July when the soil is wet, so that July will appear as January in the output.

Soil cover factor : The soil cover factor (c) slows decomposition if growing plants are present. In earlier version of the model this factor is called the 'retainment factor'

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: -

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

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

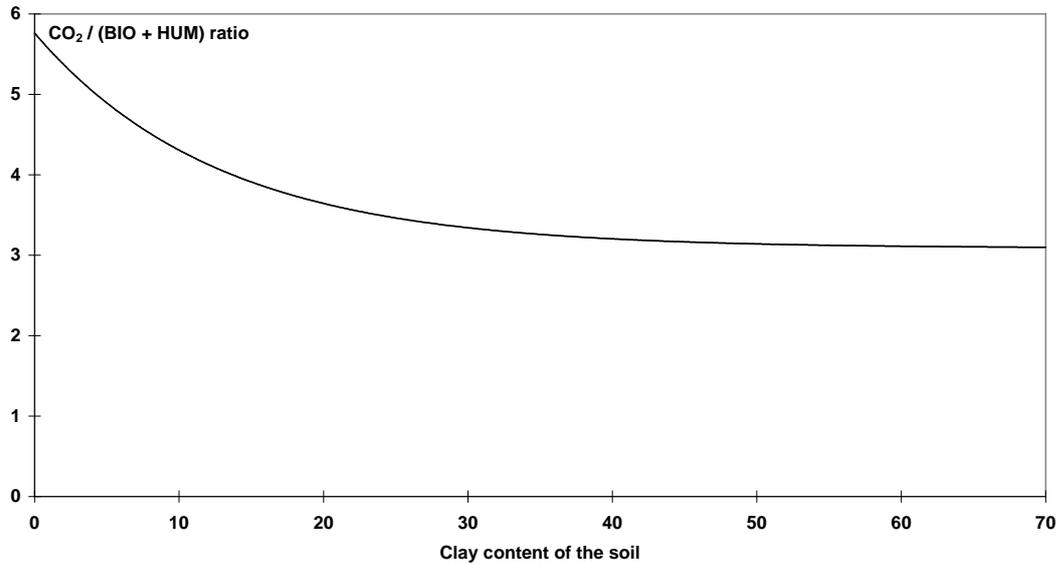
Then $x / (x + 1)$ is evolved as CO_2

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, i.e. the $CO_2 / (BIO+HUM)$ ratio.

Figure 4 - The effect of clay on the ratio of CO₂ released to (BIO + HUM) formed



Note that the above equation relating the CO₂ / (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 equivalent 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 $\Delta^{14}\text{C}$ value,

i.e. 1000 (specific activity of the sample - specific activity of the standard) / (specific activity of the standard).

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

The standard is defined as 0.95 of the ^{14}C activity of the NBS standard oxalic acid.

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

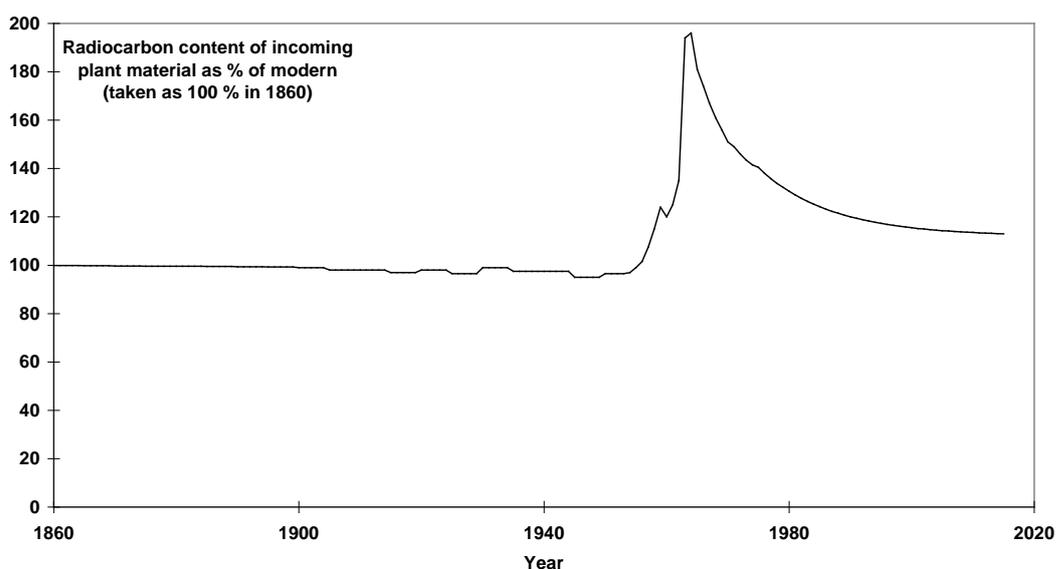
$$\Delta^{14}\text{C} = 1000 \exp(-\text{equivalent radiocarbon age} / 8035) - 1000$$

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

Equivalent radiocarbon age is defined as the radiocarbon age of a homogeneous sample having the same radiocarbon content as the measured (non-homogeneous) sample.

Before 1860, the model assumes that the radiocarbon age of the plant material entering the soil each year is zero, i.e. its $\Delta^{14}\text{C}$ 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 - shown graphically in Figure 5.

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



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 $(\Delta^{14}\text{C} + 1000) / 1000$, 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 ($\Delta^{14}\text{C} = -998.0$) and that it is of geological age rather than pedological age.

If no radiocarbon measurements are available, IOM is set using the equation below (Falloon *et al.*, 1998). This is a very rough approximation for surface soils alone.

$$IOM = 0.049TOC^{1.139}$$

where TOC is Total organic carbon, t C ha^{-1}

IOM is Inert organic matter, t C ha^{-1}

1.9 Definitions of abbreviations used

<i>a</i>	:	Rate modifying factor for temperature
<i>b</i>	:	Rate modifying factor for moisture
BIO	:	Microbial biomass
<i>c</i>	:	Rate modifying factor for soil cover
DPM	:	Decomposable plant material
FYM	:	Farm yard manure
HUM	:	Humified organic matter
IOM	:	Inert organic matter
<i>k</i>	:	Decomposition rate constant
RPM	:	Resistant plant material
SMD	:	Soil moisture deficit
<i>t</i>	:	time
<i>T</i>	:	Temperature
TSMD	:	Top soil moisture deficit
TOC	:	Total organic carbon (t C ha ⁻¹)

Part 2

2.1 To install the interface

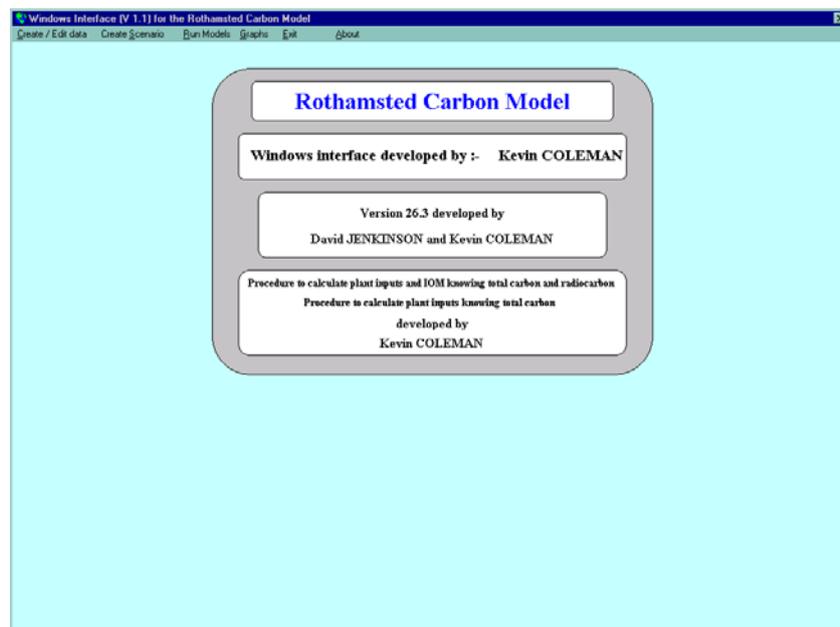
After obtaining the zip file (cmod_win.zip) for the interface, put it in a temporary directory and unzip it (you will need a password to unzip it). Once unzipped, you will have the following files, c_int_so.CAB, setup.exe and setup.lst.

Now double click on the setup.exe file, **change the destination directory to c:\model26**. If you do not do this, the model will not run because it needs files that will be installed in the c:\model26 directory, all the other choices can be left as they are.

NB: If you install the interface on to a PC with Windows NT as the operating system you may need administrator access.

2.2 To run the interface

By double clicking on the Rothamsted Carbon Model icon you will get the screen below.

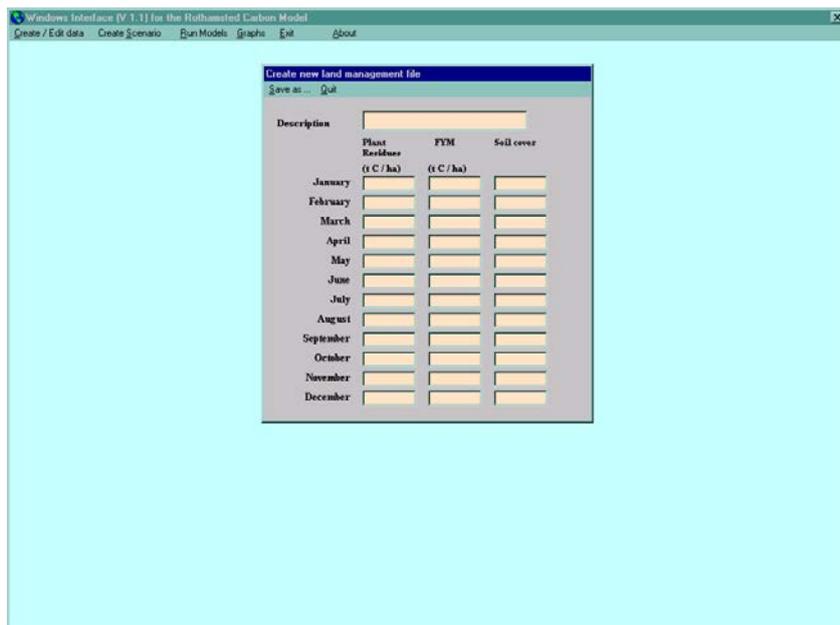
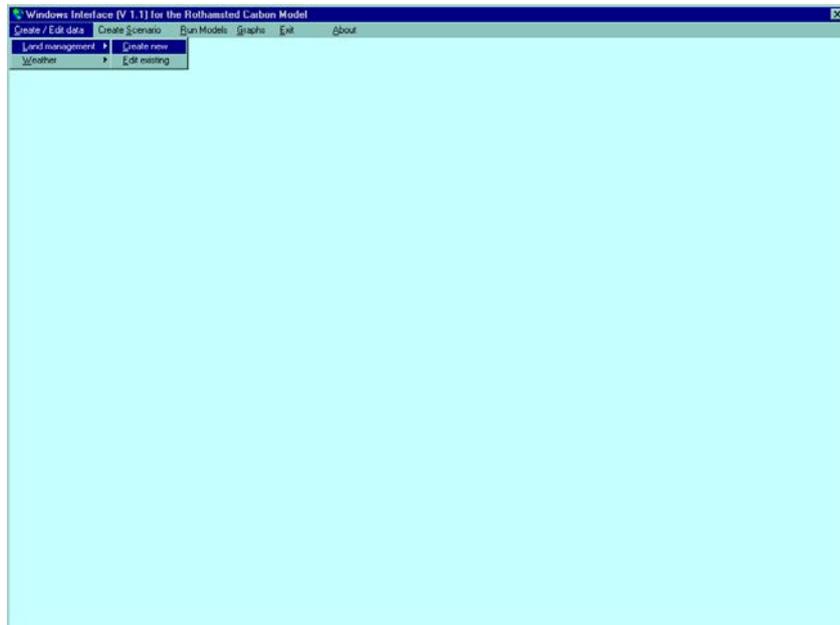


The following is a guide to the features of the interface.

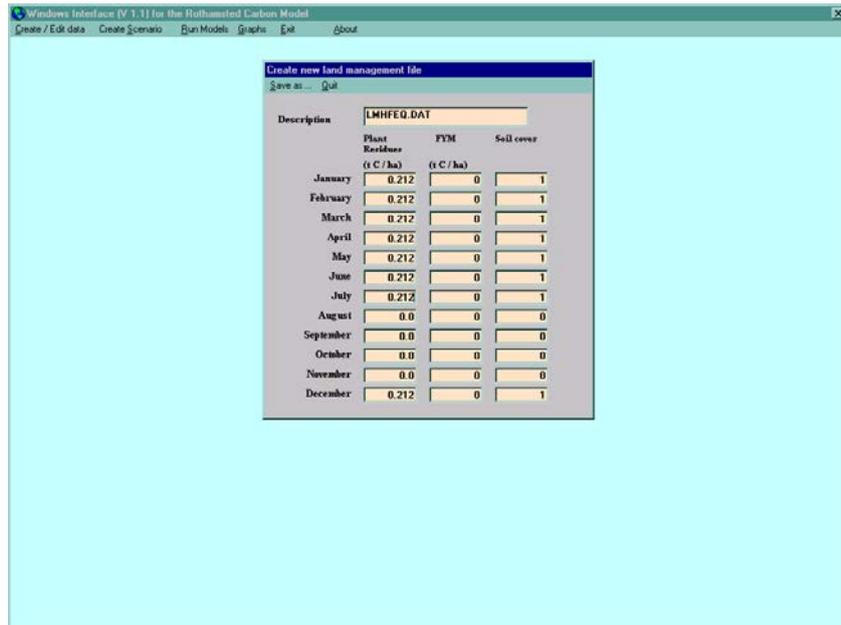
2.3 To create / edit weather and land management files

2.3.1 To create new weather and land management files

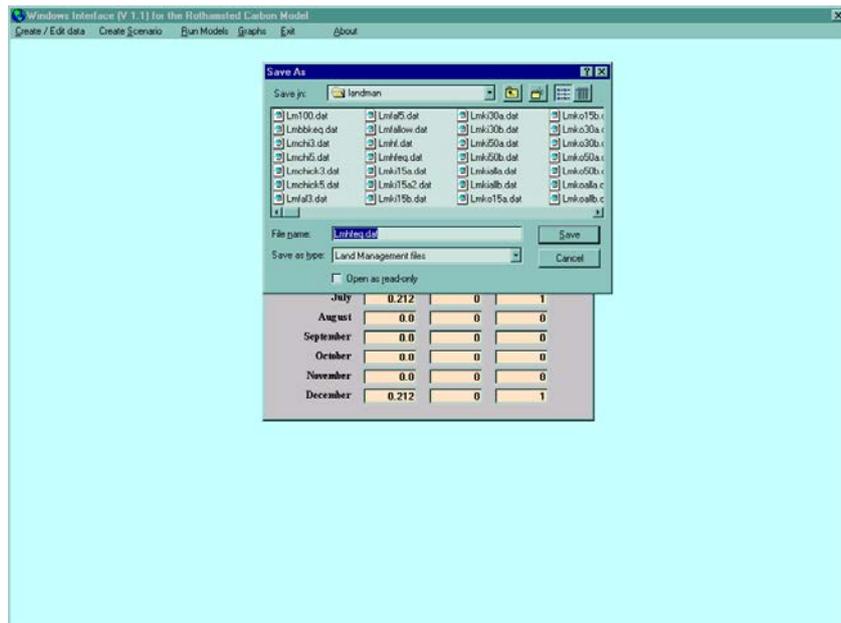
By using the mouse as shown below, or the <alt c,l,c> key, you can create a new land management file.



Move the cursor and / or the <tab> key to give a brief description of the file and enter the monthly inputs of plant residues and of farmyard manure (FYM) - if any. The units of both must be t C ha⁻¹. Also enter plant cover (i.e. whether the soil is bare, 0 or covered, 1) each month. *[NB: If the inputs of plant residues are not known, they can be estimated using one of the procedures in the run models menu. This is explained in a later section.]*



Click Save or <alt s> to save the file: you will be prompted if you have missing data or no file description.



A similar method is used to create new weather files.

2.3.2 To edit existing land management file or weather files

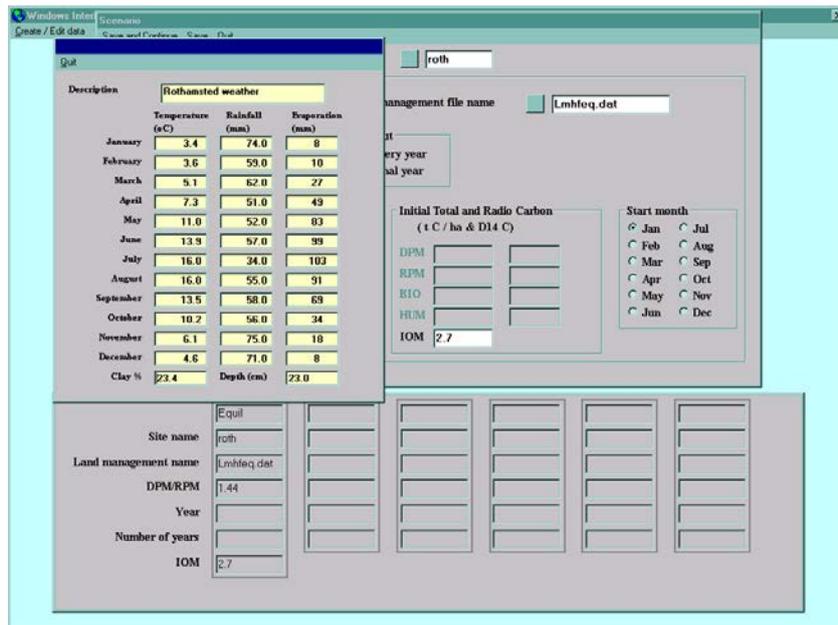
Use the mouse as shown below to highlight the Edit existing on the Land management menu which is in the Create / Edit data menu or <alt c,l,e> key and you will be prompted for the name of the land management file you want to edit.

2.4 To create a scenario

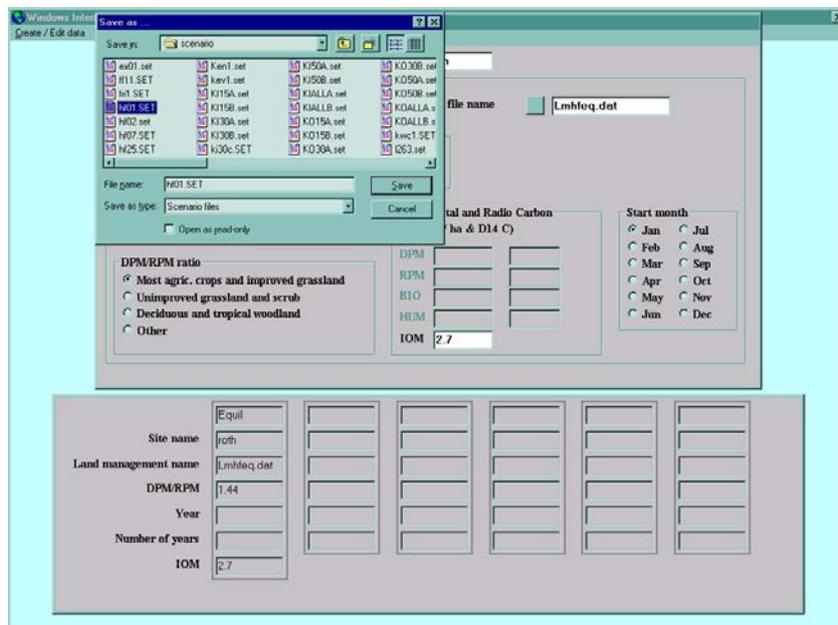
By clicking on the Create Scenario menu or by typing <alt s>, you will obtain the screen below.

The screenshot shows a Windows application window titled "Scenarios". The window has a menu bar with "Create / Edit data" and a toolbar with "Save and Continue", "Save", and "Quit". The main area contains several input fields and radio buttons. At the top, there are fields for "Output file name", "Site name", and "Land management file name". Below these are two radio buttons: "Short term" and "Equilibrium". Under "Short term", there are radio buttons for "Scans effect" and "Bomb effect", and fields for "Start year" and "Number of years". Under "Equilibrium", there is a "DPM/RPM ratio" section with radio buttons for "Most agric. crops and improved grassland", "Unimproved grassland and scrub", "Deciduous and tropical woodland", and "Other". There is also an "Initial Total and Radio Carbon" section with fields for DPM, RPM, BIO, HUM, and IOM. An "Output" section has radio buttons for "Every year" and "Final year". A "Start month" section has radio buttons for each month from Jan to Dec. At the bottom, there is a table with columns for "Site name", "Land management name", "DPM/RPM", "Year", "Number of years", and "IOM", each with a corresponding input field.

You need to enter an output file name, site name and land management file name. To obtain a list of weather and land management files already on the system, click on the command button next to *site name* or *land management file name*, then pick a file name. You can view the information in the file by clicking in the text box next to the command button. Once you have viewed the information, click Quit or type <alt q>. You need to say whether you want to run the model in short term or equilibrium mode, the IOM content of the soil and the DPM/RPM ratio. If the model is to be run in short term mode you will also need to specify the start year, the number of years the model is to be run for, number of years you would like monthly output and initial soil carbon and radiocarbon values of each pool. A scenario that will run the model to equilibrium is shown below.



Once you have given all the information required, click either save and continue, save or quit. You can also use <alt c>, <alt s> or <alt q>. By choosing save and continue, or save, you will be prompted for a scenario file name. Again you will be prompted for any missing data.



If you choose Save and Continue, you will obtain the screen below, which allows you to change the site (weather) information, land management information and the DPM/RPM ratio. If you want to change the site (weather) information click No to the question Do you want the same SITE, when you will be prompted for the name of the new site. You can change the land management information in a similar way. If you want to have more than five changes of Site or Land Management information you can edit the *.set file in any text editor (e.g. Notepad, Wordpad) to do this.

Windows Internet Explorer Scenario

Create / Edit data Save and Continue Save Year 0

Do you want the same SITE
 Yes
 No

Do you want the same LAND MANAGEMENT
 Yes
 No Lmhf.dat

Suss effect
 Bomb effect
 Start year 1852

Number of years 120

Output
 Every year
 Final year
 Number of years for monthly output 0

Do you want the same DPM/RPM
 Yes
 No

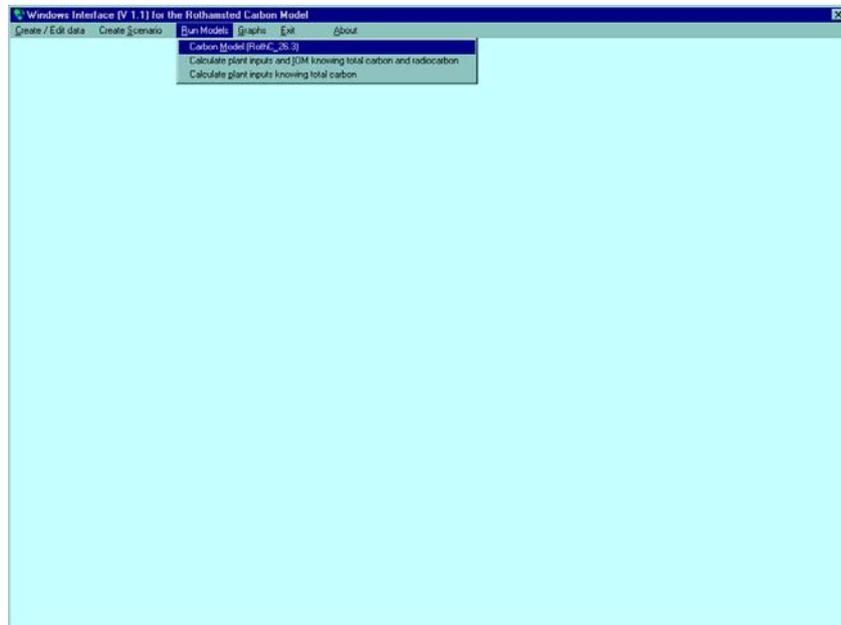
DPM/RPM ratio
 Most agric. crops and improved grassland
 Unimproved grassland and scrub
 Deciduous and tropical woodland
 Other

Site name	Equil	Short				
Land management name	foth	Lmhf.dat				
DPM/RPM	1.44					
Year		1852				
Number of years		120				
IOM	2.7					

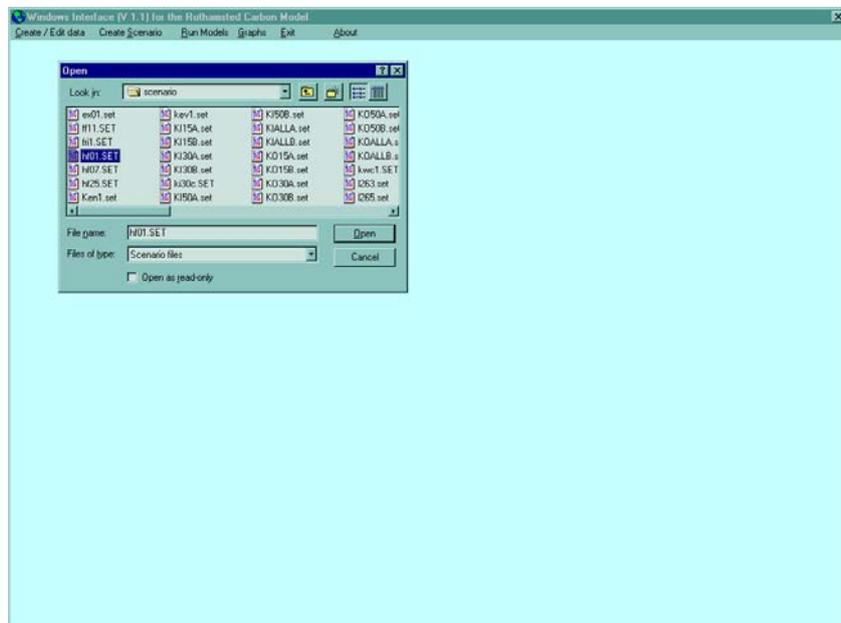
2.5 To run the model

2.5.1 To run RothC-26.3

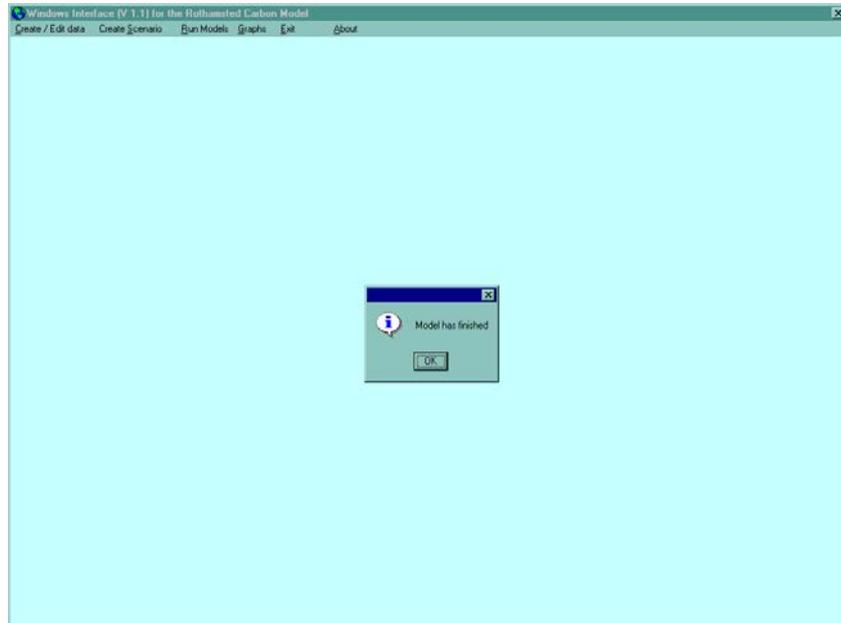
Highlight the Run model menu and click Carbon Model (RothC26-3) or use <alt r,m>



Now pick the scenario you want and run it by clicking Open or <alt o>



When the model has finished the message below will appear.

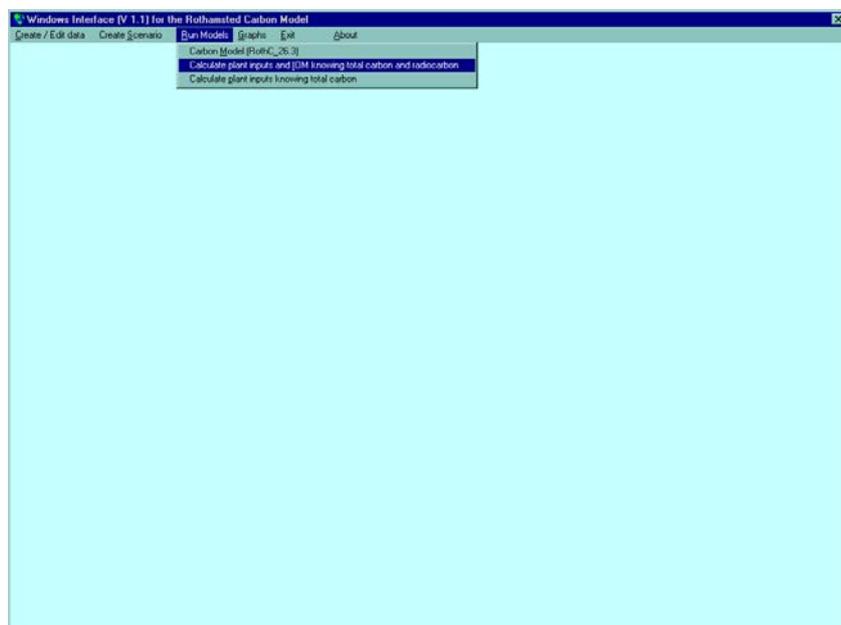


[NB: If either the weather data file (Site) or land management file does not exist a warning message will appear]

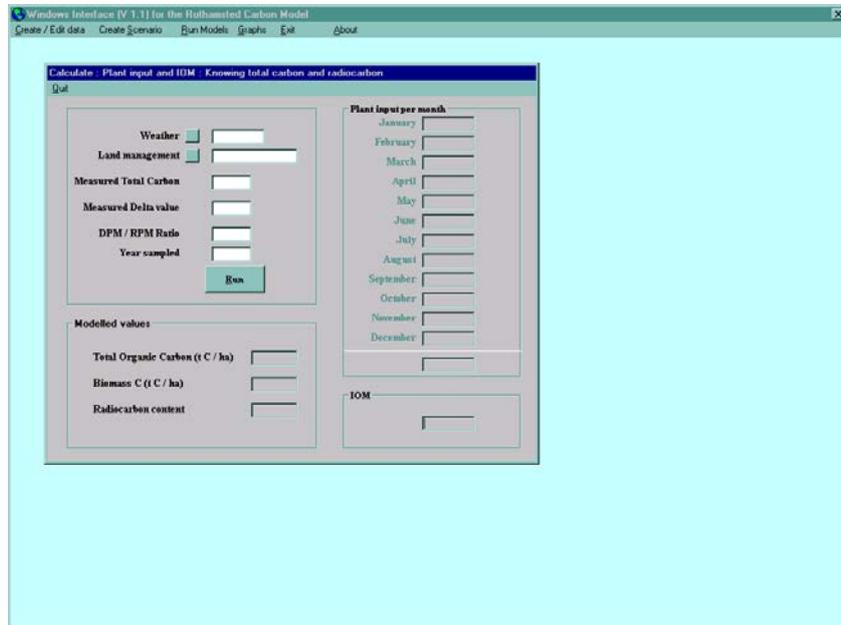
2.5.2 To calculate the annual returns of carbon to the soil and IOM content knowing total carbon and radiocarbon.

As mentioned in a previous section, if the plant inputs are not known they can be calculated, provided you know the total carbon and radiocarbon content of the soil.

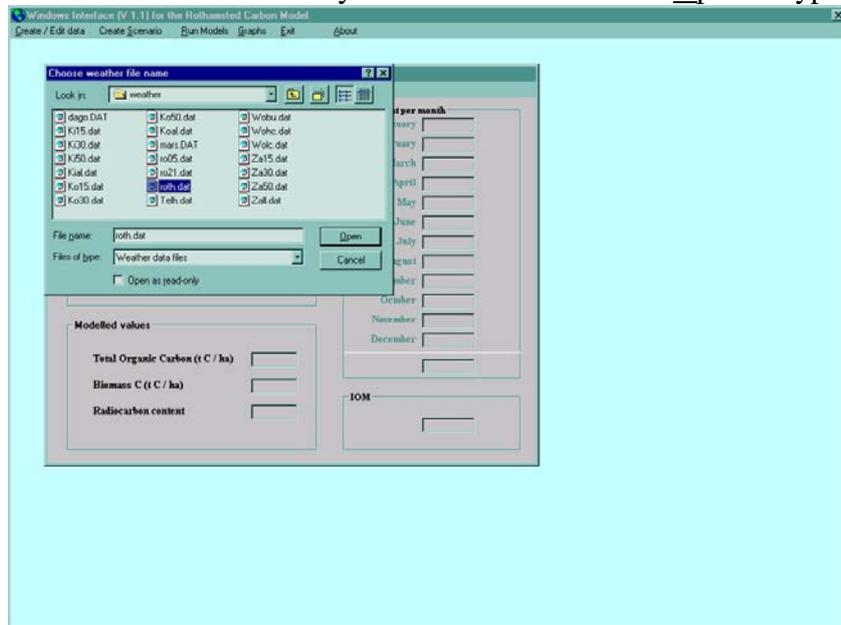
Use the mouse to highlight the Run model menu and click calculate plant inputs and IOM knowing total carbon and radiocarbon as shown below or click <alt r, i>



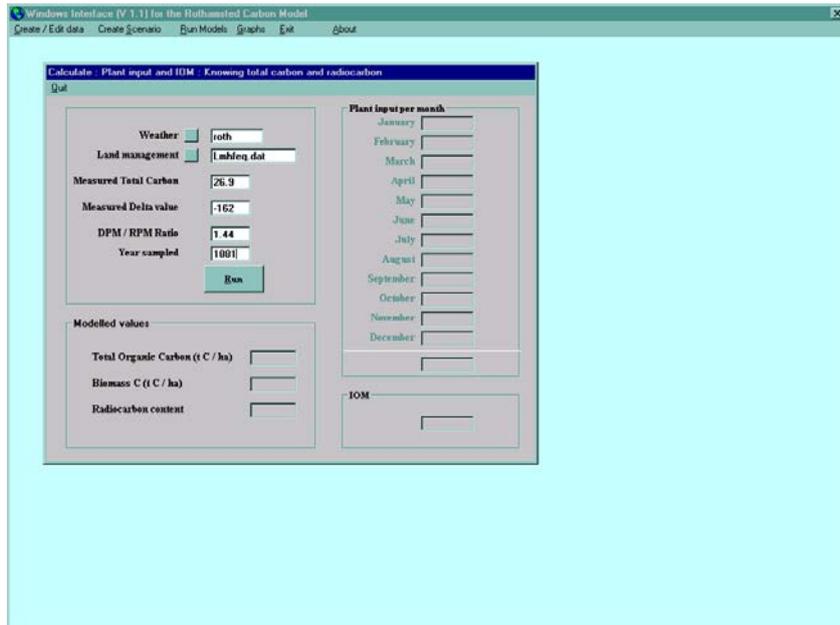
You will need to give details of the weather and land management file you want to use.



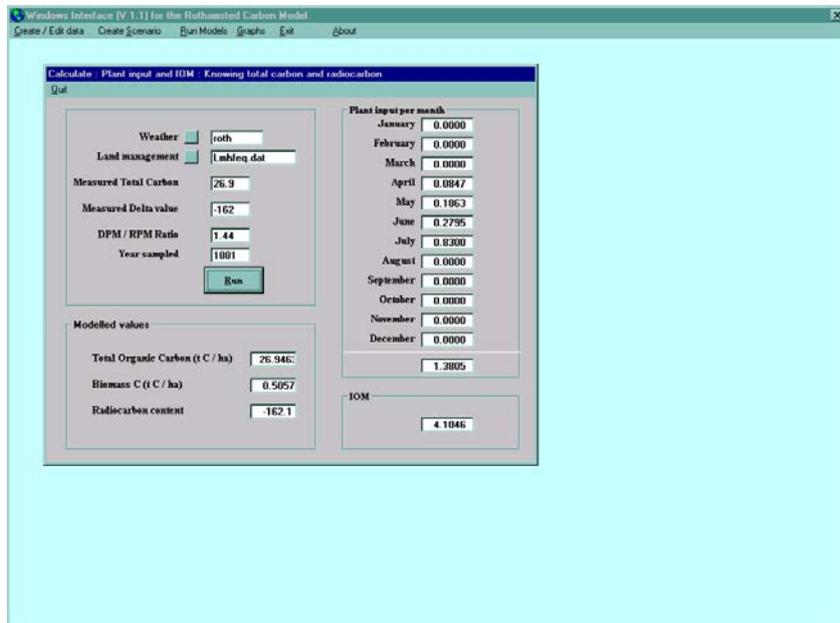
Clicking on the command button next to the weather or land management label will show which files are available. Select the file you want to use and click Open or type <alt o>.



You also have to enter details of the measured total carbon, measured radiocarbon, DPM/RPM ratio and the year the soil was sampled. Once the information has been entered, click Run or type <alt r>.

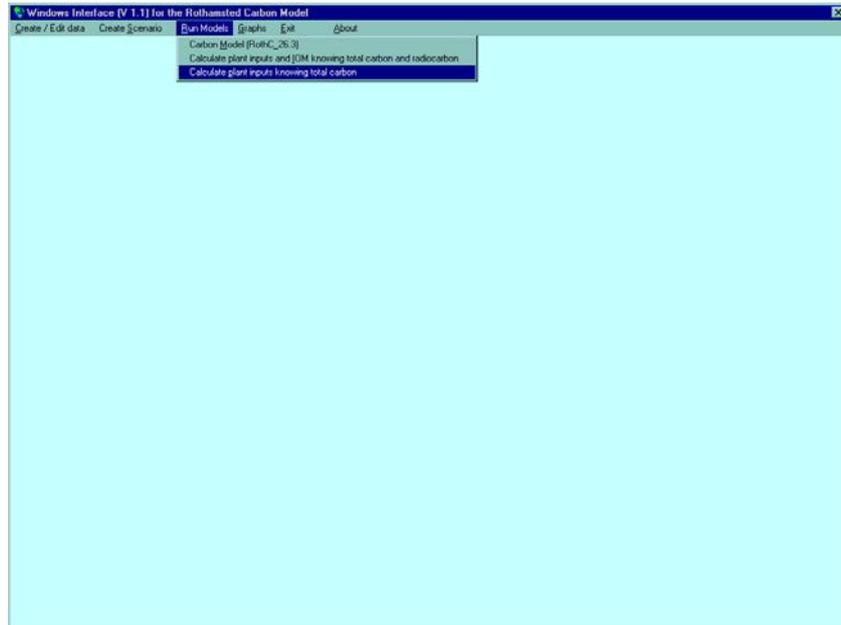


The model will calculate the plant input (t C ha^{-1}) per month and IOM (t C ha^{-1}) needed to obtain the required total carbon and value of the $\Delta^{14}\text{C}$ for the year the soil was sampled. The modelled total carbon (t C ha^{-1}), biomass carbon (t C ha^{-1}) and radiocarbon content are also shown.

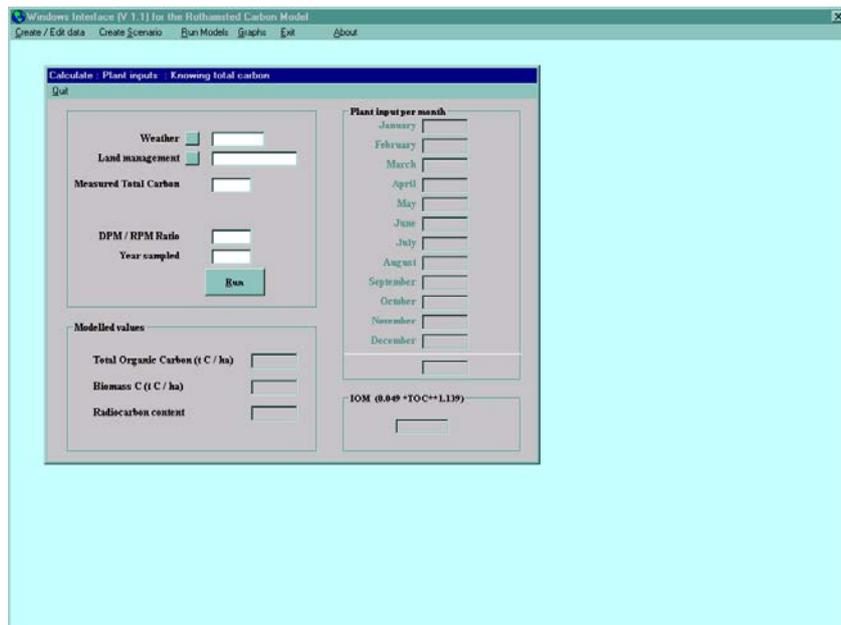


2.5.3 To calculate the annual returns of carbon to the soil knowing only total carbon content of the soil.

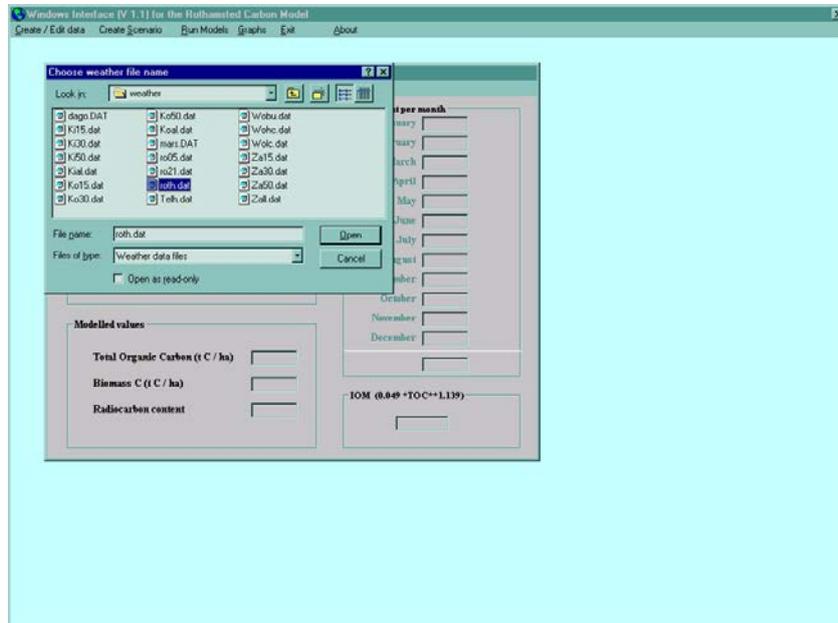
If the radiocarbon content of the soil organic C is not known, IOM is assumed to be $0.049 \times \text{TOC}^{1.139}$ from Falloon et al (1998), where TOC is the total organic carbon (t C ha^{-1}). Use the mouse to highlight the Run model menu and click calculate plant inputs knowing total carbon as shown below or <alt r, p>



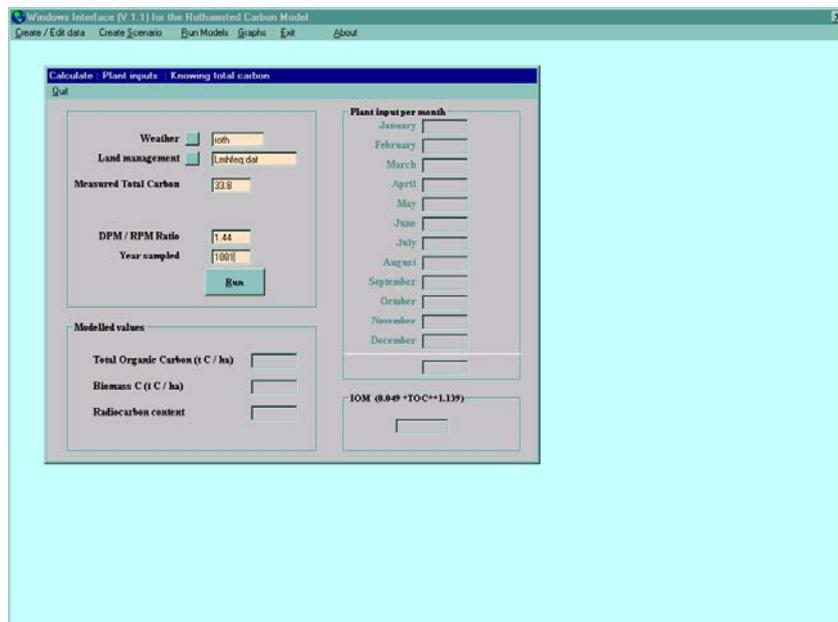
Again you will need to give the weather and land management you want to use.



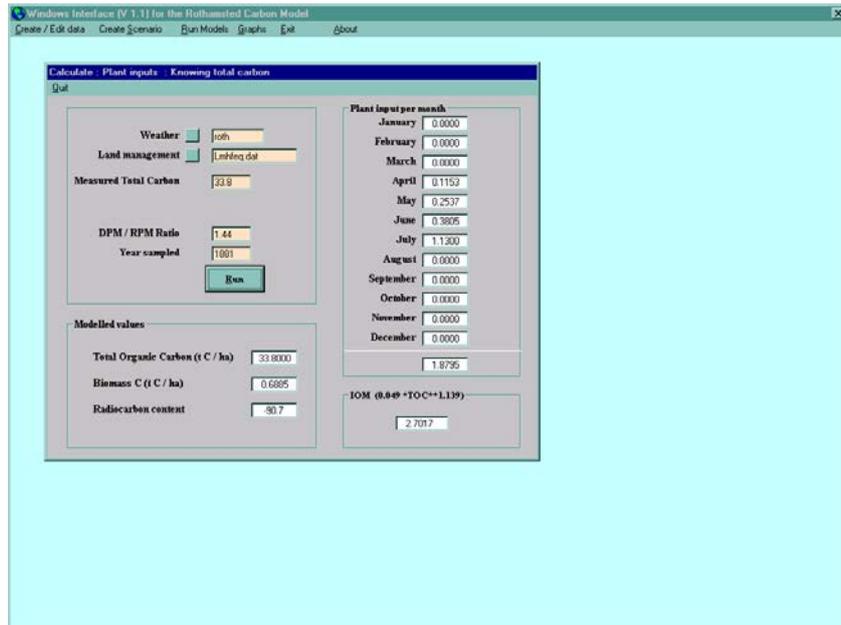
Clicking on the command button next to the weather or land management label will show which files are available. Select the file you want to use and click Open or type <alt o>.



You also have to enter the amount of carbon (t C ha^{-1}), the DPM/RPM ratio and the year the soil was sampled. Click Run or <alt r> once you have entered all the data. Because the radiocarbon content is not known, the IOM is calculated from the equation of Falloon *et al* (1998).



Again the model calculates the plant input needed to obtain the total soil organic carbon, assuming that IOM is given by $0.049 \times \text{TOC}^{1.139}$. The modelled total carbon (t C ha^{-1}), biomass carbon (t C ha^{-1}) and radiocarbon are also shown.

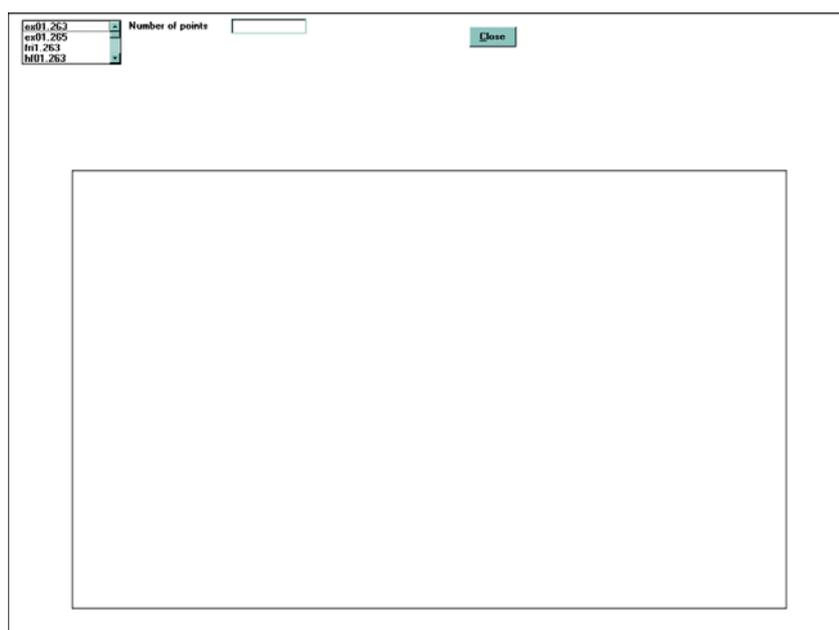


2.6 Obtaining model output in graphical form

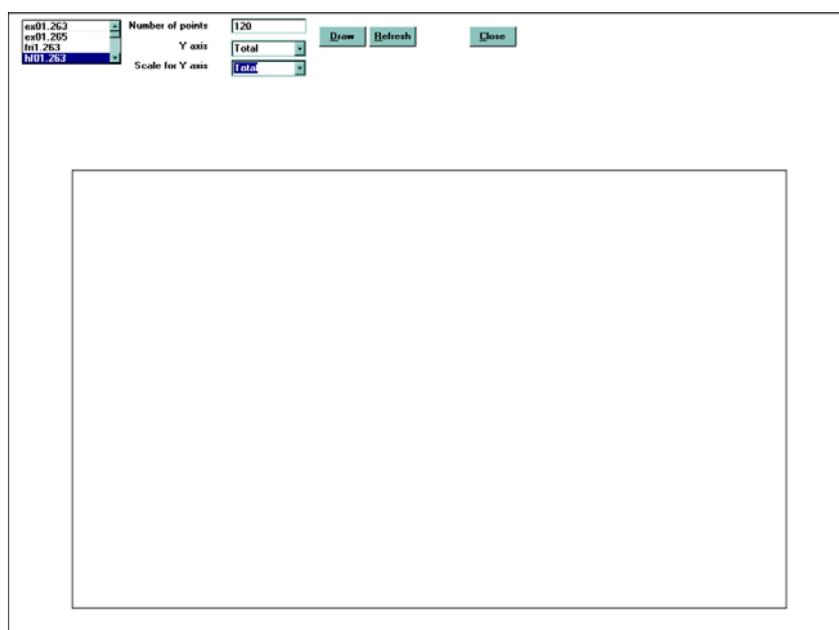
Use the mouse and click on Graphs from the main menu or type <alt g>. The file list box on the left gives all the available files that can be plotted.



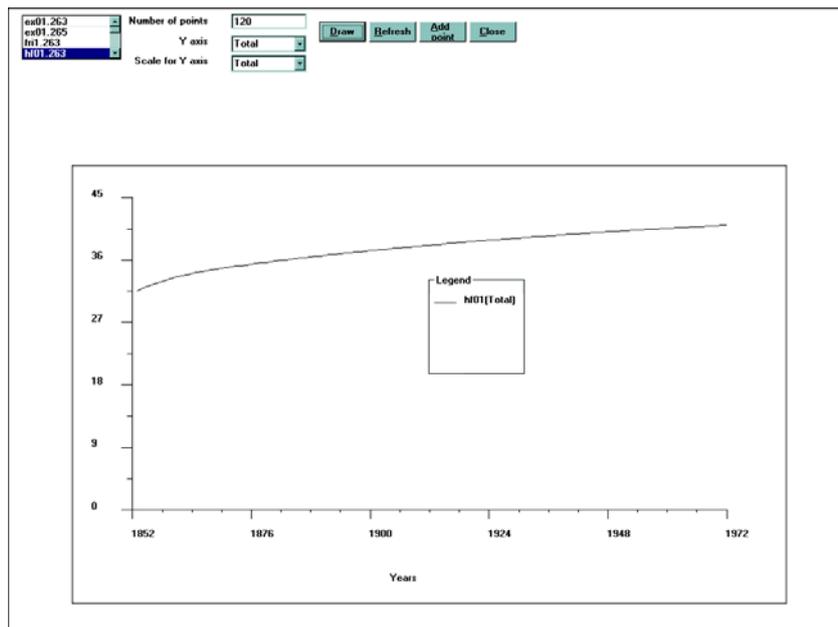
Select one by clicking on the file name. The number of points in the file is shown [NB: If you want to plot data from two different files they must both have the same number of points].



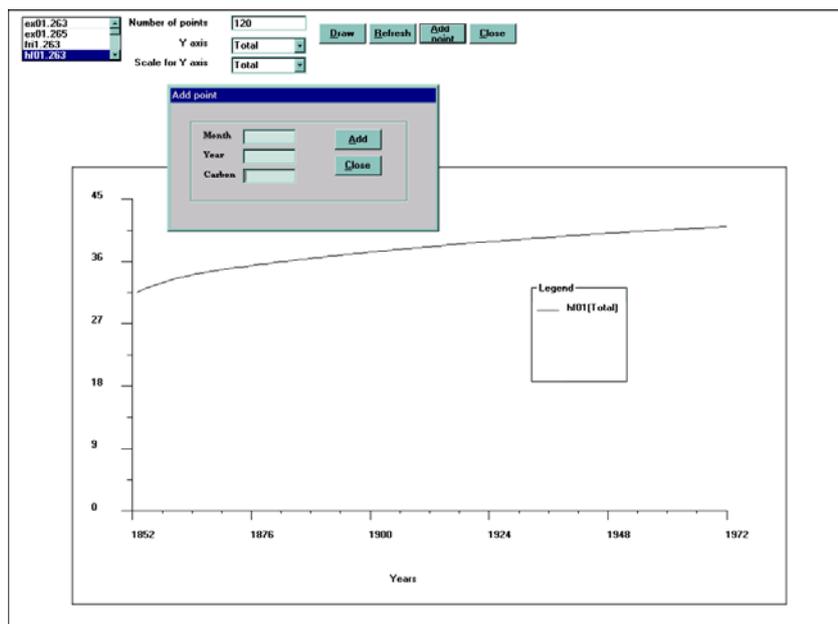
Now you select which item (e.g. Total organic carbon, Biomass, Hum) you want to plot on the y-axis and which item you want to use to scale the y-axis. [NB: The x-axis is chosen automatically from the data in the file, either years or months]. Now click Draw or type <alt d>.

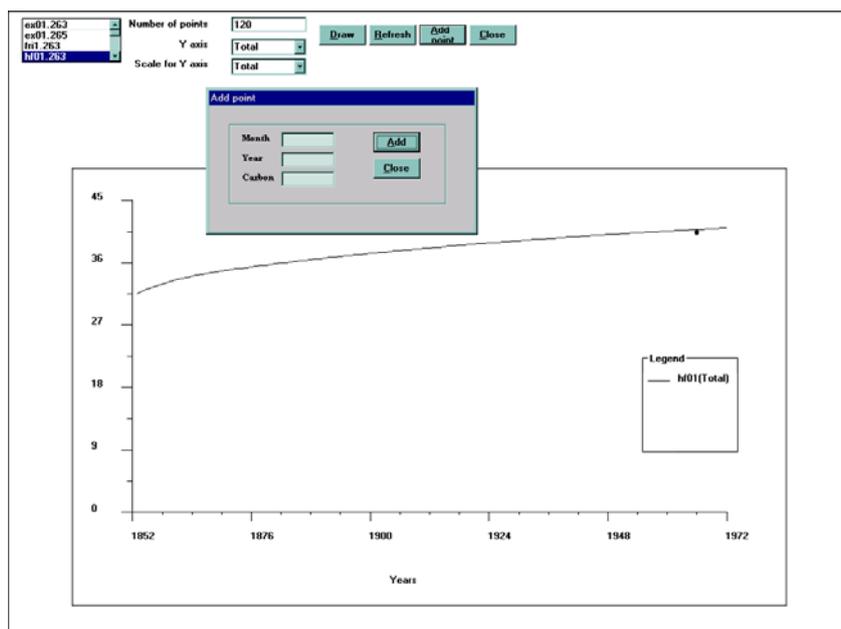
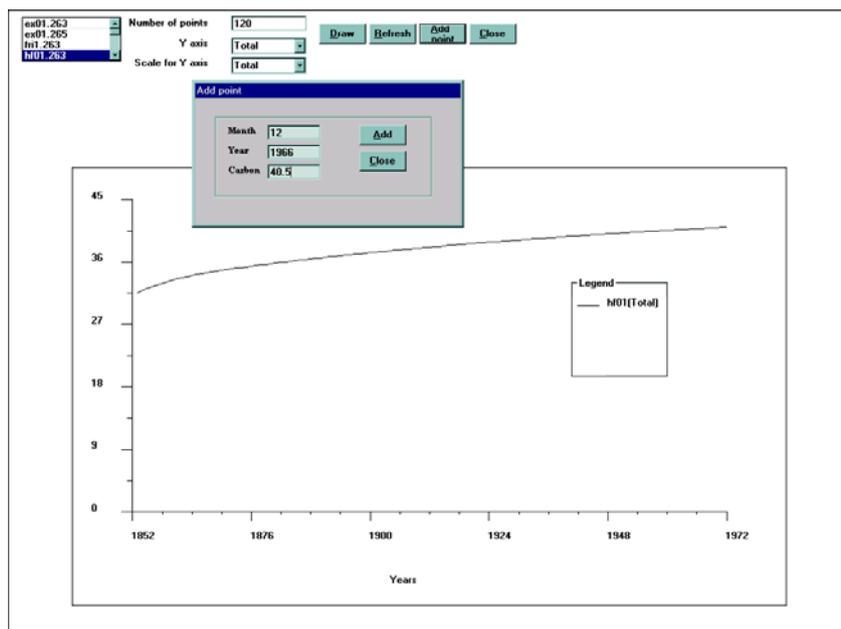


You can plot several items from the same file or different files on one graph (e.g. Total, Bio, Hum from hf01.263 or Total from hf01.263, hf02.263, hf03.263). Clicking on Refresh or typing <alt r> will clear the graph.



You can add measured points to the graph by clicking Add point or typing <alt a>. To do this you need to give the month, year and total carbon (t C ha⁻¹). Click Add or type <alt a> to insert the point on the graph.





The graphs created here allow you to look at the modelled data and compare it to measured data. The modelled data is saved in the directory c:\model26\graph. You can use any standard graphic or spreadsheet package, such as Excel, Sigma plot or Harvard Graphics to create journal quality figures.

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 2.7 t C ha⁻¹ in IOM, as calculated from the equation of Falloon *et al* 1998). Soil organic C is assumed to have been at equilibrium in 1852. The modelled plant input needed to obtain 33.8 t C ha⁻¹ in the soil is then 1.70 t C ha⁻¹ y⁻¹. This input is distributed as follows: 0.212 t C ha⁻¹ month⁻¹ from January to July and in December, with no inputs in the other four months. This distribution is no more than a guess for the mixed arable cropping that prevailed on Hoosfield before the experiment commenced in 1852. 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. A soil cover factor of 1 was used in the months with plant inputs, zero in the other four months.

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).

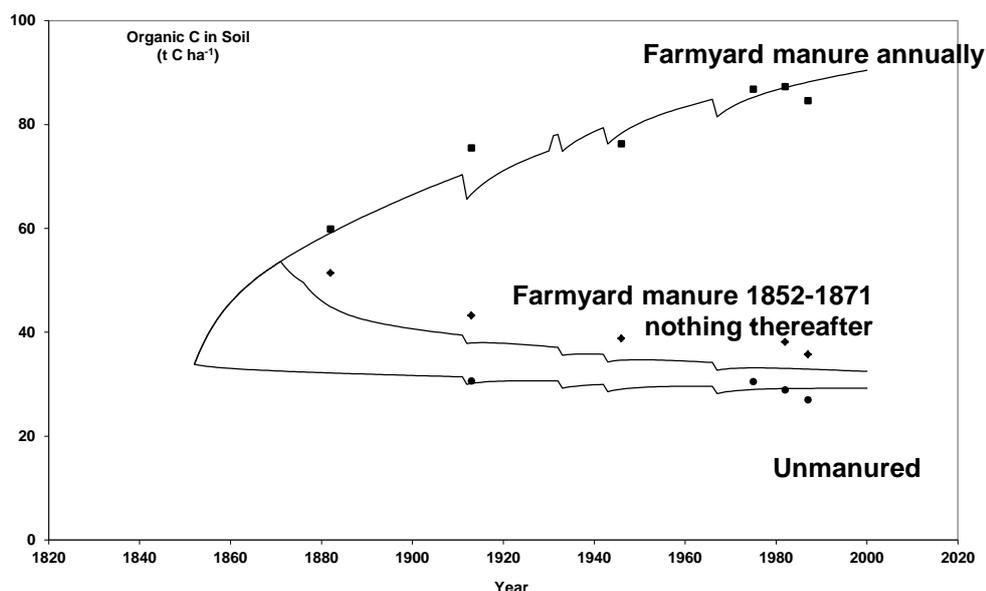
For the unmanured treatment, the annual input of plant residues was calculated to be $1.60 \text{ t C ha}^{-1} \text{ y}^{-1}$ (distributed with 0.16 t C ha^{-1} in April, 0.32 in May, 0.48 in June and 0.64 in July). A soil cover factor of one was used in April, May, June and July, zero in the other 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 calculated to be $2.80 \text{ t C ha}^{-1} \text{ y}^{-1}$ (0.28 t C ha^{-1} in April, 0.56 in May, 0.84 in June and 1.12 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 $3.0 \text{ t C ha}^{-1} \text{ y}^{-1}$) 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 ($3 \text{ t C ha}^{-1} \text{ y}^{-1}$) every February from 1852 to 1871 and nothing thereafter (plot 7-1). From 1852 to 1876, plant residue input was set at $2.80 \text{ t C ha}^{-1} \text{ y}^{-1}$ (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 $1.60 \text{ t C ha}^{-1} \text{ y}^{-1}$ (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.

Figure 6 shows the modelled data for total soil organic C in the three treatments, together with the measured data. The modelled results for the treatment receiving FYM for only 20 years are considerably lower than the measurements; agreement is closer with the other two treatments.

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



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

To see how carbon content, equivalent age and $\Delta^{14}\text{C}$ values are calculated, we will examine the first month (January 1852) of the simulation for the unmanured plot on the Hoosfield spring barley experiment (Figure 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, the Hoosfield Land Management file (with an annual input of 1.70 t C ha⁻¹ year⁻¹), a DPM/RPM ratio of 1.44 and an IOM of 2.7 t C ha⁻¹. On 31st December 1851 the state of the model is :

	Carbon (t C ha ⁻¹)	Equivalent Radiocarbon age (years)	$\Delta^{14}\text{C}$
DPM	0.1533	0.10	-0.01
RPM	4.4852	6.70	-0.83
BIO	0.6671	21.69	-2.69
HUM	25.8576	116.88	-14.44
IOM	2.7000	50000.00	-998.02
Total	33.8632	764.37	-90.75

Now consider the state on the 31st January 1852 for the unmanured plot, which does not receive any input of plant C or FYM in January. The temperature, moisture and soil cover during January give a combined rate modifying factor, *abc*, of 0.3561. Using the rate constants given in Section 1.5, the C content of the different compartments are changed as follows.

DPM becomes $0.1533 * \exp[- 10 * 0.3561 / 12] = 0.1140$

RPM becomes $4.4852 * \exp[- 0.3 * 0.3561 / 12] = 4.4455$

BIO becomes $0.6671 * \exp[- 0.66 * 0.3561 / 12] = 0.6542$

HUM becomes $25.8576 * \exp[- 0.02 * 0.3561 / 12] = 25.8423$

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

DPM 0.0393

RPM 0.0397

BIO 0.0129

HUM 0.0153

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 CO₂ in the following way:

$(3.51 / 4.51) * (\text{difference})$ is CO₂-C

$(1 / 4.51) * (\text{difference})$ 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 -C
DPM	0.0393	0.0039	0.0047	0.0307
RPM	0.0397	0.0041	0.0048	0.0308
BIO	0.0129	0.0013	0.0015	0.0100
HUM	0.0153	0.0016	0.0018	0.0119

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

$$\begin{aligned}
\text{DPM} &= 0.1140 && = 0.1140 \\
\text{RPM} &= 4.4455 && = 4.4455 \\
\text{BIO} &= 0.6542 + 0.0039 + 0.0041 + 0.0013 + 0.0016 && = 0.6651 \\
\text{HUM} &= 25.8423 + 0.0047 + 0.0048 + 0.0015 + 0.0018 && = 25.8551
\end{aligned}$$

The model calculates the age of each compartment from a matrix which starts with the age of that compartment on 31 December 1851 and adjusts it for changes occurring during January 1852. For the DPM and RPM compartments, which in this particular example receive no fresh inputs of plant material in January, the age on 31 December is increased by one month to give the age on 31 January. For the BIO and HUM compartments, the incoming material added at the end of the month comes tagged with the age of the compartment from which it came. The age of the whole compartment is then obtained by weighting the age of its components by their carbon content. The resulting values for equivalent radiocarbon age and $\Delta^{14}\text{C}$ are then

	Equivalent Radiocarbon age (years)	$\Delta^{14}\text{C}$
DPM	0.19	-0.02
RPM	6.78	-0.84
BIO	21.78	-2.70
HUM	116.91	-14.45

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.

For the unmanured plot in the Hoosfield experiment the calculated radiocarbon age of the whole soil organic C is 987 years in 1950 and 70 years in 1970, the decline being due to radiocarbon from thermonuclear testing. 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 content for a particular sampling date.

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