

Section 7

RothC-BIOTA v05 plant-soil C turnover model

Table of Contents

7. RothC-BIOTA v05 plant-soil C turnover model.....	7-1
7.1. Model description	7-1
7.2. Recent changes in model design	7-2
7.2.1. Crop rotations.....	7-2
7.2.2. N fertiliser method.....	7-2
7.3. Parameterization of RothC-BIOTA	7-4
7.4. Evaluation of RothC-BIOTA	7-5
7.4.1. Broadbalk site.....	7-5
7.4.2. Simulation of soil C	7-5
7.4.3. Modelled DM and debris inputs to soils.....	7-7
7.5. Conclusions.....	7-8
7.6. References.....	7-8
7.7. Appendices.....	7-11
A.1. An example of landuse.ini.....	7-11
A.2. Crop classification in RothC-BIOTA model.....	7-13
A.3. RothCBIOTAv05.....	7-15
A.4. Method of biomass adjustment by fertiliser.....	7-17
A.5. Crop parameters.....	7-19

7. RothC-BIOTA v05 plant-soil C turnover model

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7.1. Model description

RothC-BIOTA model was developed as a coupled link between GIS-RothCv03, the model of soil C dynamics (Coleman and Jenkinson, 1996; Falloon, 2004; Smith *et al.*, 2005; 2006) and a process-based C model in semi-natural plant systems (Wang and Polglase, 1995). RothC-BIOTA v05 was fully utilised for site applications, but it retained the spatial framework of GIS-RothCv03 so to enable future applications of RothC-BIOTA for regional and national inventories. The model input requirements are relatively simple i.e. seven monthly climate variables and some principal information on land management and soil type (Figure 7-1). Climate variables needed for RothC-BIOTA were described by Sozanska-Stanton *et al.* (2005). *Landuse.ini* input file controls climate data input (weather files are named: <sitename><simulationyear>.mon) and information on crop types and fertiliser input (Appendix A.1). Crop parameters and monthly carbon input (debris) proportions are defined for each of nine major crop types, fallow land and two grass types referred to in the model as 'INDEXes' (Appendix A.2). In the most recent version of RothC-BIOTA v05, draft inputs were defined for forests. Plant parameters for grasslands and forests need more refinement and testing.

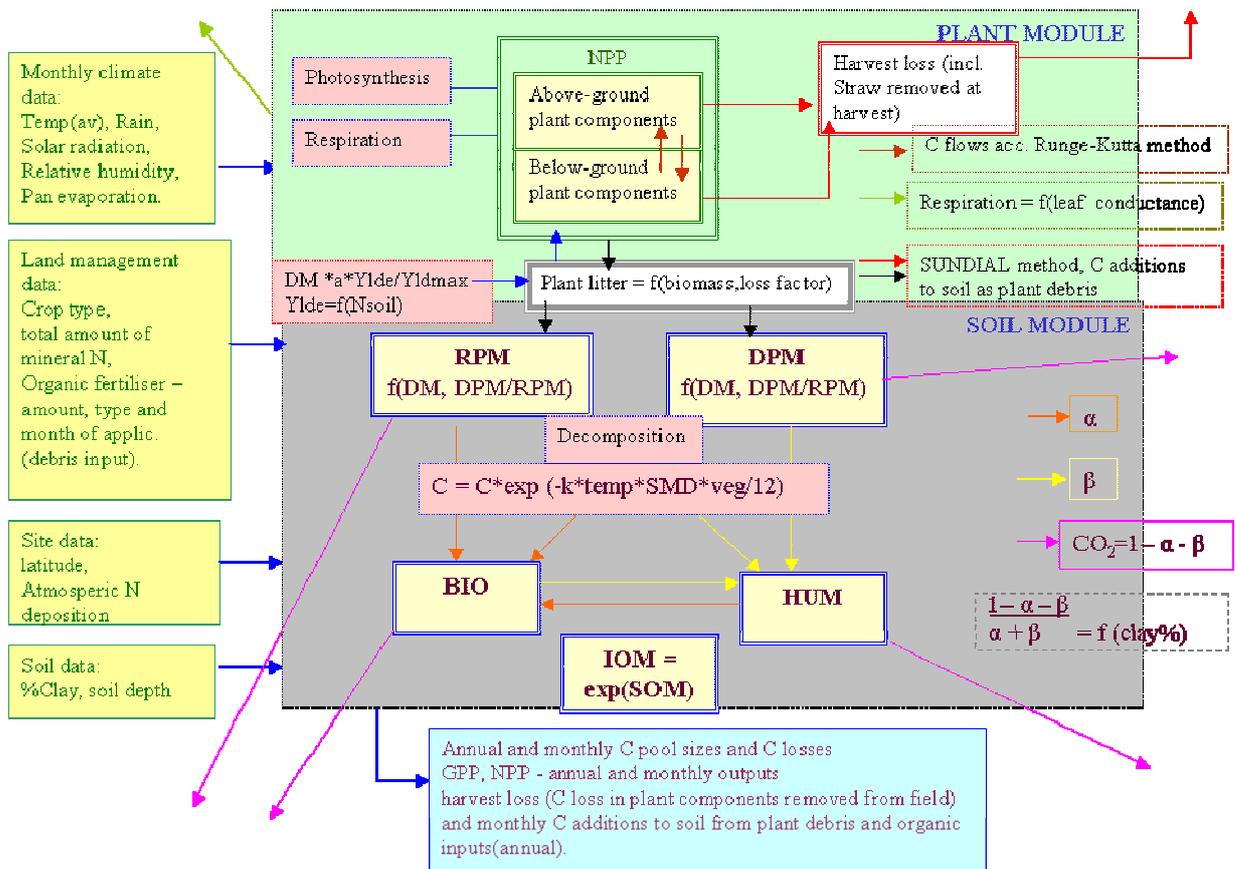


Figure 7-1 RothC-BIOTA

As BIOTA was originally developed and parameterised for natural forests and semi-natural grasslands (Wang and Polglase, 1995), it was necessary to extend the range of plant

functional types to major arable crops in the UK to enable its application for agricultural soils (Table A5. 1, Sozanska-Stanton *et al.*, 2005). A method of crop rotations was then developed to allow for different types of crop management in UK agriculture (§ 7.2.1). Further changes to the model design involved introduction of a fertiliser effect on crop growth (Figure 7-1, §7.2.2). The model can be applied either using the pre-determined plant carbon additions to soils (RothC stand-alone) or with the application of dynamic plant component (when BIOTA is activated, Figure 7-1; Sozanska-Stanton *et al.*, 2005). In the former case, monthly debris inputs are set as default inputs in the model for major crop types and management levels. Their values have been determined by fitting RothC to measurements of C inputs into soils (Jenkinson and Coleman, 1994). When the BIOTA plant component is activated, monthly plant C inputs into soils are estimated as a function of simulated standing plant biomass at the end of each month and monthly proportions of plant debris determined with the DEBRIS calculator (Figure 7-1, Sozanska-Stanton *et al.*, 2005). BIOTA simulates the physical processes of photosynthesis and C transfer between plant components at a canopy level at daily time-steps (Figure 7-1). Method of estimating SOC equilibrium was adjusted in RothC to make it compatible with the C transfer processes described by the plant module (Sozanska-Stanton *et al.*, 2005). The new RothC equilibrium method describes C decomposition and C transfers between the soil pools as a function of time on an arithmetic scale. The equilibrium is reached when the total SOC changes by less than 1 kg C ha⁻¹ over the period of 20 years (in the previous version of RothC, SOC equilibrium was assumed at 10000 years). Additionally, the original RothC method ‘fitting to equilibrium’ was retained in RothC-BIOTA to extend application of the model to conditions with limited knowledge of land use history. Under these conditions, the model can be fixed to run to a ‘fitted’ equilibrium, the dynamic plant module (BIOTA) can then be activated for ‘short-term’ runs. This method was used in some simulations described further in the text (§7.4.2).

Apart for the summary outputs of annual soil and plant C, RothC-BIOTAv05 calculates monthly values of NPP, C content of plant and litter pools and CO₂ emissions from soils (Figure 7-2). Figure 7-2a and Figure 7-2b present C dynamics in soil/plant systems for (a) winter wheat with optimum nutrient supply to crop growth, and (b) oilseed rape on soil with nutrient stress. Subsequently those data can be then used to calculate monthly NEP.

7.2. Recent changes in model design

7.2.1. Crop rotations

RothCBIOTAv05 initiates simulation with the equilibrium model, which models C dynamics for a selected equilibrium land use type (input from *landuse.ini*) until an equilibrium in soil is reached. After the equilibrium is reached, each annual model cycle is controlled by *landuse.ini* file (Appendix A.1), which informs the model on the change of crop types between simulation years. The *Landuse.ini* file is read with the subroutine *ReadRotationsFile*. The code controlling rotations is defined in the subroutine *SetNextRotation* (Appendix A.3-1) and loading crop parameters in the subroutine *SelectCrop* (Appendix A.3-2).

7.2.2. N fertiliser method

The coupled model could only be applied to agricultural systems, when effects of different management levels were accounted for in the biomass production. The original BIOTA had already taken into account the limiting effect of climate on the plant growth in non-optimal conditions. Consequently, the effect of nutrient availability was to be introduced using the

same approach, in which the biomass growth would be reduced on soils with nutrient (N^1) stress. This methodology was developed as follows. The model contains a reference table of the optimum yields for all major UK crops (Table A5. 2) based on published research (<http://www.hri.ac.uk/envveg/paper/pap-eng.htm>; <http://www.agr.gov.sk.ca/DOCS/crops/>). Total soil N available to crops (soil N) is estimated in the model as a simple summary of mineral N and organic fertiliser inputs and the level of atmospheric N deposition. The expected crop yield is calculated as a function of plant N uptake (equation 2, Figure 7-1) which was adopted from SUNDIAL model (Smith and Leech, 1995; equation 1).

$$U_t = k_1(e^{k_2 \cdot G} - 1) \quad (1)$$

$$G = \ln((U_t + k_1)/k_1)/k_2 \quad (2)$$

where: U_t - crop N uptake at harvest, k_1 and k_2 are crop parameters defined by SUNDIAL, G - crop yield

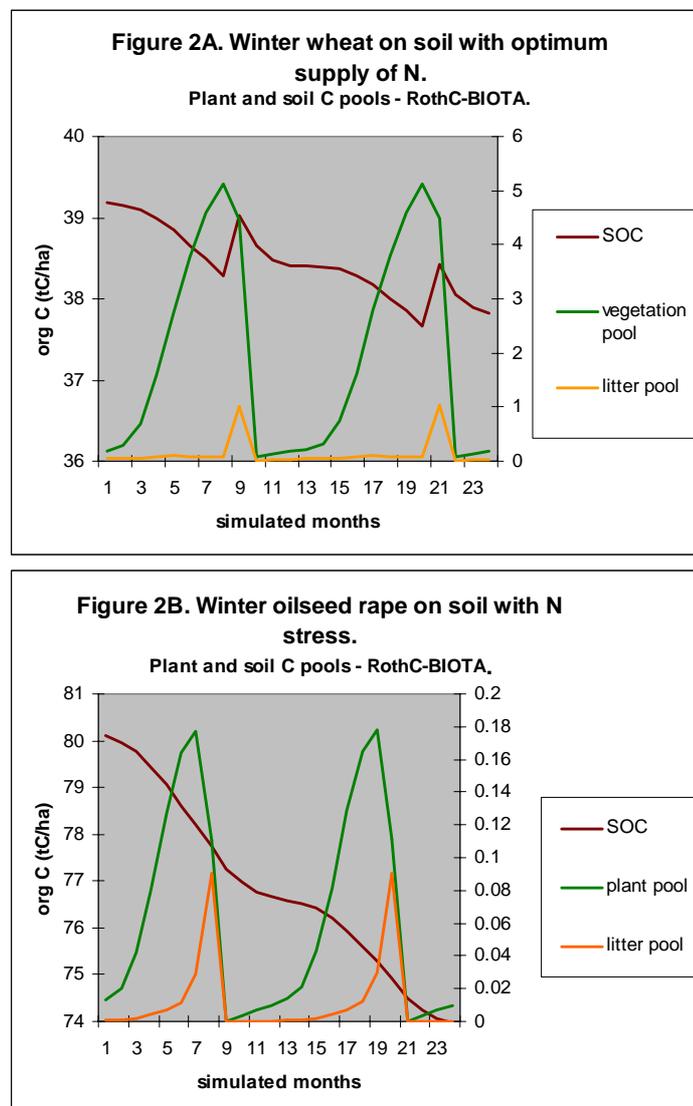


Figure 7-2 Monthly C dynamics in plant pools and soil for two crop types.

¹ Note that we excluded P and K effect in the current version of the model.

The RothC-BIOTA_{v05} model does not simulate N losses from soils, which will introduce some uncertainty² to the estimated yield. The ratio of the yield in simulated conditions and the maximum yield in optimum conditions (Table A5. 2) is then applied to reduce the monthly plant biomass (equation 2). This approach assumes that the entire plant biomass will be reduced proportionately to the grain.

The methods to calculate N additions and their effect on plant biomass are included in module Nfertiliser_cap. The following routines were designed to calculate the stages of N fertiliser method:

1. Yield is calculated by function ExpectedYield (Appendix A.3-1)
2. Yield ratio is estimated by function Ratio (Appendix A.3-2)
3. Biomass is adjusted with function AdjustBiomassWithRatio (Appendix A.3-2).

7.3. Parameterization of RothC-BIOTA

Initial crop parameters were defined on the basis of literature (Table A5. 1). The coupled model with plant parameters from literature was then applied to estimate average yields for different UK crops. The yields were calculated for three different levels of crop management defined in plant parameter files by FertLow and FertMed. The ranges of yields simulated by RothCBIOTA were compared with the average yields published in literature (Figure 7-3; MAFF, 1998). The average yields were simulated for cereals and oilseed rape with standard error of 0.649 and a maximum residual error of 15% (for winter oats). Model considerably under-predicted yields for root crops, particularly potatoes, sugar beet and carrots (Figure 7-3). Standard error for root crops was 8.137, with the maximum residual difference of 70% for potatoes. The crop parameters were satisfactory for cereals and oilseed rape, as the average yields were well within the ranges simulated by the model for different management levels (Figure 7-3). As there was a considerable difference between simulated and measured yields for root crops, the crop parameters for those PFTs had to be adjusted. We subsequently carried out sensitivity analysis for selected plant parameters important for DM production in BIOTA module. Their values were varied within the ranges reported in literature (Table A5. 2, based on Table A5. 1). Model was most sensitive for the changes to partitioning of C between above-ground plant components and roots. The highest yields were simulated for potatoes when C split between above and below ground plant was 20:80, for sugar beet 40:60 and carrots and turnips 50:50. Those values were applied together with the highest values for the other tested parameters to obtain the best fit. There was a considerable improvement in the simulated average fresh yields with the observed average yields for potatoes and turnips falling now within the range of yields simulated for low and high fertiliser inputs (Figure 7-3). Standard error for the selected crops was reduced from 8.137 to 5.154 and the residual difference for potatoes decreased to 41%.

² This limitation ought to be addressed in the future by means of linking the model to another N-cycle model that dynamically simulates N losses (SUNDIAL, NCYCLE).

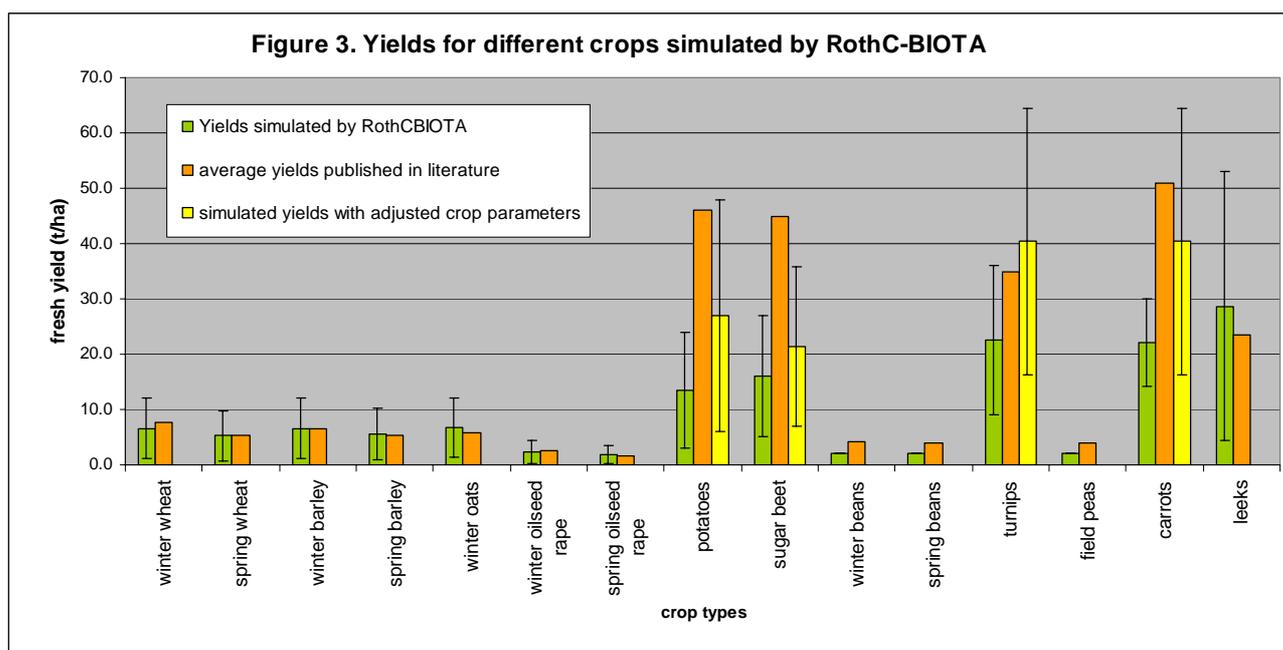


Figure 7-3 Yields for different crops simulated by RothC-BIOTA

7.4. Evaluation of RothC-BIOTA

7.4.1. Broadbalk site

The site is located 40 km north of London at IACR-Rothamsted (latitude=51°N49', longitude=0°W21'), it has cool temperate climate with mean annual temperature of 9.1 °C and rainfall 693 mm. Soil is classified as flinty-silty clay loam over clay-with-flints (25 % clay, 57 % silt and 15 % sand) also known as stagnogleyic brown earth. The field experiment started in 1844, there are several sections with continuous wheat and four other rotation sites (involving also potatoes, forage maize, winter oats and legumes). There are several replicated plots with mineral and organic fertiliser treatments including no additions since 1852, plots N1,N2,N3,N4,N5,N6 with mineral N input as ammonium nitrate of 48, 96, 144, 192, 240 & 288 kg N/ha/y, respectively, FYM plot with 35t/ha added and a plot with a combination of FYM+N2. More details can be obtained on SOMNET Web site.

7.4.2. Simulation of soil C

The coupled model was evaluated for Broadbalk site, section 8, on the following plots:

Plot 3 - no fertiliser amendments

Plot 8 - mineral N input of 144 kg N /ha

Plot 21 – FYM input of 35t/ha and mineral N of 96 kg N/ha.

The old version of RothC showed a good fit to measurements with fixed equilibrium SOC of 30 t C ha⁻¹ and pre-determined debris inputs to soil (based on measurements) (Figure 7-4a, Figure 7-4b, Figure 7-4c). When RothC-BIOTA was first used to simulate the C dynamics on that site, the results were worse than the fitted RothC, as we observed a higher SOC at equilibrium (>40 t C ha⁻¹) and steady decline of SOC for plots 3 and 8. SOC increased on plot 21, but not sufficiently for the model to accurately simulate the observed C levels in soil. As the equilibrium level simulated with RothC-BIOTA was too high for plot 3, we fitted the

equilibrium level to 32 t C ha^{-1} , which was higher than when RothC was fitted. The new simulated trend corresponded better with the measurements on plot 3 and suggests that there is a steady decline in SOC (Figure 7-4a), which confirms previously published work (Glendining *et al.*, 1996). The best fit of RothC-BIOTA was obtained when we reduced the limiting N effect on the yield ratio by 100% (Figure 7-4a).

Figure 4. RothC-BIOTA simulation of Broadbalk site: wheat under three management systems.

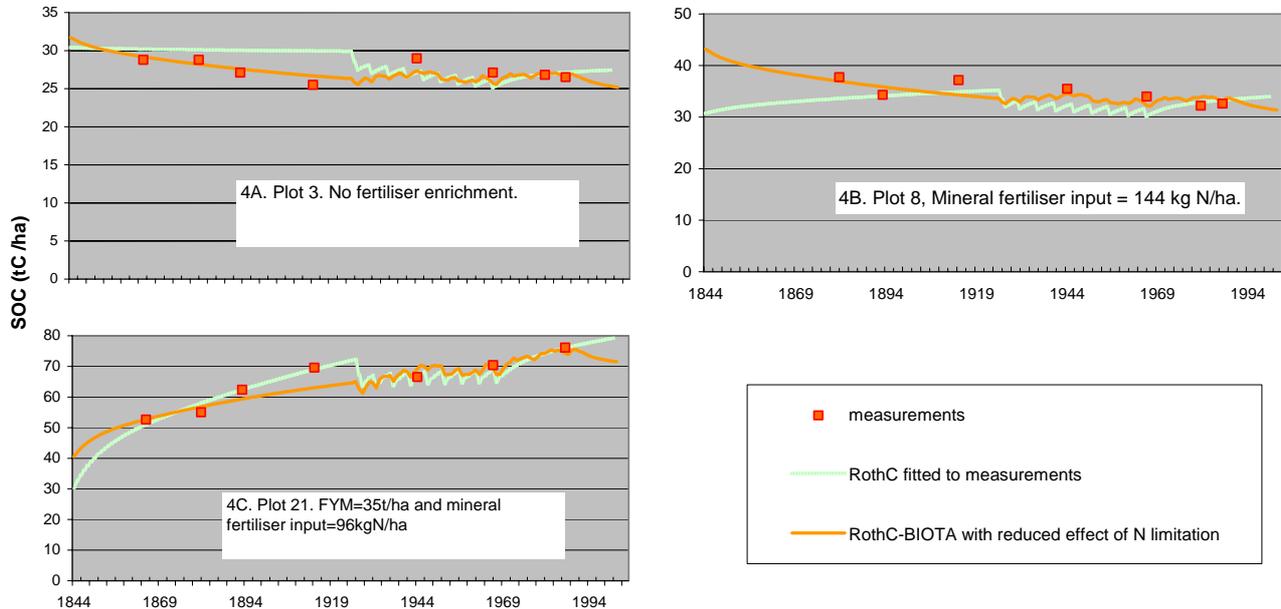


Figure 7-4 RothC-BIOTA simulation of Broadbalk site: wheat under three management systems

In order to improve the model results, the N limitation effect on yield ratio was reduced by 75% and 50% for plots 8 and 21, respectively. There was a decreasing trend in SOC simulated for plot 8 (with N mineral input), which might be explained by the equilibrium SOC simulated too high on that plot (Figure 7-4b). SOC simulated by RothC-BIOTA at equilibrium on plot 21 better corresponded with SOC dynamics in succeeding measurements than the previously used 30 t C ha^{-1} (Figure 7-4c). Although the fitted RothC results suggest a higher rate of increase in SOC, there is a large unexplained decline in soil C in 1926-1929 (Figure 7-4c). The lower rate of SOC increase estimated by RothC-BIOTA does not explain a very high measurement of 70 t C ha^{-1} in 1914. It is very possible, however, that there were some unusual conditions that caused apparent high C sequestration, e.g. larger plant addition to soil due to climatic conditions.

Broadbalk results suggested that the current N-cap method introduces too high a limitation to the plant development simulated by BIOTA. The SOC level at equilibrium can benefit from fitting to measurements in some conditions. This was particularly confirmed by further evaluation of the model on BadLauchstaedt site, where soil receives organic fertiliser inputs every other year. RothC-BIOTA calculated SOC of 18.7 t C ha^{-1} , much lower than measured 88.2 t C ha^{-1} . The reason for poor reflection of initial soil C level is a very limited knowledge of land use management prior to equilibrium. The model can only simulate single crop type without fertilisation (in this case, spring barley), which might be different from the actual crop and management. It is known that the site was originally under grass, but there is no information on the timing of land use change – this may have greatly influenced the initial level of SOC. Under these conditions RothC-BIOTA benefits from fitting the equilibrium SOC to the measurement.

7.4.3. Modelled DM and debris inputs to soils

The accurate simulation of SOC with the dynamic plant component of RothC-BIOTA depends on (1) simulated plant biomass and (2) proportion of DM input to soil. Evaluation of the simulated plant biomass was carried out using yield data from the Electronic Rothamsted Archive Broadbalk (ERA). RothC-BIOTA estimates yield for each crop type as a proportion of above ground biomass (unit: t C ha⁻¹) removed from the field at harvest. The proportions are fixed values for each major crop type and they include harvested part e.g. grain for cereals, and part of cartable plant e.g. straw. Cartable plant components can contribute to harvested plant from 0% e.g. cereal straw incorporation to 100% e.g. all above-ground components of the potato plants. The knowledge of crop management is often very limited, particularly for long-term experiments. Previous evaluation of the coupled model for the Hoosfield site (Sozanska-Stanton *et al.*, 2005) suggested that when all straw was assumed to be removed from the field (i.e. 100% contribution to harvested DM), the simulation was most accurate. The same scenario was assumed for Broadbalk.

The results for optimal nutrient conditions showed that the average C content in winter wheat on section 9 (continuous crop) was accurately simulated for the study period (1968-2001) at 3.77 t C ha⁻¹ (measured average = 3.8 t C ha⁻¹), and on section 1 it was within one standard deviation from the measured mean (4.5 t C ha⁻¹). On plots with no fertiliser input, C content in DM was underestimated by the model, but still within one standard deviation from the measured mean. The climatic effect on DM variability between different years was not well represented by the model (Figure 7-5). The model underestimated DM on more than 20 occasions, with better estimates on the fertilised plot.

Figure 5. DM production simulated by RothC-BIOTA for Broadbalk.

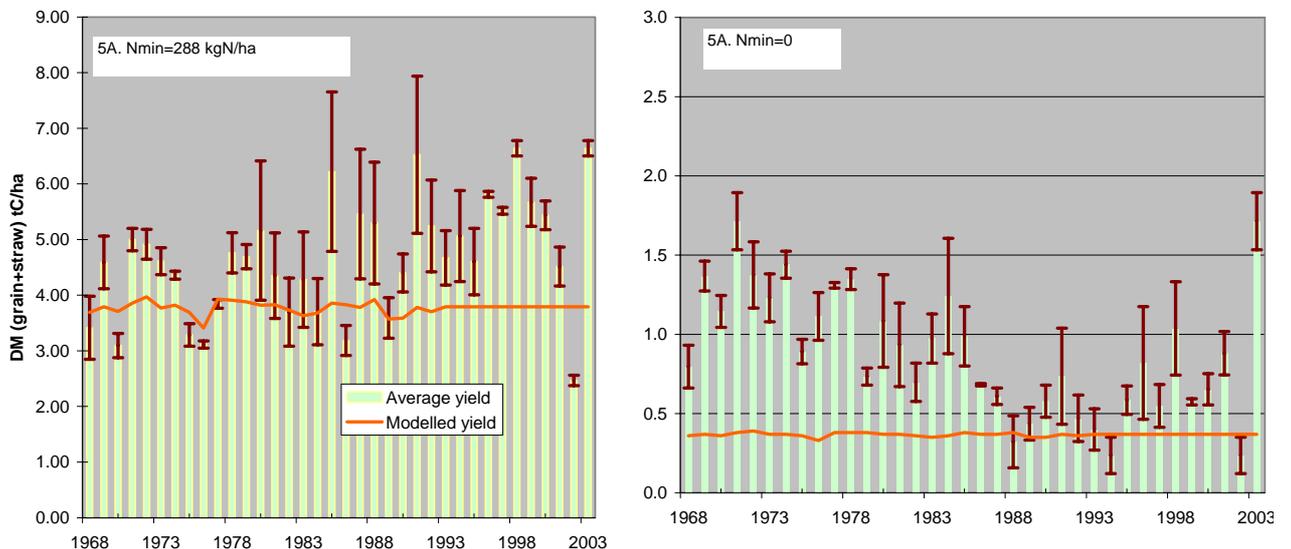


Figure 7-5 DM production simulated by RothC-BIOTA for Broadbalk

Evaluation of the % DM input to soil was estimated for plot 3 (N fertilizer inputs=0 kg N ha⁻¹) and plot 8 (N = 144 kg N ha⁻¹). The ratio of plant debris input to total DM was calculated at 0.2 for plot 8, and 0.6 for plot 3. RothC-BIOTA estimated the ratio at 0.2 for both plots. The modelled debris input is too low on unfertilised plots, which is caused by a strong limitation of N-cap method.

7.5. Conclusions

RothC-BIOTA was developed as a coupled link between RothC, the model of soil C dynamics, and BIOTA, a process-based C model extended in this project to agricultural systems. The model was parameterised for 30 different crop types and evaluated with average yield data published in literature for major 15 crop types. Detailed evaluation of SOC dynamics under three management regimes was carried out for one UK site (continuous wheat and arable crops rotations) and a German site (arable crops rotation, results not presented in detail). We have also presented model results of DM production on two contrasting replicated plots at the same UK site. The evaluation showed that the model was able to simulate accurately SOC dynamics, but some adjustments to the modelling methods were required. RothC-BIOTA was also recently developed to simulate C dynamics in ley-arable systems and forests. Further evaluation of RothC-BIOTA in other systems, particularly in ley-arable rotations, will be necessary, and an alternative approach to representing N limitation may be necessary.

7.6. References

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7.7. Appendices

A.1. An example of landuse.ini

An example of landuse.ini defined for Wind Farm site with ley-arable rotation for years 1973 – 2004. Mineral N fertiliser varied between 150 – 220 kg N/ha, except for years with grass cover (null input). There was no organic N input (normally specified in each line after mineral fertiliser).

```
[SiteName]
site=WindFarm
latitude=51.78
Natmodepo=-9999 ; use -9999 for NODATA

[SoilData]
Clay=25.0
SoilDepth=23.0
Ceq=35.0 ;arbitrary from Rothamsted
BaseYear=1972

[Equilibrium]
Weather=equi
landUse=PermGrass

[Rotations]
lines=32
; Columns below represent: Crop type, climate year, year counter, minN input, orgN
input<optional>, orgfert type<optional>, month of org input<optional>
; NOTE: real climate file will be called <site>yy.mon
1=WinOilRape 1973 1 150.0
2=WinWheat 1974 1 185.0
3=WinWheat 1975 1 185.0
4=WinWheat 1976 1 185.0
5=WinWheat 1977 1 185.0
6=AnnGrass 1978 1 0.0
7=WinOilRape 1979 1 185.0
8=WinWheat 1980 1 185.0
9=WinWheat 1981 1 185.0
10=WinWheat 1982 1 185.0
11=WinOilRape 1983 1 150.0
(...)
32=WinWheat 2004 1 220.0
```


A.2. Crop classification in RothC-BIOTA model.

Table A2. 1: Crop types and other vegetation classes in RothC-BIOTA

Crop / plant types	Reference name in RothC-BIOTA	RothC-BIOTA INDEXes
Winter wheat	WinWheat	WinCer
Winter barley	Win Barley	
Winter oats	Win Oats	
Winter rye	Win Rye	
Linseed	Linseed	
Spring wheat	SprWheat	SprCer
Spring barley	SprBarley	
Spring oats	SprOats	
Triticale	Triticale	
Winter oilseed rape	WinOilRape	WinOtCrop
Setaside	Setaside	
Spring oilseed rape	SprOilRape	SprOtCrop
Forage maize	ForMaize	
Forage rape	ForRape	
Forage rye	ForRye	
Winter beans	WinBeans	Legume
Spring beans	SprBeans	
Field peas	FieldPeas	
Vining peas	ViningPeas	
Potatoes	Potatoes	Potat
Sugar beet	SugarBeet	SugBeet
Heart cabbage	HeartCabbage	NRotVeg
Spring cabbage	SprCabbage	
Leeks	Leeks	
Cauliflowers	Cauliflowers	
Lettuce	Lettuce	
Brussels sprouts	BrusselsSprout	
Onions	Onions	RootVeg
Carrots	Carrots	
Turnips	Turnips	
Fallow land	Fallow	Fall
Annual grass	AnnGrass	AnnGrass
Permanent grass	PermGrass	PermGrass
Forest	Forest	For

A.3. RothCBIOTAv05.

A3-1. Method controlling land use change in RothCBIOTAv05.

```

!      =====
      subroutine SetNextRotation()
!      =====
      use RothCBiota
      use management
      use vegparams
      use yield
      implicit none

      character(len=255) vegName
      character(len=255) vegClass
      integer(kind=4) cropIndex

      if(Get_RunningEquilibrium()) return

      if(currentRotation .eq. privNumRotations) then
         if(privRotations(privNumRotations)%years .eq. 0) return
      end if

      if((currentRotation .eq. 0) .or. (privRotations(currentRotation)%years .eq. 0))
      then
         currentRotation=currentRotation+1
         vegName = trim( privRotations( currentRotation )%crop)
         vegClass = CropIndexToName( SubCropToCrop( SubCropNameToIndex(   privRotations(
            currentRotation )%crop ) ) )

         if(oldVegName .ne. vegName) then
            call LoadVegParams( trim(vegClass)//'.ini' )
            oldVegName=vegName
            cropIndex=CropNameToIndex(trim(vegClass))
            call SelectCrop(cropIndex)
         end if
      end if
      privRotations(currentRotation)%years=privRotations(currentRotation)%years-1
end subroutine SetNextRotation

```

A3-2. Fragment of subroutine SelectCrop that control input of crop parameters according to current crop (selected by the code above).

```

!      Copy the correct crop data to the "global" array

      if(FIT .eq. .false.) PLADD(:,1) = privPLADD(:,1,CropType)
      ICROP(:,1) = privICROP(:,1,CropType)
      if (IFYMOT .eq. 0) FYMADD(:,1) = privFYMADD(:,1,CropType)

```


A.4. Method of biomass adjustment by fertiliser.

A4-1.

```

!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!
      real*8 function ExpectedYield(vegIndex, soilNmin)
!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!
      integer(kind=4), intent(in) :: vegIndex
      real(kind=8) :: soilNmin
real(kind=8) a,b
! Initialise
      a=kpar1(vegIndex)
      b=kpar2(vegIndex)
if (soilNmin .lt. 20) soilNmin = 20.0
! Estimate current yield using Smith, Leech (1995) function
      ExpectedYield=(LOG((soilNmin + a)/ a))/ b           !called also 'y2'
end function ExpectedYield

```

A4-2.

```

!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!
      real(kind=8) function Ratio(y1,y2)
!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!
      real(kind=8), intent(in) :: y1,y2
      Ratio = y2/y1
      end function Ratio

```

The above function is used in Biotamodel as follows:

```

if ((SubCropIndex .ne. 32) .or. (SubCropIndex .ne. 33)) then
yieldRatio = Ratio( MaxYield(subCropIndex), ExpectedYield( subCropIndex, soilN ) )
end if ; this excludes grasslands

```

```

!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!
      real(kind=8) function AdjustBiomasswithRatio(biomass,ratio)
!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!
      real(kind=8), intent(in) :: biomass
      real(kind=8), intent(in) :: ratio
      real(kind=8) adjustedbiomass, factor
      factor=1.0! introduced to test sensitivity of the model
      adjustedbiomass=biomass*ratio*factor
      AdjustBiomasswithRatio=adjustedbiomass
      end function AdjustBiomasswithRatio

```

The above function is applied in Biotamodel to adjust plant pools:

```

do p=1,4
  if ((currentRotation .ne. 0) .and. (yieldRatio .lt. 1.0d0)) then
    Vegetation(p)= AdjustBiomasswithRatio(RunningPools(p), yieldRatio )
  else
    Vegetation(p)=RunningPools(p)
  end if
enddo

```


A.5. Crop parameters.

Table A5. 1: List of vegetation parameters used by RothC-BIOTA.

Parameter	Name (BIOTA model)	Value for						Units
		grass	w/ spr wheat	w/spr barley	sugar-beet	oil-seed rape	potato	
Biomass respiration at 0°C	Rmo	0.003	0.003	0.003	0.003	0.003	0.003	gC/day/gC
Specific Leaf Area index	SLA	0.02	0.02* 0.08* ¹ (0.05-0.13)	m ² /gC				
Max potential electron transport rate	ejmax	85	160	169	226	187	140	μmol/m ² /gC
partitioning of C in veg pools	falp(1)	0.6	0.81**	0.81**	0.40**	0.74**	0.95**	fraction
partitioning of C in veg pools	falp(4)	0.4	0.19**	0.19**	0.60**	0.26**	0.05**	fraction
fraction of litter entering DPM pool	fbet(1)	0.6	0.6	0.6	0.6	0.6	0.6	fraction
fraction of litter entering DPM pool	fbet(4)	0.6	0.6	0.6	0.6	0.6	0.6	fraction
vegetation residence time of leaves (years)	resdL	1.2	1.0	1.0	1.0	1.0	1.0	years
vegetation residence time of roots (years)	resdR	1.2	1.0	1.0	1.0	1.0	1.0	years
fraction of roots in soil layer 1	FracRootLayer1	1.0	0.43 ²	0.43	0.59 ³	0.72 ⁴	0.5-0.6 ⁵	fraction
fraction of roots in soil layer 2	FracRootLayer1	0.0	0.57 ²	0.57	0.41 ³	0.28 ⁴	0.4-0.5 ⁵	fraction
aerodynamic conductance	g _s	0.03	0.03 (0.02-0.05)	0.03 (0.02-0.05)	0.03 (0.02-0.05)	0.03 (0.02-0.05)	0.03 (0.02-0.05)	m/s
Luening/Lohamer model for stomatal cond vs. Humidity	a ₁	6.6	6.6	6.6	6.6	6.6	6.6	kPa
Luening/Lohamer model for stomatal cond vs. humidity	d ₀	1.0	1.0	1.0	1.0	1.0	1.0	
Thickness of soil payer 1		230	200''	200''	200''	200''	200''	mm
Thickness of soil layer 2		770	1200'''	1200'''	1000'''	1600'''	800'''	mm

* parameters obtained from WOFOST model (Boons-Prins *et al.*, 1993); in brackets measurements by Filler and Hay (2002).

*¹ average from the range suggested by Fitter and Hay (2002) in 'Environmental physiology of plants', p.47.

** proportions were estimated on the basis of measured dry weight of above and below ground components obtained from literature (all references used).

² proportion of roots was estimated from measurements of root length at different depths on 5 August (Gregory *et al.*, 1978). Top layer (0-20cm) had ~9 cm/cm³ of roots, and the rest of soil (20 – 140 cm) had ~11.7 cm/cm³ roots. This suggested that with similar root diameter for entire root system, there were 43.5% and 56.5% roots in the top layer and in the subsoil.

³ proportion of sugar beet roots in the soil layers was estimated on the basis of root density in top 50 cm measured by Brown and Biscoe (1985) for 8 soil samples (Figure 7-4, attached). Top soil layer (0-20 cm) had total root length of 3.8 cm/cm³, the remainder of the soil (20-50cm) had 2.6 cm/cm³. This represented proportions of 59.4% and 40.6% respectively.

⁴proportion of oilseed rape roots in the two soil layers (0-20 and 20 – 100cm) was estimated from the root length measured on 23 July by Barraclough (1989), table 1, attached. The roots' lengths in top and lower soil layers were: 7.46 and 2.91 km/m², which represented 72% and 28%, respectively.

⁵proportion of potato roots in two soil layers was estimated on the basis of mean root lengths of the third sample presented by Vos and Groenwold (1986) on Figure 7-5, attached. The range of roots depths for top (0-20 cm and subsoil (20-80 cm) layers in 1982 and 1983 were 2.3 – 3.6 cm/cm³ and 1.6 – 3.4 cm/cm³, respectively. This represented proportions of 60-50% and 40-50%, respectively. The top measurement for the hill location (-20cm) was excluded, so the estimated proportions represent plant for below hill location.

Table A5. 2: Simulated fresh yields for four selected arable crops and different values of selected crop parameters.

Crop parameter	Parameter ranges	Average simulated fresh yields*			
		[t/ha]			
Selected root crops		Potatoes (46 t/ha)**	sugar beet (44.8 t/ha)**	Turnips (35 t/ha)**	Carrots (51 t/ha)**
Specific Leaf Area Index (SLA) [m ² /gC]	0.04	13.4 (3-23.8)	16.1 (5.1-27.1)	22.5 (9-36)	22.1 (14.1-30)
	0.05	17.1 (3.8-30.3)	18.4 (6.1-30.7)	30 (12-48)	29.5 (19-40)
	0.06	19.3 (4.3-34.2)	19.6 (6.5-32.7)	34.7 (14-55.5)	34.2 (22.1-46.3)
	0.07	20.7 (4.7-36.8)	20.3 (6.7-33.8)	37.6 (15-60.3)	37.1 (24-50.2)
	0.08	21.7 (4.9-38.5)	20.7 (6.8-34.6)	39.5 (15.8-63.3)	38.9 (25.2-52.7)
	0.09	22.3 (5-39.7)	20.9 (6.9-35)	41 (16.5-65.5)	40.3 (26-54.6)
	0.1	22.9 (5.1-40.6)	21.1 (6.9-35.3)	41.8 (16.8-67)	41.2 (26.7-55.8)
	0.11	23.2 (5.2-41.2)	21.3 (7.1-35.5)	42.6 (17-68.3)	41.9 (27.1-56.9)
	0.12	23.5 (5.3-41.7)	21.4 (7.1-35.7)	43.2 (17.3-68.3)	42.6 (27.5-57.7)
	0.13	23.7 (42.1)	21.5 (7.1-35.9)	43.8 (17.5-70)	43 (27.7-58.3)
Maximum potential electron transport rate (Ejmax) [μmol/m ² /gC]	85	8.4 (1.8-15)	9.1 (3-15.2)	13.6 (5.5-21.7)	13.3 (8.5-18.1)
	90	8.9 (1.9-15.9)	9.6 (3.1-15.9)	14.5 (5.8-23.2)	14.2 (9.2-19.3)
	95	9.5 (2.1-16.8)	10 (3.4-16.8)	15.5 (6.3-24.7)	15.2 (9.8-20.6)
	100	10 (2.3-17.8)	10.5 (3.5-17.5)	16.3 (6.5-26.2)	16.1 (10.4-21.8)
	105	10.5 (2.4-18.6)	10.9 (3.6-18.1)	17.3 (7-27.7)	17.1 (11-23.1)
	110	11 (2.5-19.5)	11.2 (3.7-18.8)	18.1 (7.3-29)	17.8 (11.5-24.2)
	115	11.4 (2.6-20.3)	11.6 (3.8-19.4)	18.8 (7.5-30.2)	18.6 (12.1-25.2)
	120	11.8 (2.6-20.9)	11.9 (3.9-20)	19.8 (8-31.5)	19.3 (12.5-26.2)
	125	12.2 (2.7-21.7)	12.3 (4-20.5)	20.5 (8.3-32.7)	20.1 (12.9-27.3)
	130	12.5 (2.8-22.3)	12.5 (4.1-20.9)	21.1 (8.5-33.7)	20.7 (13.3-28.1)
135	12.9 (2.9-22.9)	12.9 (4.2-21.5)	21.8 (8.8-34.7)	21.3 (13.8-28.9)	

	140	13.4 (3-23.8)	13.1 (4.3-21.9)	22.5 (9-36)	22.1 (14.2-30)
	145	13.5 (3-24.1)	13.4 (4.4-22.4)	23 (9.3-36.7)	22.6 (14.6-30.6)
	150	13.8 (3.1-24.6)	13.6 (4.4-22.7)	23.6 (9.5-37.7)	23.2 (15-31.4)
	155	14.2 (3.2-25.1)	13.8 (4.4-23.1)	24.2 (9.8-38.7)	23.8 (15.4-32.3)
	160	14.4 (3.2-25.6)	14.1 (4.7-23.5)	24.7 (10-39.5)	24.3 (15.6-32.9)
	165	14.7 (3.3-26.1)	14.3 (4.7-23.9)	25.1 (10-40.2)	24.8 (16-33.5)
	170	14.9 (3.3-26.6)	14.5 (4.8-24.2)	25.6 (10.3-41)	25.2 (16.3-34.1)
	175	15.2 (3.4-27.4)	14.7 (4.9-24.4)	26.1 (10.5-41.7)	25.7 (16.7-34.7)
	180	15.4 (3.4-27.4)	14.8 (4.9-24.8)	26.6 (10.8-42.5)	26.1 (16.9-35.4)
	185	15.6 (3.5-27.8)	15 (5-25.1)	27 (10.8-43.2)	26.5 (17.1-36)
	190	15.9 (3.5-28.2)	15.1 (5-25.3)	27.5 (11-44)	27.1 (17.9-37.7)
	195	16.1 (3.6-28.6)	15.3 (5-25.6)	27.8 (11.3-44.5)	27.4 (17.7-37)
	200	16.3 (3.6-28.9)	15.4 (5.1-25.8)	28.2 (11.3-45.2)	27.8 (17.9-37.7)
	205	16.5 (3.75-29.3)	15.7 (5.2-26.1)	28.6 (11.5-45.7)	28.1 (18.1-38.1)
	210	16.7 (3.75-29.7)	15.8 (5.2-26.4)	29 (11.5-46.5)	28.5 (18.3-38.7)
	215	16.9 (3.8-30)	15.9 (5.2-26.6)	29.3 (11.8-47)	28.8 (18.5-39.1)
	220	17.1 (3.8-30.3)	15.9 (5.2-26.6)	29.7 (12-47.5)	29.1 (18.8-39.6)
	225	16.1 (3.9-30.5)	16 (5.3-26.8)	30 (12-48)	29.5 (19-40)
Partitioning of C in vegetation pools (a)	20/80	18.9 (1.4-36.4)	14.7 (3.9-25.5)	9.5 (3.8-15.2)	9.4 (6-12.7)
	30/70	18.7 (2.9-34.4)	13.7 (3.1-24.2)	17 (6.8-27.2)	16.8 (10.8-22.7)
	40/60	16.1 (3-23.8)	16.1 (5.1-27.1)	22.5 (9-36)	22.1 (14.2-30)
	50/50	13.6 (4.3-22.8)	12.3 (4.7-19.8)	23.1 (9.3-37)	22.7 (14.6-30.8)
	60/40	8.2 (4.6-11.8)	10.5 (5.1-15.9)	20.6 (8.3-33)	20.3(13.1-27.5)

* Values represent average simulated fresh yields, in brackets: fresh yields with low and high level of fertilising; ** In brackets there are average published fresh yields for the crop types.