SECTION 5

Linking Soil and Vegetation Carbon in Dynamic Models.

Linking Soil and Vegetation Carbon in Dynamic Models.

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1 Introduction.

A comparative study of two C cycle models was undertaken. Existing inventory approaches that use emission factor methods may be limited for modelling C dynamics, especially under changing environmental conditions or as a result of plant cover removal. This report uses dynamic C cycle models that better replicate the nature of decomposition processes in soil/plant systems. The dynamic C cycle models selected were BIOTA, a vegetation/soil C cycle model developed at CEH (Centre for Ecology and Hydrology), and RothC, a soil C cycle model developed at Rothamsted and widely applied in different environments. The work envisages further application of linked models to predict C dynamics under a wide selection of land use types and management practices in the UK. It is necessary to evaluate and test the sensitivity of both models for the main land use types and land use change scenarios in the UK.
In this study, comparing RothC and BIOTA, input data differences between the models were minimised and soil and vegetation parameters in BIOTA were made comparable to RothC. Both models simulated different soil C content, which this could only partly be explained by climate variables and different methods estimating soil moisture. Models were compared in three grassland fields, for which measurements were collated by IACR-Rothamsted and CEH, Edinburgh.

2 RothC versus BIOTA.

2a General description of the models.

RothC v26.3 is a functional field-scale model of organic carbon turnover in non-waterlogged topsoils that estimates total organic C, microbial biomass and radiocarbon age of soil C pools (Coleman and Jenkinson, 1996). The model considers the effect of soil type, temperature, moisture content and plant cover on C turnover in soils. RothC was originally developed on the basis of field experiments at Rothamsted, but later it was adopted for other soils and climates (Coleman and Jenkinson, 1996; Coleman et al., 1997; Jenkinson et al., 1999).
BIOTA is a process-based regional-scale C cycle model describing photosynthesis at the canopy level and defining transfers of C in the plant/soil system (Milne et al., 2001a, b). It was first parameterized for forest ecosystems by Wang and Polglase (1995) for three global biomes. A detailed description of photosynthesis process in the plant component of the model, which is controlled by daily changes in air temperature and longer-term changes in CO_2 concentration, provides input to the soil C pools. C turnover in soil is controlled by environmental variables.

2b. Similarities between the models.

In BIOTA, an entire soil part of the model has been based on RothC. Functions that describe relationships between environmental factors (i.e. soil moisture, temperature and vegetation cover) and decomposition are the same in both models. Further, in this comparative study, many soil and vegetation parameters and soil description were adjusted in BIOTA to minimize effect of input data and emphasize intrinsic differences due to structure of the models.

2c. Differences between BIOTA and RothC.

- C input to soil from vegetation. As RothC does not have the aboveground component, it uses annual input of total C from plant residue provided from other sources. In recent model applications data of C inputs from vegetation were estimated through inverse modeling (Coleman et al., 1997; Falloon and Smith, 2002). BIOTA estimates C input to soil based on NPP and a turn-over rate for above ground plant parts.
- Soil moisture deficit (SMD). In RothC SMD is a simple difference between rain and 75% of pan evapotranspiration. Accumulated SMD increases to maximum which depends on clay content (equation 1).
  $SMD_{max} = -(20.0 + 1.3(CLAY) - 0.01(CLAY)^2)$ (1)
- In BIOTA, soil moisture is modeled with implemented four-root-layer-model (FRLM; Ragab et al., 1997). SMD is estimated as a function of field capacity (FC), soil moisture, water extracted by roots and drainage from above layer. Water uptake by vegetation depends on potential transpiration rate calculated with Penman-Monteith function.
- Carbon pools. There are four active pools of organic C in RothC: DPM, RPM, HUM and BIO, and a resistant pool, IOM. The current version of BIOTA describes only the four active C pools.
- Resolution of input weather data. Input weather data were determined by the time step of the models. RothC requires monthly weather data (table 1) and has a monthly time step. BIOTA needs more detailed daily weather information for FRLM component (table 1), which simulates water dynamics at a daily resolution. This affects outputs of the models. Both RothC and BIOTA produce annual outputs of C content in different pools, but RothC can also produce an optional monthly files for each year. Daily results from the water model of BIOTA are produced for each year.
- Model outputs. They are determined by the complexity and character of the model. RothC is a simple functional model of C dynamics in soils, the outputs reflect this character. The model describes annual C pool contents and their radiocarbon ages. It also produces annual total C in soil and loss due to CO_2 emissions. In addition to pool C content, BIOTA also outputs annual net primary productivity (NPP), net ecosystem productivity (NEP) and soil respiration.
- Model simulations. RothC has two types of simulations: equilibrium runs (for 10 000 years) and short-term runs for a number of years specified by a user. Current version of BIOTA simulates C dynamics until an equilibrium state is reached. In this comparative study BIOTA was adjusted to run for a short-term period after equilibrium has been reached to produce results corresponding to RothC. It was also made compatible to RothC simulations and it can run for fixed 10 000 years, when equilibrium is reached.

Table 1. Input requirements of and types of parameters that can be varied in RothC and BIOTA.

Inputs according to models	Roth C	BIOTA
Required input data	-monthly weather data of rainfall, average air temperature and pan evapotranspiration -clay content of soil -soil cover (distribution throughout the year) -monthly C input of plant residue -FYM input -soil sampling depth -inert organic matter content	-daily weather data of rainfall, solar radiation, vapour pressure and minimum and maximum air temperature, -day length -geographical location of the site -type of vegetation cover (currently available – grass, forest)
Optional input data (models provide default values)	-DPM/RPM ratio (residue quality factor)	-soil moisture characteristics (data of field capacity, wilting point) -cation exchange capacity -soil depth (thickness of two layers),

3 Field measurements used in the comparative study.

RothC and BIOTA were compared for three sites: (1) Highfield and (2) Park Grass from Rothamsted and (3) Doo Brae, located near Bush Estate, CEH Edinburgh. Data for the first two sites were obtained from Pete Falloon and Kevin Coleman of IACR-Rothamsted, who carried out earlier simulations of RothC (Smith et al., 1997; Falloon and Smith, 2001). The climatic data for Bush Estate were obtained from CEH (R. Storeton-West). Land use and soil data were provided by U. Skiba of CEH, Edinburgh and A. Lilly of MLURI, Aberdeen. Soil moisture data were also obtained from U. Skiba, who measured gravimetric moisture content on two field plots in Doo Brae between Sept. 1995 and Aug. 1996. In addition to the supplied data, this study collected six soil samples from two soil depths (0-5cm and 5-10 cm) to estimate soil C and soil porosity at Doo Brae on 28.03.2002. The information was required to obtain characteristics of Bermeryside soil series. Carbon content was estimated at 8.6 % (2 SE = 1.1 %), bulk density was 1.03 g / cm^3 (2 SE = 16 %), and porosity 0.57 cm^3/cm^3 (2 SE = 12 %). A general description of land use types and soils of the sites used in this study is presented in table 2.

Table 2. Description of three experimental sites used for the comparative study.

Location Characteristics	Highfield	Park Grass	Doo Brae
Soil type	Silty clay loam	Silty clay loam	Bermeryside series
Land use	Unimproved grassland pre-1959, Fallow from 1960	Mown unfertilized grass	Grazed grassland (low stocking density)
Data available	Soil C content	Soil C Content	Soil C content and SMD
Period of study	Long-term data	Long-term data	Short- term study - 1995/96 and on 28/03/2002

4 Simulation results of RothC and BIOTA.

4a. Highfield.

RothC estimated soil C content at 80.1 tC/ha with 3.24 tC/ha input from litter prior to 1959, when grassland was ploughed. This lead to a dramatic decrease of 16 tC/ha measured in 1963 (figure 1). The reduction in C content simulated by RothC following land use change was smaller than measured, the difference between RothC result and the measurement was 9 t C/ha (figure 1). The reason behind such a difference might be due to a much greater loss of CO_2 than suggested by the model as a result of increased bacterial activity when there is an abundance of organic matter in soil.

BIOTA estimated a much lower soil C content at equilibrium – 53.7 t C/ha (figure 1). The lower result was caused by spatially smoothed values of CRU data (Climate Research Unit) that represent rainfall, temperature, vapour pressure and solar radiation for 0.5° x 0.5°. When Rothamsted weather data were used, BIOTA simulated a similar level of C in the period prior to 1959 event (figure 1). Dynamics of C release from soil were even less corresponding to measurements than those simulated by RothC, as BIOTA over-estimated soil C in the post-1960 period. This would suggest that the two models have different methods of estimating decomposition. C input from vegetation into soil was fractionally lower than that used by RothC (3.14 and 3.24 tC /ha, respectively). The minor difference could result in a lower total C estimate, but it does not explain the differences in C loss due to ploughing of grass. Further tests should observe the different definition of C turnover rates in both models.

Figure 1. Change in C soil due to grass ploughing at Highfield - simulations compared with measurements.

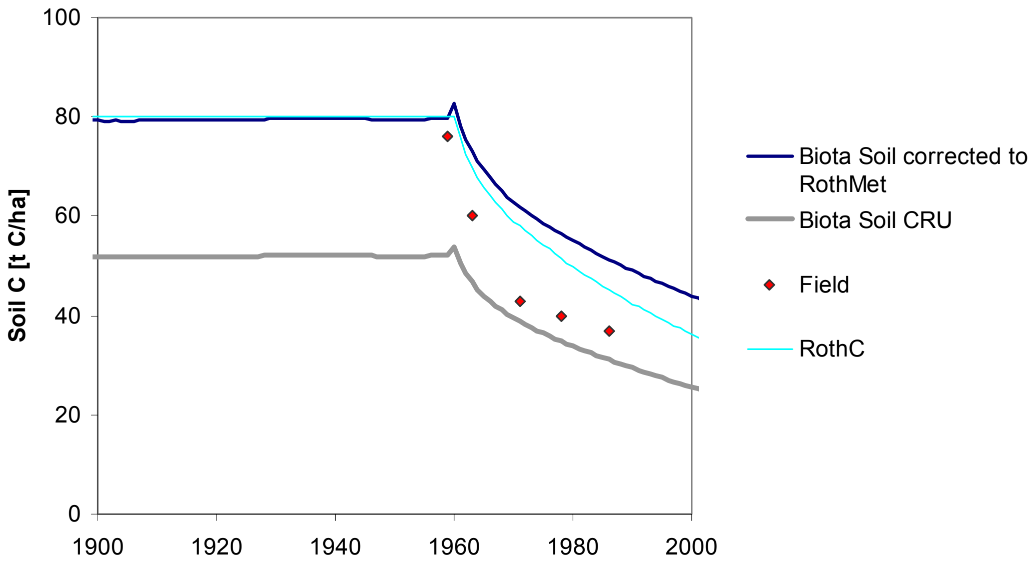
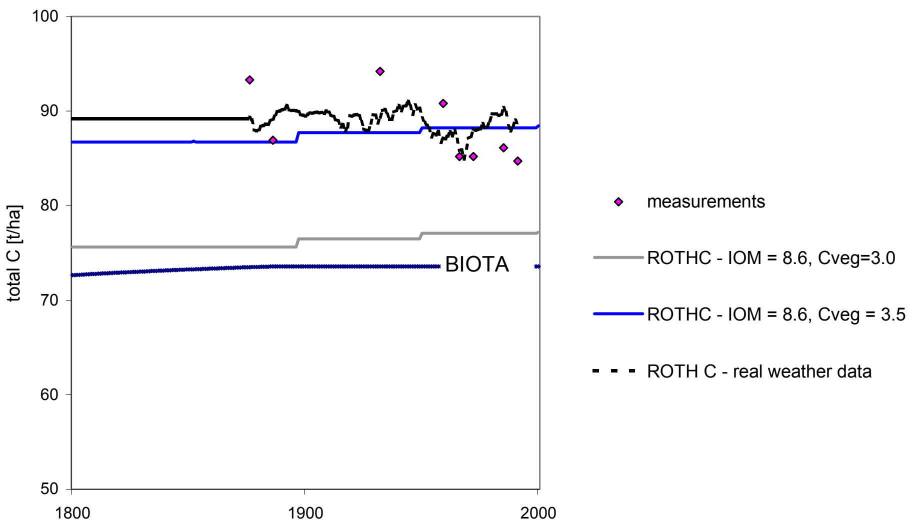


Figure 2. Park Grass with no fertiliser input.



4b. Park Grass.
On a permanent grassland plot at Rothamsted with no fertiliser input both models underestimated soil C content by approximately 10 t C/ha (figure 2). When C input from vegetation was adjusted in RothC by inverse modelling method (Coleman et al., 1997) to a higher value of 3.5 t C / yr, the predicted total C content (88 tC /ha) was in the range of measured values (84 – 93 tC /ha). The variability was not replicated as average weather data were used. Introduction of annually varied weather data improved simulated total C only in some years (1876, 1932 and 1966). The reason for RothC not replicating the measured variability could be explained by spatial heterogeneity with the plots, which was suggested by Smith et al. (1997).
BIOTA underestimated soil C considerably at 73.5 tC/ha (figure 2), which could be explained by a much lower C input from litter estimated at 3.14 tC/yr. It is expected that adjustment of C turnover rates controlling C input from vegetation in BIOTA would improve the results from that model.

4c. Doo Brae.
C content measured at 0 – 10 cm depth on the sheep-grazed grassland with Bermeryside series soil classified as loamy sand was 88 tC /ha. RothC slightly overestimated C content at equilibrium at 91 t C/ha with an assumed input to soil from grass of 3.4 tC per annum. The assumed level of vegetation input was adopted from the other sites with similar management conditions (Highfield). The difference might be either the effect of too high C input or carbon content of IOM, which was chosen arbitrary at 3.8 t C/ha.
BIOTA underestimated total soil C at 54.8 tC /ha for 0-10 cm layer. This was despite a higher input from vegetation in Doo Brae of 3.8 tC per year (comparing with RothC 3.4 tC /yr).
All three sites showed that BIOTA has a tendency to underestimate soil C at equilibrium in comparison with RothC. The differences might be caused by different decomposition rates, which are adjusted by environmental factors of soil moisture and temperature. RothC and BIOTA use different methods to estimate soil moisture. Further work involved evaluation of soil moisture estimated by the models for Doo Brae.

5 Soil moisture evaluation.
The differences between methods used by RothC and BIOTA to estimate soil moisture deficit (SMD) are presented in section 2. Both methods (RothC and BIOTA) were evaluated with field measurement results of gravimetric moisture content collected at Doo Brae (section 3).
BIOTA was run using four different scenarios of soil moisture properties (table 3).

Table 3. Scenarios used to adjust BIOTA output to field measurements.

Soil moisture characteristics (presented as volumetric fractions)	Scenario-1 (fig. 3a)	Scenario-2 (fig 3b)	Scenario-3 (fig. 3c)	Scenario-4 (fig 3d)
Wilting point	0.37	0.361	0.350	0.50
Field capacity	0.2	0.146	0.20	0.29

Scenario-1 represents the default values used by BIOTA. Low values of wilting point (WP) and field capacity (FC) used for Doo Brae by the model caused considerable underestimate of soil moisture (figure 3a). Soil texture properties were used to estimate FC and WP with Hall et al. (1977) equations that predict soil moisture properties as functions of clay and silt content and the values of soil porosity and bulk density. Considerable underestimate of this scenario-3 (figure 3b) suggests that the data of soil texture might have been inaccurate (as obtained from the neighbouring field). Another reason might be inappropriate application of Hall's equations to this Scottish soil (Allan Lilly of MLURI, pers. com.) as Hall established the relationships for a selection of English soils. An increase in the original FC improved simulated moisture during winter 1995/96 (Scenario-3, figure 3c). Finally, both FC and WP were adjusted to obtain the best fit of BIOTA to the measured moisture (table 3). This resulted in close similarity of simulated and measured soil moisture in late autumn 1995 and late summer 1996 (figure 3d). The differences observed in winter are a result of saturated conditions, which are not simulated by BIOTA. A higher measured moisture during spring and early summer is probably caused by too high evapotranspiration simulated.

RothC calculated an overall higher soil moisture deficit than BIOTA, particularly in summer (figure 4). This caused lower soil moisture than measured, which is expected to slow down decomposition of organic C and might underestimate C losses to the atmosphere. This corresponds with the observation made by Falloon and Smith (in press) in their comparison of RothC with CENTURY, and the findings of this study at Highfield after land use change (section 4a). This also might partly explain a higher C soil content simulated by RothC for Doo Brae than measured in 2002.

Evaluation study of soil moisture and soil C at Doo Brae indicated that models are particularly sensitive to soil moisture and turnover rates of vegetation pools. Water component of BIOTA is more accurate in simulating soil moisture dynamics, but slower rate of decomposition of RothC represented better highly organic Scottish soil. Further tests are necessary to define an optimal approach for modelling C dynamics.

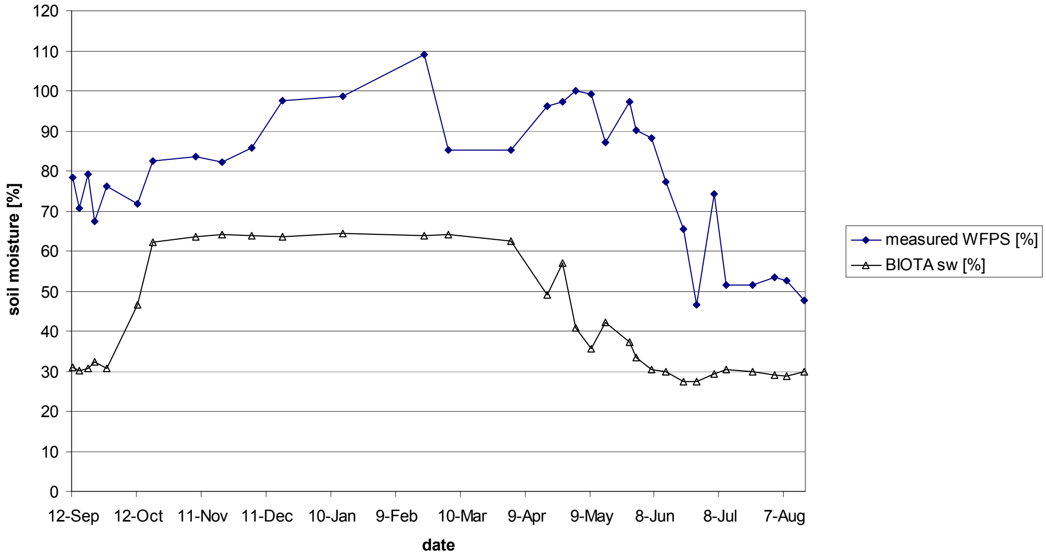
6 Conclusions and further work.

This comparative study of RothC and BIOTA performance on a selection of grassland sites in England and Scotland outlined differences between the models. Overall RothC simulated higher soil C content on both Highfield and in Doo Brae. On the former, the difference was explained by differences between input climate data. On Doo Brae, however, lower soil C content predicted by BIOTA was a result of a higher soil moisture that lead to faster decomposition and C loss. The study showed that the different approaches to simulating soil moisture had an important effect on results of both models. Lower soil moisture simulated by RothC might explain some earlier found slower C turnover (Falloon and Smith, 2002) and observed here higher total C content in moist Scottish soils. More explanation is needed for the slow decomposition of C following ploughing of grass on Highfield, where BIOTA showed even higher over-estimate of soil C.

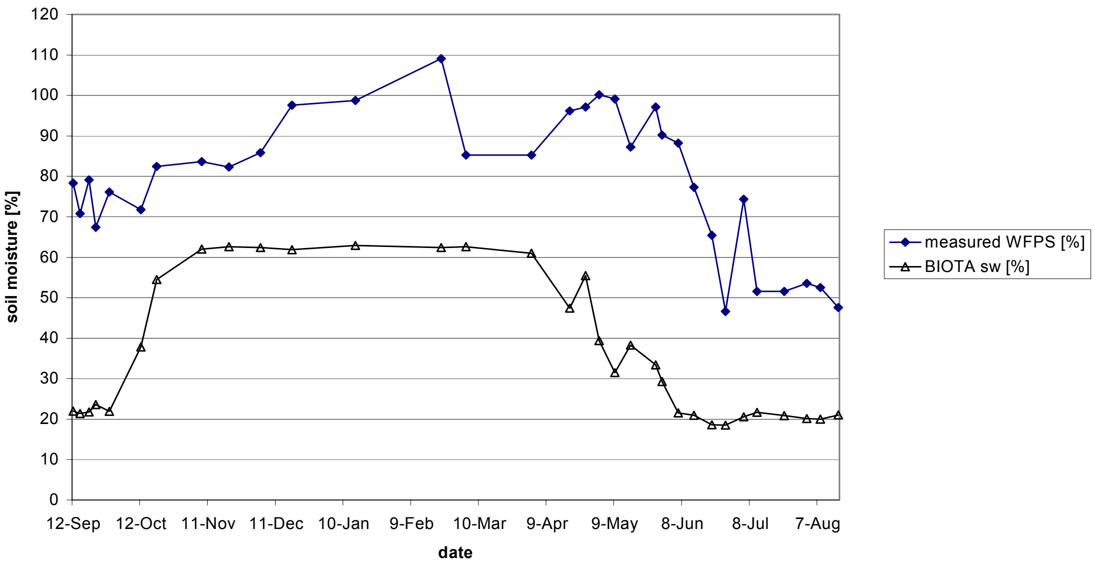
Further work should concentrate on defining new soil and vegetation parameters for both models for other land use types and locations. This will involve further collation of field measurement data from literature. Additionally, this study showed that a detailed comparison of methods used by the models to define decomposition of C is needed. This will be based on the field data presented here, and the new collated measurements.

Figure 3. Results of adjustments of soil moisture parameters for BIOTA.

(a)



(b)



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