Modelling organic matter turnover in New Zealand soils

Aroon Parshotam, Surinder Saggar, Kevin Tate and Roger Parfitt

Landcare Research, Massey University campus, Palmerston North, New Zealand

Abstract To ensure the sustainability of land systems in terms of nutrient cycling and maintenance of soil physical conditions, there is a need to understand soil organic matter and its dynamics. It has been suggested that soil carbon (C) models developed internationally do not perform well under New Zealand's unique climatic and soil mineralogical conditions. To test this hypothesis, we conducted New Zealand plant litter decompostion studies and assessed the influence of abiotic factors on decomposition rates. These factors were characterised by estimating system mean residence times (MRTs) from estimates of first-order rate coefficients in a simple, three-compartment model. A range of residence times, obtained for decomposition were related to New Zealand climatic conditions and soil properties. We summarise this work and extend this study to apply the Rothamsted soil-C turnover model to our data. We aim to demonstrate that relationships of MRTs with climate and soil properties unique to New Zealand can be useful as rate-reduction factors in soil organic matter models parameterised from long term data sets.

1. INTRODUCTION

With the formulation and development of mathematical models that simulate changes in SOM, there have been considerable advances in understanding soil organic matter (SOM) dynamics. These models require climatic parameters and soil process information. Although much information is available on the independent effects of climatic and soil factors on SOM turnover from controlled studies, little is known about the quantitative aspects of the combined effects under field conditions. Inadequate data on carbon turnover rates, for a wide range of climates, soil types and mineralogies, as found in New Zealand, presently limit the use of such models (Saggar et al. [1996]).

In many SOM turnover models, the SOM "system" is divided into a number of conceptual compartments or "pools". The transfer of material from one compartment to another is usually assumed to obey first-order kinetics. A range of methods has been used to incorporate abiotic functions in SOM models to adjust the decomposition rate of SOM at standard conditions to the actual conditions of soil temperature, water content and texture. There are often insufficient data available, and the great variation in individual rate-coefficient estimates makes it impossible to relate these parameters to soil characteristics and climatic conditions. Most models that describe SOM in terms of transfers from one pool to another, therefore, include the combined effects of climate and soil properties as a single, overall, rate-process control (Jenkinson et al. [1987], Parton et al. [1987]). The derivation and validation of these rate-reduction or rate-modifying factors in many SOM models is neglected in the literature but has significant impact on the performance of SOM models (see Rodrigo et al. [1997]).

The wide range of climates, soil types and mineralogies makes New Zealand an ideal location in which to study the effects of climate and soil properties on decomposition. In our recent work (Saggar et al. [1996], Parshotam et al. [in press]), we reported on ryegrass (*Lolium hybridum* Hausskn) decomposition studies in New Zealand soils of contrasting clay content, mineralogy and climatic conditions. An easily measurable soil index, the mean residence time (MRT), was derived from microbial biomass-^{14}C and residual-^{14}C data, by assuming a three-compartment model of SOM. This time constant was useful for estimating the average life of ^{14}C within a soil pool and the soil system, and explained the differences in the rates of ^{14}C-labelled ryegrass decomposition and its stabilization due to clay surface area (Saggar et al. [1996]) and climatic effects such as temperature, annual rainfall and rainfall days (Parshotam, [in press]). Our studies have provided a range of ^{14}C residence times for the decomposition of ryegrass under field conditions in New Zealand, and relationships were derived with soil properties and climatic conditions. These relationships can be used either as "average" system rate reduction factors in soil C turnover models or to validate rate-reduction factors in existing SOM models. It is our aim to relate these MRTs to rate reduction factors in models developed from long-term data sets in other parts of the world.

The objective of this study was to i) summarise our work on ^{14}C residence times of ^{14}C-labelled ryegrass at New Zealand sites of contrasting rainfall, temperature and soils, and ii) apply the Rothamsted soil-C turnover model to our data with the aim of relating system MRTs to rate modifying factors in the model.

2. SITE DESCRIPTION

2.1 Experimental sites

The six experimental sites used in this study (Figure 1) were selected to represent major climatic regions of New Zealand; and were located at research stations with meteorological enclosures.

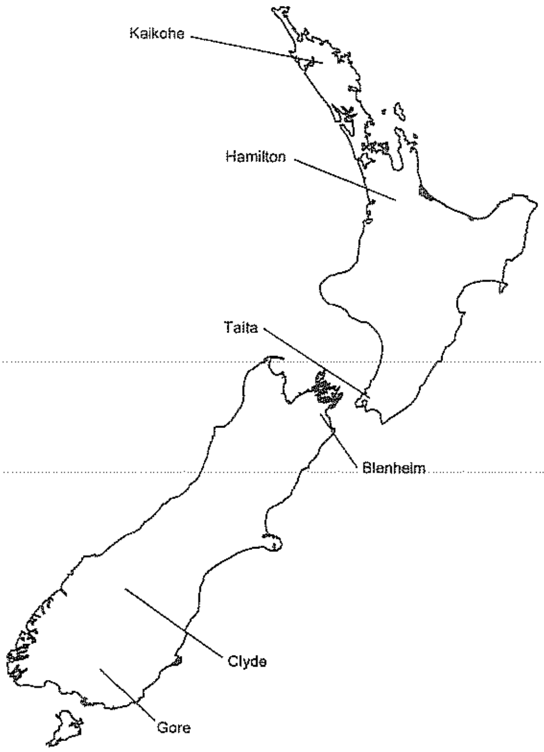


Figure 1: Map of New Zealand showing the location of experimental sites.

2.2 Climatic descriptions of sites

Climatic data are from sites that represent major climatic regions of New Zealand. Kaikohe represents a climatic zone with warm humid summers and mild winters. Hamilton represents climatic conditions similar to those of Kaikohe but with somewhat lower values of mean annual rainfall and temperature. Taita represents a region with evenly distributed rainfall with warm summers and mild winters. Blenheim represents a climatic zone with very warm summers and day temperatures that occasionally exceed 32°C, with dry foehn winds, a marked decrease in the amount and reliability of rain in spring and summer, and moderate winter temperatures. Clyde represents a semi-arid climatic zone, with very warm dry summers and cool winters. Gore represents a climatic zone with mild summers and cool winters.

2.3 Collection of meteorological data

Climatic data was gathered during the period of the experiment. At sites where meteorological data collection was discontinued or where there were incomplete data over the study period, data from adjoining meteorological stations were included.

2.4 Contrasting soils

The four contrasting soils were: Halcombe silt loam; Horotiu silt loam; Hauraki clay; and Naike clay from the central North Island, New Zealand. These soils were selected to provide, respectively, the following four clay contents and types: (i) low clay content and vermiculitic; (ii) low clay content and amorphic; (iii) high clay content and kandic, and (iv) high clay content and smectitic. Clay percentages were: 24% for Halcombe silt loam, 16% for Horotiu silt loam, 56% for Naike clay and 60% for Hauraki clay. The decomposition study with the four contrasting soils was conducted under the same climatic conditions at Taita.

2.5 Soil samples

The method of collecting soil samples is given by Saggar et al. [1996].

2.6 Decomposition in the field

The method of amending soil samples with uniformly labelled ryegrass and destructively sampling these is given by Saggar et al. [1996]. The experimental period used to determine the climatic and soil property effects were 2 and 5 years, respectively.

3. CONCEPTUAL MODEL

The kinetic model used to derive mean residence times (MRT) has been described by Saggar et al. [1996], and is summarized here. Briefly, the system was divided into three homogeneous compartments or ‘pools’ (see details in Figure 2) and formulated by assuming first-order kinetics. The system was assumed to be at steady state with no change in total C.

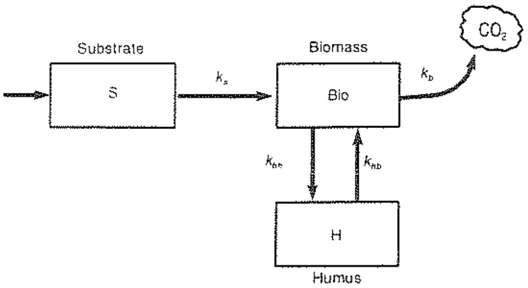


Figure 2: Schematic representation of the three-compartment model used to model ^{14}C in the soil, microbial biomass and humus. The parameters k_s, k_b, k_{bh} and k_{hb} represent the first-order rate-transfer coefficients.

The model equations may be expressed in the matrix form

$$\frac{d}{dt}\begin{pmatrix} S \\ BIO \\ H \end{pmatrix} = \begin{pmatrix} -k_s & 0 & 0 \\ k_s & -(k_{bh}+k_b) & k_{hb} \\ 0 & k_{bh} & -k_{hb} \end{pmatrix}\begin{pmatrix} S \\ BIO \\ H \end{pmatrix} \quad (1)$$

with initial conditions $S(0)=S_0$, $BIO(0)=0$ and $H(0)=0$. Here, S represents the amount of ^{14}C-labelled ryegrass substrate carbon added to each soil, BIO denotes ^{14}C-biomass, and H, denotes humus-^{14}C (Figure 2).

3.1 Parameter Estimation

Two algorithms were used to estimate the parameters k_s, k_{bh}, k_b and k_{hb} (Figure 2) from the analytical solution. These were the methods of Bates et al. [1986] and Jenrich and Bright [1976]. Initial estimates of these parameter values were obtained by exponential peeling and by nonlinear regression from the above analytical solution. The results of these algorithms were consistent with each other.

3.2 Mean Residence times

The mean residence times (MRT) of ^{14}C in individual compartments of the system were obtained from the rate coefficient estimates. The system MRT is the sum of individual compartment MRTs and is given by

$$MRT = \frac{1}{k_s} + \frac{1}{k_b}\left(1 + \frac{k_{bh}}{k_{hb}}\right) \quad (2)$$

4. ROTHAMSTED SOIL-C TURNOVER MODEL

To date, the Century model (Parton et al. [1987]) and the Rothamsted C turnover model (Jenkinson et al. [1987]) have undergone the most field testing and validation. Good correlation between observed data and simulated results is reported. These models and other soil-carbon turnover models are increasingly used in climate-change and land-use studies in New Zealand (Parshotam et al. [1995]). The Rothamsted soil-C turnover model is a five-compartment model where first-order rate coefficients are modified by functions of clay %, moisture content and temperature. Details of the model are given by Parshotam (1995). The model uses climatic data (temperature, evapotranspiration and rainfall) and clay percent. As with similar studies (Jenkinson et al. [1992]), the DPM:RPM ratio of 1.44 was assumed for improved grassland.

5. RESULTS

5.1 Climate data

Annual rainfall, annual number of rainfall days and temperature data obtained during the sampling period (Table 1) were consistent with data obtained from the sites from long term averages.

Site	*Temp °C*	*Annual rainfall (mm)*	*Annual rainfall days (>1 mm)*
Kaikohe	15.1, 14.7	1335, 1600	148, 145
Hamilton	13.2, 13.3	1119, 1200	128, 131
Taita	12.5, 12.6	1372, 1400	151, 132
Blenheim	12.3, 12.9	819, 1000	76, 80
Clyde	10.3, 10.6	332, 340	69, 65
Gore	9.5, 9.7	1078, 920	158, 158

TABLE 1. Annual averages for temperature, rainfall and rainfall days over the 2-year period of the experiment, and long-term averages.

5.2 Model parameter estimation

An estimate of the model parameters from the analytical solutions of the model equations is given in Table 2.

Site	k_s	k_{bh}	k_{hb}	k_b
Kaikohe	15.79	8.63	0.36	12.85
Hamilton	26.33	8.53	0.47	13.98
Taita	9.70	9.44	0.64	12.63
Blenheim	16.40	8.95	0.54	16.77
Clyde	8.24	9.32	0.27	14.81
Gore	12.01	8.98	0.39	16.60
Halcombe	4.61	3.59	0.19	12.81

Horotiu	4.80	5.59	0.20	8.37
Hauraki	2.40	4.89	0.20	7.38
Naike	5.94	3.72	0.22	7.66

TABLE 2. Model first-order rate coefficients, k (y^{-1}) in Figure 2. k_s, k_{bh}, k_{hb} and k_b are the rate-transfer coefficients for substrate, biomass-humus, humus-biomass and biomass respectively.

5.3 Mean Residence Times (MRT)

The mean residence times (MRT) are given in Table 3.

Soil	*S*	*BIO*	*H*	*System*
Kaikohe	0.06	0.08	1.86	2.00
Hamilton	0.06	0.07	1.30	1.43
Taita	0.10	0.08	1.16	1.34
Blenheim	0.06	0.06	0.98	1.10
Clyde	0.12	0.07	2.36	2.55
Gore	0.08	0.06	1.40	1.54
Halcombe	0.22	0.08	1.47	1.77
Horotiu	0.21	0.12	3.32	3.65
Hauraki	0.42	0.14	3.36	3.91
Naike	0.17	0.13	2.20	2.50

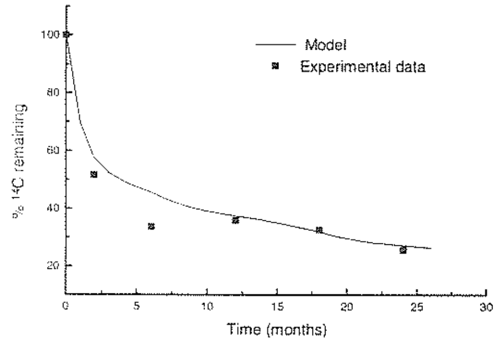
TABLE 3. Mean residence times (MRT) of system and compartments (in years).

6. ROTHAMSTED SOIL-C TURNOVER MODEL APPLICATION

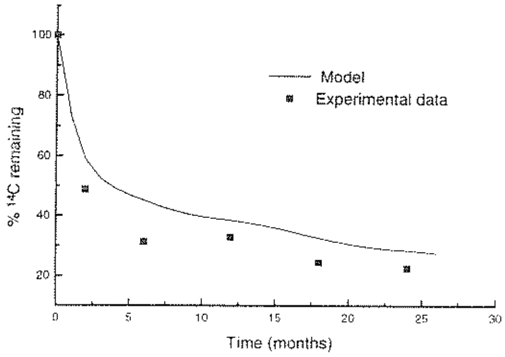
The Rothamsted soil-C turnover model was assessed by application of the model to our data from contrasting climatic and soil conditions.

6.1 Application of the model to data from contrasting climatic conditions.

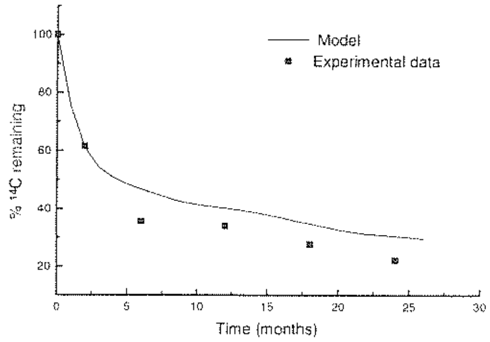
i) Kaikohe



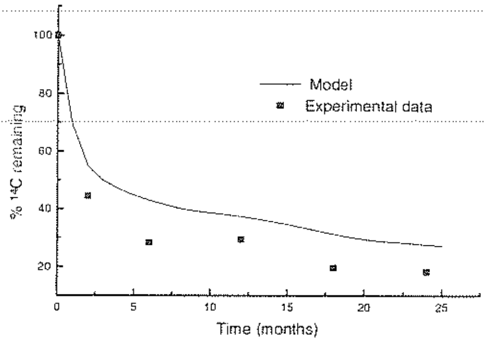
ii) Ruakura



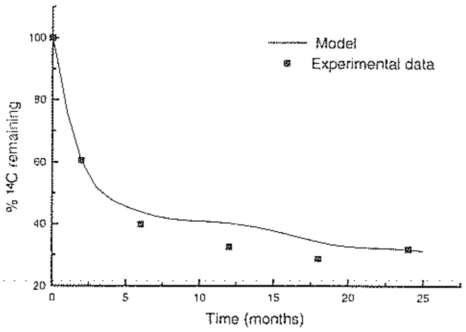
iii) Taita



iv) Blenheim



v) Clyde



vi) Gore

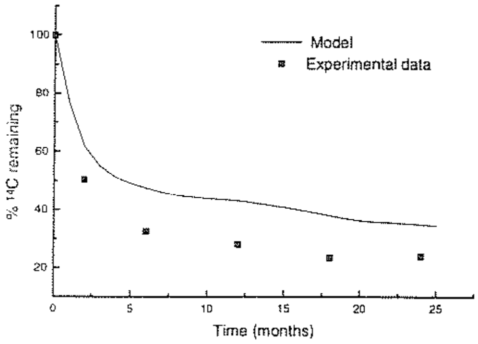
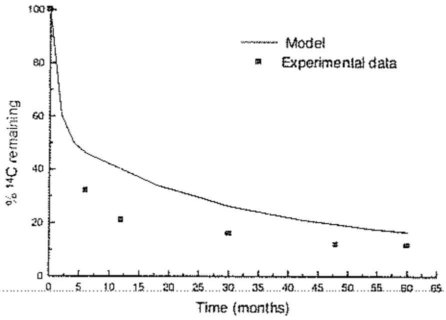


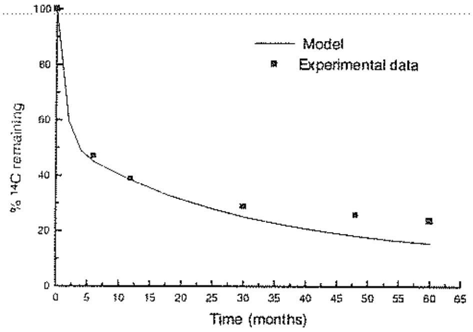
Figure 3: Comparison of observed, and modelled data for 6 sites of contrasting environmental conditions

6.2 Application of the model to data from contrasting soils.

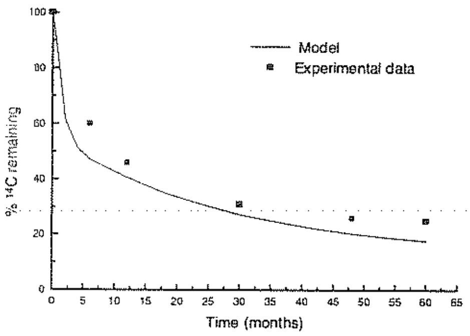
i) Halcombe silt loam



ii) Horotiu silt loam



iii) Hauraki clay



iv) Naike clay

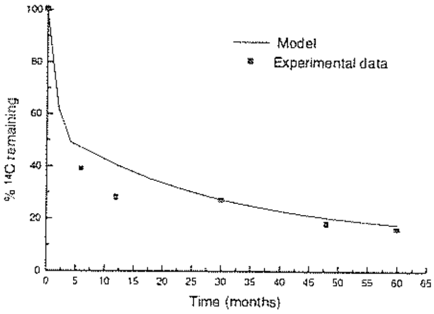


Figure 4: Comparison of observed, and modelled data for the 4 sites with contrasting soils

7. DISCUSSION

Many climatic and soil factors affect decomposition and organic matter stabilization. Although controlled experiments indicate the important factors to be included in SOM models, the combined effect of the factors from these studies may yield poor predictive properties. It is impossible to determine the effects of individual factors on decomposition as some factors may interact or even cancel the effects others. Our study involving MRTs quantifies the overall effects of abiotic factors on decomposition under field conditions, including their interactions.

Microbial biomass and system MRTs was higher for the soils of high clay content and surface area (Horotui, Hauraki and Naike) indicating the influence of clay content and surface area on turnover. Limiting moisture conditions at Clyde slowed decompostion rates resulting in a high system MRT.

Rate modifying factors in the literature are often derived from exponential decay rate constants by assuming a single-compartment model of SOM. We believe that a system MRT derived from a three-compartment model may better represent factors controlling decomposition.

The Rothamsted soil-carbon turnover model adequately describes the broad trend of changes in residual ^{14}C with decomposition over time. The model predicts our data within 15% in all cases. However, the model overestimated residual ^{14}C in the majority of the soils under contrasting climatic conditions because it did not adequately simulate changes during the early stages of decomposition. Decomposition rates are faster under New Zealand conditions compared with conditions under which the model was developed. As New Zealand soils maintain sufficient moisture throughour the year, they are likely to enhance the decomposition rates. The extent to which these differences in turnover rate influence prediction cannot be measured without knowing the turnover rates in the model. Studies addressing this issue will be the focus of future research.

When the model was applied to contrasting soils incubated under similar climatic conditions, the model adequately described changes in residual ^{14}C over time in all soils except Halcombe, a soil with least clay content and surface area.

8. CONCLUSION

Many climatic and soil factors affect decomposition and organic matter stabilization. It is impossible to determine the effects of individual factors on decomposition as some factors may interact or even cancel the effects of others. The overall effects of abiotic factors on decomposition under field conditions, including their interactions may be quantified and related to individual abiotic effects by defining a mean residence time of ^{14}C in the system. Although these MRTs can be useful as rate modifying factors in SOM models we face a difficulty when comparing these with rate modifying factors in existing models. The same abiotic factors governing decomposition in both cases need to be considered.

The Rothamsted soil-C turnover model adequately simulates data from all sites. However the model overestimated residual ^{14}C in the majority of the soils studied.

Future work will involve i) relating MRTs derived in our study with rate modifying factors in the Rothamsted soil-C turnover model, ii) a closer examination of the abiotic factors affecting decomposition at Rothamsted with those affecting decomposition in New Zealand, and iii) comparing MRTs with rate modifying factors in existing SOM models using methods given by Rodrigo et al. [1997].

9. REFERENCES

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