Short communication

Soil carbon model Yasso07 graphical user interface☆

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ARTICLE INFO

ABSTRACT

In this article, we present a graphical user interface software for the litter decomposition and soil carbon model Yasso07 and an overview of the principles and formulae it is based on. The software can be used to test the model and use it in simple applications. Yasso07 is applicable to upland soils of different ecosystems worldwide, because it has been developed using data covering the global climate conditions and representing various ecosystem types. As input information, Yasso07 requires data on litter input to soil, climate conditions, and land-use change if any. The model predictions are given as probability densities representing the uncertainties in the parameter values of the model and those in the input data — the user interface calculates these densities using a built-in Monte Carlo simulation.

Software availability

Software name: Yasso07 User Interface (Yasso07-UI)
Developer: J. Liski, Finnish Environment Institute
Software engineer: J. Rasinmäki, Simosol Oy
First available: 2009
Hardware requirements: None
System requirements: Windows, Linux, or OS-X
Software requirements: Python 2.5 on OS-X
Availability: www.environment.fi/syke/yasso
Source code: code.google.com/p/yasso07ui
Programming languages: Fortran 90 (Yasso07), Python (Yasso07-UI)
Software package size: 39 Mb (Windows), 34 Mb (Linux/OS-X)

1. Introduction

The decomposition of organic matter (OM) is, in addition to photosynthesis, the other important process that regulates the terrestrial carbon cycle. Decomposition controls carbon dioxide (CO_2) emissions from soils into the atmosphere and affects the carbon stocks in the soils. Estimates of these emissions and the stock are therefore needed in order to estimate the terrestrial carbon budget. Recently, concern about climate change has increased interest in terrestrial carbon cycle. Terrestrial ecosystems act as remarkable sinks and sources of atmospheric CO_2 and, consequently, have a significant effect on climate (IPCC et al., 2007).

The carbon cycle of soils has been modelled using a variety of approaches and techniques, and different soil carbon models exist; e.g. Century (Parton et al., 1987, 1992), CoupModel (Jansson and Karlberg, 2004), Q-model (Rolff and Ågren, 1999), ROMUL (Chertov et al., 2001), RothC (Coleman and Jenkinson, 2005), DECOMP (Wallman et al., 2006), and Yasso07 (Liski et al., 2005; Tuomi et al., 2009, 2011a). Due to the high spatial variability of soil cabon stocks (e.g. (Post et al., 1982) and high uncertainty in their changes (e.g. (Post et al., 2001), and because measuring these variables directly is difficult, laborous, and expensive, soil carbon models are commonly used to estimate these stocks and their changes (e.g. Peltoniemi et al., 2006, 2007; Mäkipää et al., 2008).

Some of the aforementioned models describe soil carbon cycle at a rather detailed level. For this reason, they also require detailed input information. Such information is not always available, which makes it difficult to apply these models in large geographical scales or at national level. However, the Yasso07 model requires only little easily accessible input information to operate (Tuomi et al., 2009, 2011a).

Software are already available to operate the CENTURY (Parton et al., 1987, 1992) and RothC (Coleman and Jenkinson, 2005) soil carbon models but the growing number of practical applications has increased the demand of easily accessible soil carbon models (). Acknowledging this demand, we constructed a graphical user interface software for the Yasso07 model. This software, hereafter Yasso07-UI, can be used to operate the model and study its performance in estimating the litter decomposition and soil carbon cycle prior to possibly implementing the model into other simulation softwares. Yasso07-UI is also suitable for various practical applications, such as greenhouse gas inventories (Finland's Fifth National Communication under the United Nations Framework Convention on Climate Change, 2009) and estimation of the effects the removal of forest harvest residues has on carbon balances of boreal forests (Repo et al., 2011).

Estimating the modelling uncertainties as reliably as possible has been a topic in several recent studies (e.g. Post et al., 2008; Updegraff et al., 2010; O'Hagan, 2011). We acknowledge the importance of accounting for all the sources of uncertainty. In this work these sources are (1) the uncertainties of the model parameters; (2) the uncertainties in the values of the input variables, such as the amount of OM initially in the soil and the litter input to the soil; and (3) the uncertainties in the chemical quality of the litter input. Our software takes all these sources of uncertainty into account by using a built-in Monte Carlo simulation.

2. Model structure

Yasso07 model describes litter decomposition and soil carbon cycle based on the chemical quality of the OM and climatic conditions (Tuomi et al., 2009). Decomposition of woody litter depends additionally on the physical size of the litter (Tuomi et al., 2011a). The model works by dividing fresh OM, e.g. leaf, fine root, and woody litter, into four chemically distinguishable fractions that decompose at their unique rates. These fractions are water solubles (W), ethanol solubles (E), acid hydrolysables (A), and compounds neither soluble nor hydrolysable (N). In addition, there is a humus (H) fraction, assumed to consist of more recalcitrant compounds, that receives a part of the decomposition products of the A, W, E, and N fractions. Carbon flows between the different fractions are shown in Fig. 1 (for detailed mathematical formulae describing the Yasso07 model structure, see also (Tuomi et al., 2009).

With one exception, Yasso07-UI is based on the same structure as was used in (Tuomi et al., 2009, 2011a). Since there were systematical differences in the mass loss rates between the European and American litter bag measurements used to determine the parameter values of the model earlier (Palosuo et al., 2005; Tuomi et al., 2009), we modelled these differences in a more consistent manner by assuming that a fraction of the OM in the litter bags is transferred out of the bags with varying rates. This process called leaching, can be driven by water flowing through the litter bags. Since the mesh size was different between the European and American litter bags (1.0 mm and 55 μm, respectively), it is natural that the leaching rates can also be different. The different mesh sizes have an effect also by filtering faunal decomposers in different manners. We modelled the different leaching rates as additional free parameters and replaced the original model (Eq. (1) of (Tuomi et al., 2009)) by

$$\dot{\mathbf{x}}(t) = \mathbf{A}\mathbf{x}(t) + \mathbf{b} - \omega_i \mathbf{I} P_a, \mathbf{x}(0) = \mathbf{x}_0, \qquad (1)$$

where **x** is a vector describing the amount of organic carbon in each modelled compartment, **b** is the input vector to the system, **A** is a decomposition matrix, $\omega_i, i = 1, 2$ are free parameters describing the precipitation induced leaching rates in European (ω_1) and American (ω_2) litter bags, $\mathbf{I} = (1,1,1,1,1)^T$ is a constant column vector,
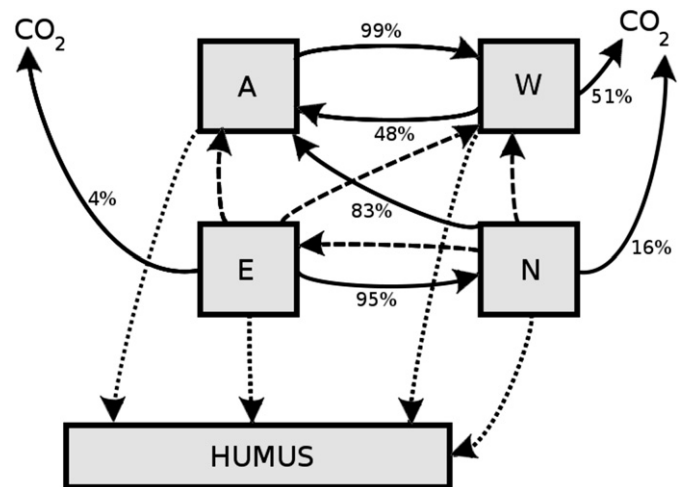

Fig. 1. Flow diagram of the Yasso07 model and the relative magnitudes of each mass flow between labile compund groups of organic carbon and more calcitrant humus; acid hydrolysables (A), water solubles (W), ethanol solubles (E), and compounds neither soluble nor hydrolysable (N). The carbon flows whose magnitudes differ statistically (95% confidence) from zero (solid arrows) between and out of the A, W, E, and N fractions (square boxes); the small flows (dotted arrows) into humus (bottom box), each approximately 0.5%; and the mass flows (dashed arrows) whose MAP estimates were indistinguishable from zero but whose 95% Bayesian confidence interval was broader than 0.05. See Table 1 for details.

and P_a is the annual precipitation. We selected this model formulation because this effect was not present exclusively in the water soluble compartment W. We tested a model with $\mathbf{I} = (0,1,0,0,0)^T$, where the unity corresponds to the compartment containing the water soluble compounds, but this model was found to have much lower posterior probability and it could not fully account for the differences between the European and American litter bags.

The far greater mesh size of the European litter bags likely enables greater leaching rate. This difference may also have an effect on the faunal accessibility to the litter inside the bags, which could increase the mass loss rate in litter bags with greater mesh size slightly (Bradford et al., 2002; Irmler, 2000). However, this effect could not be quantified from the available data. Therefore, we simply analysed the data and estimated the parameter probability density functions (PDF's) using Eq. (1) but calculate the model predictions in the Yasso07-UI using the original equation because the OM may be leached out of the litter bags but not out of the whole soil system. The parameters $\omega_i, i = 1, 2$ can in fact be considered as only nuisance parameters that help understanding the process of making the measurements but not the process of decomposition. This improvement had minor effects on the model parameter values − see Table 1 and Tuomi et al. (2009).

The extension of the model into the woody litter regime is that introduced in (Tuomi et al., 2011a). Its three parameters describing the effect the physical size of pieces of woody litter have on the decomposition, namely, ϕ_1, ϕ_2, and r, are also shown in Table 1.

3. The coverage of measurements and model predictions

The data used to construct the Yasso07 model consisted of several individual datasets describing the mass loss rate of leaf, fine root, and woody litter in a variety of climatic conditions (Tuomi et al., 2009, 2011a). The time and climate coverage of measurements is the range of reliable applicability of the Yasso07 model and the Yasso07-UI introduced here. Despite the fact that the model could be applicable beyond this coverage, the reliability of such applications cannot be known. Therefore, we describe this range briefly.

Table 1
MAP parameter values of Yasso07 and their 95% confidence limits.

Parameter	Value	Unit	Interpretation
α_A	0.72 ± 0.09	a^{-1}	decomposition rate of A
α_W	5.9 ± 0.8	a^{-1}	decomposition rate of W
α_E	$0.28^{+0.07}_{-0.04}$	a^{-1}	decomposition rate of E
α_N	$0.031^{+0.011}_{-0.004}$	a^{-1}	decomposition rate of N
p_1	0.48 ± 0.06	–	relative mass flow, W → A
p_2	$0.01^{+0.15}_{-0.01}$	–	relative mass flow, E → A
p_3	$0.83^{+0.16}_{-0.23}$	–	relative mass flow, N → A
p_4	$0.99^{+0.01}_{-0.05}$	–	relative mass flow, A → W
p_5	$0.00^{+0.08}_{-0.00}$	–	relative mass flow, E → W
p_6	$0.01^{+0.20}_{-0.01}$	–	relative mass flow, N → W
p_7	$0.00^{+0.01}_{-0.00}$	–	relative mass flow, A → E
p_8	$0.00^{+0.01}_{-0.00}$	–	relative mass flow, W → E
p_9	$0.02^{+0.23}_{-0.02}$	–	relative mass flow, N → E
p_{10}	$0.00^{+0.01}_{-0.00}$	–	relative mass flow, A → N
p_{11}	0.015 ± 0.015	–	relative mass flow, W → N
p_{12}	$0.95^{+0.05}_{-0.16}$	–	relative mass flow, E → N
ω_1	-0.151 ± 0.008	$a^{-1}m^{-1}$	precipitation induced leaching (Europe)
ω_2	$0.000^{+0.0}_{-0.002}$	$a^{-1}m^{-1}$	precipitation induced leaching (Americas)
β_1	9.5 ± 2.0	$10^{-2}\,°C^{-1}$	temperature dependence
β_2	$-1.4^{+0.6}_{-0.9}$	$10^{-3}\,°C^{-2}$	temperature dependence
γ	-1.21 ± 0.14	m^{-1}	precipitation dependence
p_H	4.5 ± 0.8	10^{-3}	mass flow to humus
α_H	$1.6^{+0.3}_{-0.2}$	$10^{-3}\,a^{-1}$	humus decomposition rate
ϕ_1	-1.71 ± 0.16	cm^{-1}	first order size dependence
ϕ_2	0.86 ± 0.10	cm^{-2}	second order size dependence
r	0.306 ± 0.013	–	size dependence power

The climatic range of the measurements of non-woody litter covers more than 90% of the globally available climatic conditions on land, excluding only the driest deserts and glaciers (Tuomi et al., 2009). The litter types included in the data used to develop the model in terms of the initial chemical compositions of litter, cover a wide variety of litters from conifers and broadleaved trees to shrubs and grasses, covering also a variety of different initial nitrogen concentrations (Tuomi et al., 2009). The measurements used to develop the model include an extensive data set on decomposition of non-woody litter across Europe, and North and Central America ($N = 9605$), data sets on the decomposition of woody litter in Finland and neighbouring regions in Estonia and Russia ($N = 2102$) (Tuomi et al., 2011a). Therefore, the Yasso07-UI can be applied reliably to a wide variety of litters from different species in almost any climatic conditions.

The time-span of non-woody litter mass loss measurements covers the first twelve years of decomposition of fresh litter extensively. In longer timescales, of hundreds of years, the litter becomes less important and the decomposition of humus starts to dominate the model predictions because of its low decomposition rate. These timescales are also covered by the available measurements (Liski et al., 1998, 2005; Tuomi et al., 2009) and the model is reasonably trustworthy in predicting the carbon stocks of soils in the global scale as well (Tuomi et al., 2011b).[3] This makes the model trustworthy in predicting the mass loss of non-woody litter in all the timescales.

For woody litter, the measurements used to develop the model include branches and stems ranging from 0.5 to 60 cm in diameter,

and the mass loss of these woody biomass components has been followed for 1–70 years since the start of decomposition (Tuomi et al., 2011a). Hence, the model is reliable in describing decomposition of wood in this timescale.

4. Yasso07 user interface

The Yasso07-UI package contains the Yasso07 model core and the Yasso07-UI software that exploits this model when calculating the predictions. There is also a sample of 100 000 vectors drawn randomly from the posterior probability density of the Yasso07 model parameters included in the package. Using this sample, it is possible to calculate the consequent uncertainty estimates for the model predictions. Because of the availability of this sample, the uncertainty in the measurements, i.e. all the noise and variation not taken into account by the model, is inferenced directly into the predictions of the Yasso07-UI.

4.1. Input and output information

The Yasso07-UI works with input information that is easily accessible in practice. This information consists of: 1) the initial state of the soil in terms of the amount of ash free organic carbon in the soil and its chemical quality in terms of AWEN fractions; 2) the climatic conditions as monthly or annual precipitation and mean monthly or annual temperature; and 3) the estimated ash free organic carbon input into the soil in non-woody and woody litter, including the estimated size distribution of the woody litter – again in terms of the AWEN chemical fractions. The sequential extraction procedures to estimate carbon in the AWEN fractions are described in detail in e.g. McClaugherty et al. (1985); (Berg et al., 1991a,b, 1993); Trofymow (1998). A list of chemical compositions of selected litters is provided at the Yasso07 project website (Yasso07-UI manual).

The lack of accurate information on the initial state of the simulated soils is not limiting because given some constant litter input to the soil, the software can be used calculate the long-term stationary state of the soil to be used as the initial state. For modelling purposes, this state is completely defined using the total mass of OM in the soil and its division into the AWEN and H compartments in the model and by making the assumption that the litter input to the soils in terms of amount of carbon is equal to the output.

The litter input to the soil is given to the software by defining the magnitude of the carbon flow into the soil in monthly of annual timescales. It can be given as a constant input or defined as a time-series describing e.g. the annual variations in the input or some long-term trend. The climatic conditions can also be given as some constant values or as time-series with monthly or yearly steps. This enables the user to investigate e.g. the effects climate change or short-scale changes in weather have on the soil carbon stocks and heterotrophic respiration.

The Yasso07-UI presents the modelled estimates for the user in a variety of ways. The results are always available as raw numbers that describe the maximum a posteriori (MAP) estimate, the mean, standard deviation, and 95% confidence intervals, or simply as a sample describing the probability density of the predictions. In addition, the software plots figures showing the amount of OM in each model compartment, the amount of OM in woody and non-woody litters, the total amount of OM, and the estimated respired CO_2 as a function of time.

4.2. Uncertainty in the Yasso07-UI

The uncertainty estimates for model predictions are calculated in two phases. First, a sample is drawn from the joint probability density of the model parameters. When this sample is set large

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[3] This claim refers to a manuscript in preparation. However, some of these results are accessible through the Yasso07 web site: www.environment.fi/syke/yasso.

enough (preferably at least few hundred), it represents the uncertainty in the parameter values of the model caused by the uncertainty and all the unmodelled excess noise in the measurements. In such cases, all the information in the measurements used to construct the model is inferenced to the model predictions as well. The sample size $N = 1$ corresponds to using only the MAP parameter estimates (Table 1) without any uncertainty estimation.

As a next step, the uncertainties in the initial state of the system (i.e. mass of OM and its chemical composition) and in the litter input are taken into account. The initial mass, and the percentage of mass in each compartment, are assumed to be Gaussian random variables. The means and the standard deviations of these values are set by the user and the Yasso07-UI draws random values from these distributions. The litter input is treated similarly.

The uncertainty estimation then proceeds as follows:

1. A sample of size N is drawn from the joint posterior density of the model parameters.
2. For each parameter value $\theta_i, i = 1,...,N$, a random initial state is drawn from the PDF's of the initial state given by the user.
3. For each parameter value θ_i, a random input is drawn from the user defined PDF's of the input for the next time-step.
4. The state of the system is calculated after the time-step for every θ_i and corresponding initial state and input.
5. This procedure is repeated by using the new state as the initial state of the next time-step.
6. The basic estimates describing the probability density of the model predictions; such as mean, standard deviation, and 95% confidence intervals; are calculated for each time-step in the output file.

If the uncertainty of the input information is not known, we recommend the following settings. The uncertainty in the initial mass, namely its standard deviation, should always be set to at least 10% based on the variations in the available data. This choise would account for the observed variability in the mass remaining measurements of approximately 10−15% of the initial mass (Berg et al., 1993; Gholz et al., 2000; Tuomi et al., 2009). The uncertainty in the initial chemical composition was found to be approximately 5% for each chemical component. This is approximately the amount of variation in the chemical composition of litter from a sinle plant species (Berg et al., 1991a,b).

For woody litter, the uncertainties set by the user should always be at least equal to those of non-woody litter. According to the measurements of Palviainen et al. (2004); Vávřová et al. (2009), the chemical composition of woody litter, in terms of AWEN compounds, does not vary more than that of non-woody litter. Also, the uncertainty in the litter input or initial state mass is not likely to be more than 10% for woody litter with diameter less than 10 cm. However, for woody litter with diameter greater than this, the uncertainty in the mass should be set to at least 15−20%. This is roughly the amount of variation in the measurements used to construct the woody litter extension of the Yasso07 model (Tuomi et al., 2011a). Further, if e.g. the exact size distribution of the woody litter is not known, additional uncertainty should be added to the input and initial state mass estimates to account for all the actual uncertainty in the modelled system.

5. Conclusions and discussion

We have introduced a graphical user interface for the litter decomposition and soil carbon model Yasso07. This user interface, Yasso07-UI, can be used to calculate point- and uncertainty estimates for litter decomposition, soil carbon stocks, and CO_2 emissions from soils in changing conditions with easily available input information. The user interface is applicable in a wide variety of climatic and environmental conditions because it takes into account all the information in the data sets used to build the Yasso07 model (Tuomi et al., 2009, 2011a).

The Yasso07-UI software can be used as a preliminary tool for assessing whether the Yasso07 model can predict decomposition-related phenomena with respect to some specific set of measurements. These measurements could be e.g. litter mass loss measurements, soil carbon stock measurements, heterotrophic respiration measurements, or other measurements describing some features of the carbon cycle in soils. If the model appears to be consistent with the data, the Yasso07 model can be easily implemented into different modelling purposes because its source code is freely available, the model has a simple structure, and the input information it requires is commonly readily available.

Because of the nature of the measurements used to build the Yasso07 model, there are cases where it is not known whether the model is applicable or not. These cases include swamps and marshlands, where the limited availability of free oxygen limits the decomposition heavily. This effect is not taken into account by our model. Also, the applicability of our model to modelling carbon stocks of mineral soils has not been tested throughly. Further, the model predictions regarding the decomposition of woody litter remain to be compared to wood decomposition data from temperate and tropical climates. We aim at developing the model further by extending its range of reliable applicability to these environmental and climatic conditions.

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