ICBM

(Introductory Carbon Balance Model)

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Overview

ICBM is a simple soil carbon model suitable for making projections of soil C dynamics in temperate and tropical land-use systems, originally for agricultural land. It has been used for *IPCC greenhouse gas reporting* on arable land in Sweden, USA and Norway. The model is based on *two state equations* and *five parameters* describing *two compartments, Young and Old soil C* (see Fig below) and can be downloaded as a simple Excel® spreadsheet, but also be a component in very complex simulation systems describing daily soil carbon dynamics in soils, cropping systems, climates, regions for a whole country during 30 years or more.

However, the basic idea is to be able to make projections of soil C dynamics in a 30-year perspective even when detailed data are lacking. The information necessary is a *rough estimate of annual carbon input* to soil, a *coarse measure of residue quality* and *some information about climate*. If basic weather station data (air temperature, precipitation, evapotranspiration) and water-related soil properties are available, a more exact projection can be made. Typically the model is used for answering questions such as: If I return all crop residues instead of taking them away from the field, *how much soil carbon will I have gained after 30 years*? If only limited local data are available, rough estimates (climate zone, crop yield etc.) still will make projections possible. Compared with more complex models, this approach is *rapid and simple* and does not necessarily give worse results.

Recommended reading:

Andrén, O., Kätterer, T., Karlsson, T. and Eriksson, J. 2008. **Soil C balances in Swedish agricultural soils 1990-2004, with preliminary projections.** *Nutrient Cycling in Agroecosystems* 81:129-144. PDF

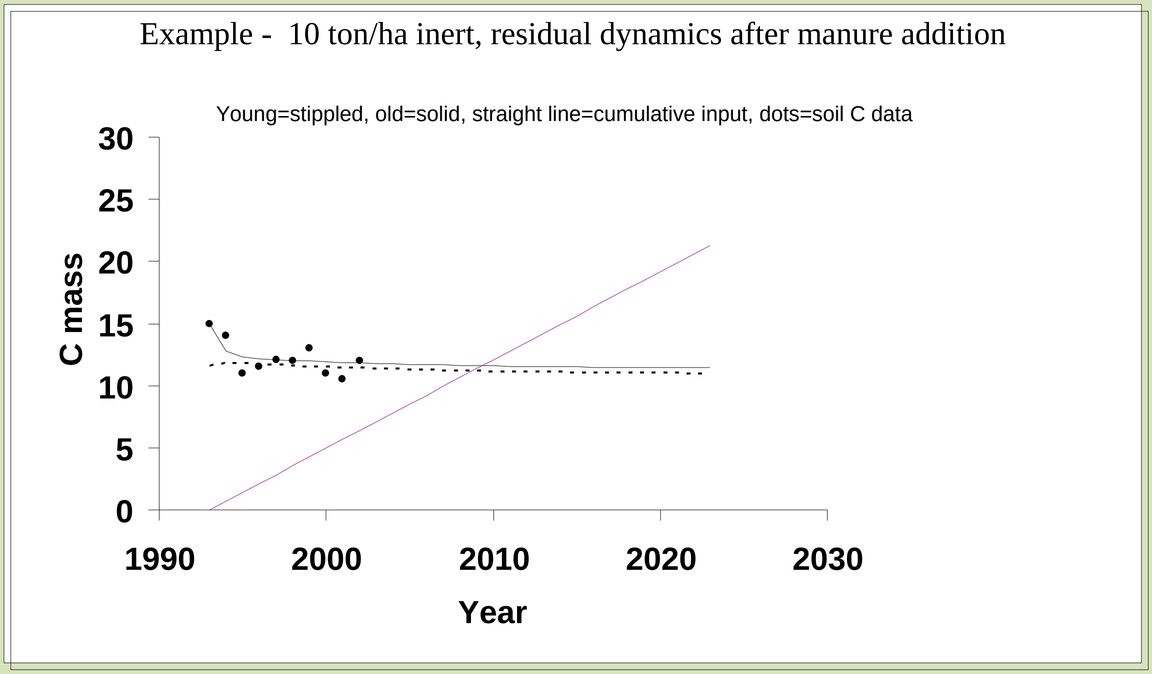
Andrén, O., Kihara, J., Bationo, A., Vanlauwe, B. and Kätterer, T. 2007 **Soil climate and decomposer activity in sub-Saharan Africa, estimated from standard weather station data – used in soil carbon balance calculations**. *Ambio* 36:379-386. PDF

Andrén O, Kätterer T and Karlsson T. 2004. **ICBM regional model for estimations of dynamics of agricultural soil carbon pools**. Nutrient Cycling in Agroecosystems 70:231-239. PDF

Andrén, O. and Kätterer, T. 1997. **ICBM - the Introductory Carbon Balance Model for exploration of soil carbon balances**. Ecol. Appl. 7(4):1226-1236. PDF

I recommend studying at least the 1997 paper and the text in the following before downloading and trying the model. I will also reply to email and give some free advice.

Parameter	Symbol	Typical dimension	Typical range
Input	i	t ha^{-1} year^{-1}	0-5
Decomp. rate constant for Y	k_Y	year^{-1}	0.8
Humification factor	h	dimensionless	0.1-0.6
Decomp. rate constant for O	k_O	year^{-1}	0.006
External control factor	r_e	dimensionless	0.8-5



Downloads:

ICBM_2_0 Excel - The workbook has four or more input pages, and the user can input a unique set of parameters in each page for 30-year projections

ICBM_inert_2_0 Excel – as above, but you can set a fraction of total C as inert and exclude it from the calculations

re_clim_5 Excel – Calculate climate influence on decomposition in soil from air temperature, precipitation, and evapotranspiration

Full_ICBM - readable SAS program listing equations for original ICBM – can be read with text editor

Wat_Mod_SAS – readable SAS program listing equations for the water model for climate factor calculations

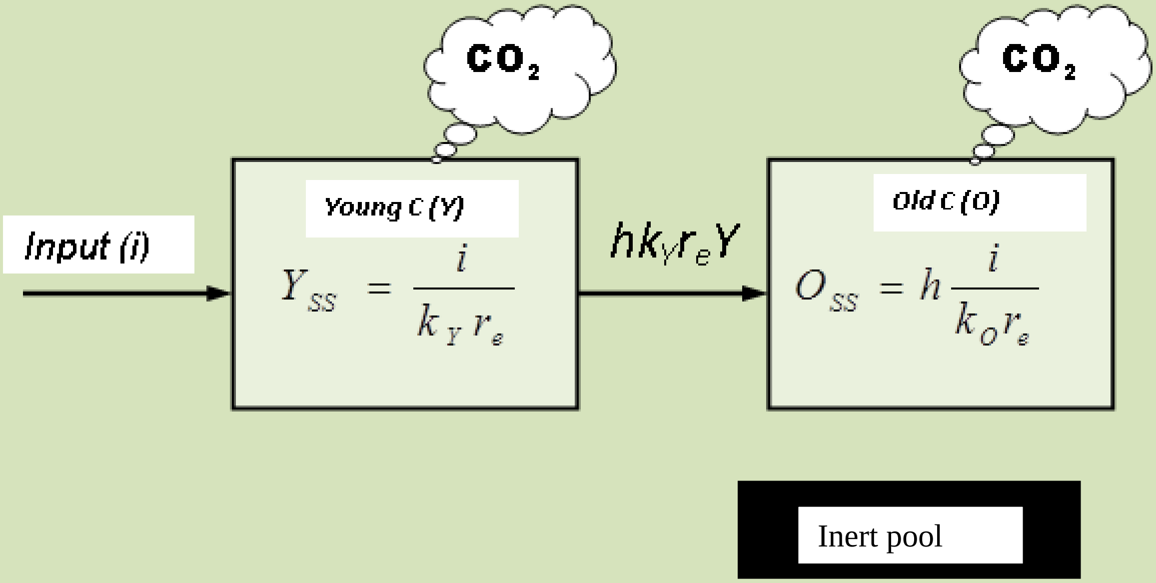
Web address for downloads: www.oandren.com/icbm

More programs, e.g., the whole program setup for national budgets (described in the 2004 paper listed above) available on request.

Details

ICBM does not stand for InterContinental Ballistic Missile, but the model has made an impact on several continents: Europe, North America and Africa. ICBM rapidly can be parameterized for conditions quite different from those it was originally calibrated for, and projections can be made from this base parameterization. ICBM is intermediate between IPCC Tier 1 linear calculations and more complex modeling approaches. The simplest models suitable for simulating long-term dynamics over periods of decades utilize a single dynamic pool and possibly an additional, inert, pool that resides outside of model dynamics. ICBM is conceptualized with one rapid and one slow soil carbon pool (Andrén and Kätterer 1997), which is the minimum required to capture aspects of both short and long-term dynamics. If required, a third inert carbon pool can be readily added to ICBM to represent an inert partition of the total soil carbon mass. This partition then remains static outside the dynamics of the two active pools. The relative simplicity of the ICBM model structure seems to match both the gentle long-term dynamics and inherent uncertainties that typify data in most long-term field trials.

ICBM was originally parameterized to a long-term field trial, in this case in Uppsala, Sweden (Andrén and Kätterer 1997). A climate- and soil-based activity index, *re_clim*, which provides model portability by estimating a site-specific soil activity index relative to the Uppsala site has been presented (Andrén et al. 2007). The Excel versions of ICBM are aimed towards non-modelers, with the intent of providing a rapid means of producing estimates of impacts from various future management scenarios or to assess long-term data in response to various experimental treatments.



ICBM has two state variables or pools, “Young” (*Y*) and “Old” (*O*) soil carbon, and five parameters: i, k_Y, h, k_O, and r_e. The “humification coefficient” (*h*) controls the fraction of *Y* that enters *O* and ($1-h$) then represents the fraction of the outflow from *Y* that becomes CO_2–C. Parameter r_e summarizes all external influence (mainly climate) on the decomposition rates of *Y* and *O*. Note that r_e only affects decomposition rates; r_e does not influence *i* or *h* (Figure 1). See Andrén and Kätterer (1997) for complete list of equations as well as strategies for estimating parameter values. The model has been successfully been applied to agricultural field data from Sweden (Karlsson et al. 2003; Andrén et al. 2004, 2008; Kätterer et al. 2004), European field trials (Kätterer and Andrén 1999), Western and Eastern Canadian agricultural regions (Bolinder et al. 2006, 2007a, 2008; Campbell et al. 2007), Norwegian arable land (Kynding Borgen in review) and work is in progress to adapt it to sub-Saharan African conditions (Andrén et al. 2007). ICBM has also been expanded to a larger family of related model structures, including more carbon pools and also nitrogen dynamics (Kätterer and Andrén 2001).

The reasons more in detail for this simple approach are:

1) *Easy* and rapid to use and understand, usually only three parameters to ‘play’ with, using guessed or ‘rules-of-thumb’ parameter values. All parameter values used can be

reported in a small table, so the readers can make their own judgments of their validity and can easily repeat or modify the exact model simulations presented.

2) Observed soil carbon dynamics in a 30-year perspective as well as the *precision* of soil carbon mass measurements do not warrant a more complex model.

3) In spite of the model simplicity, complex and exact data sets and functions can be used to *generate* the parameter values used in the spreadsheet (Andrén et al. 2007).

4) The simple core model can easily be inserted into more complex applications and run simultaneously as a *simulation* model for different climates, cropping systems and soils, with many different parameter settings, e.g., for national soil C budgets (Andrén et al. 2004, 2008) or within a GIS grid.

The easiest way of using ICBM is the Excel® spreadsheet (*ICBM 2.0, above*) that can be downloaded or run directly. The workbook has four or more input pages, and the user can input a unique set of parameters in each page. For each parameter set, a 30-year projection is instantaneously made, and the results from using the different parameter combinations are presented in separate and combined graphs. The program has additional text help, visible when the cursor is in a cell with a little triangle in the corner. There are also options for ‘goal-seeking’, answering questions like: “How much more annual input is needed to increase soil carbon mass from 40 to 50 ton ha^{-1} after, e.g., 20 years?” Another option is to optimize selected parameters to measured data, i.e., fitting the model to data. In this case, error mean square and R^2 are reported.

A comprehensive description of the initial parameterization of ICBM is given by Andrén and Kätterer (1997), and in the following we will suggest how to adapt the parameters to local conditions.

First, parameter r_e, which summarizes the external influences on soil organic matter decomposition rates will be discussed. This parameter mainly is based on soil temperature and moisture, but it can also be modified according to different degree of cultivation or oxygen starvation due to water-logging. Soil temperature and moisture can be calculated from daily meteorological data paired with soil and crop properties, and the daily activity can be calculated using a factor $r_{e\_temperature} \times r_{e\_moisture}$. This approach is common in climate-dependent modeling and is a simple way of describing the fact that when one of the factors is close to zero the value of the other factor does not matter much – e.g., if the soil is very dry, almost no decomposition will take place even if the temperature is +35°C. The daily calculations of activity can then be expressed as an annual mean, which in one value combines temperature and moisture conditions and their daily interaction. The degree of soil cultivation (or the difference between cereals and a grass ley) can then be applied as another multiplier, r_{e_cult} . We have normalized r_e to 1 for cereal cropping in central Sweden (Andrén et al. 2004), and for Sweden r_e ranges from about 1.3 in cereal cropping regions in Southern Sweden to about 0.7 in grass leys in Northern Sweden (Andrén et al. 2008). The actual calculations of r_e that are used when climatic (daily temperature, rainfall and evapotransporation), soil (wilting point, field capacity) and crop (green leaf area, degree of cultivation) data are available are made using a SAS program called $W2r_e$ (Andrén et al. 2004), but can also be calculated within a spreadsheet. When the soil properties used for calculation of water storage parameters (water content at wilting point and field capacity) are unknown, these can be calculated from soil texture data (Kätterer et al. 2006).

There is also a simplified climate parameter, r_{e_clim}, which uses a standard soil (clay loam) and cropping system (black fallow) to give a pure climatic factor for comparisons. The value for r_{e_clim} is calculated from standard meteorological data only (daily temperature, rainfall and evapotransporation), normalized to 1 for Central Swedish climate, and typical values have been calculated for sub-Saharan Africa (Andrén et al. 2007) as well as Canada (Bolinder et al. 2007a). An r_{e_clim} value of 3 indicates that the decomposition rate of soil organic carbon is three times faster than in central Sweden just due to climatic differences, and that the same annual input as in Sweden would result in 1/3 of the soil C mass at steady state (A basic spreadsheet for calculating r_{e_clim} is available at the website).

Second, the annual input, i, is estimated as the sum of carbon inputs from the crop and manure. The approach we use for crop inputs is to apply allometric functions to yield data, i.e., using estimates of the relations between crop yield, roots, stubble and straw (Paustian et al. 1990; Kuzyakov and Domanski 2000; Andrén et al. 2004; Bolinder et al. 2007b). The annual C input (i) can admittedly never be exactly measured, and in some cases it may be best to optimize this parameter to obtain a good fit to available soil carbon measurements (within reasonable limits).

Third, the humification coefficient, h, which determines the proportion of young soil C that becomes old soil C (humus) must be set. In the original ICBM paper (Andrén and Kätterer 1997) we showed how to estimate h using, e.g., litter-bags, and default values to use when more detailed information is unavailable are: Crop residues about 0.12, manure about 0.35, processed sewage sludge about 0.5. When manure or sewage sludge is added, a weighted average for h based on the relative inputs from manure and crop residues is used.

Parameters k_Y and k_O have usually not been changed, since they are multiplied by r_e in the model equations and thus an increase in r_e can be balanced by a reciprocal decrease in k_Y and k_O (Figure above). However, if the relative contributions of Y and O to total soil carbon mass at steady-state need to be changed, k_Y and k_O can be set to other values.

Initial carbon mass in the topsoil is crucial for the outcome of the projections – if it is high a decrease will be projected and if it is low we an increase will be projected (Kätterer and Andrén 1999). Since carbon mass is notoriously difficult to measure with high precision, it is sometimes better to modify the measured initial value to a value that fits the model projections, particularly if the apparent changes between the initial and second sampling are unrealistic, e.g., if the apparent increase in soil carbon mass is greater than the carbon added. The initial distribution between young and old C (Y_0 and O_0) can be set to the steady-state values calculated by the spreadsheet However, if the modeled period of time starts with, e.g., an addition of mulch, Y_0 can be set to a higher value. Alternatively, if the modeling is preceded by a long period of black fallow Y_0 can be set close to 0 (Andrén et al. 2001).

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