AMG: a simple SOC balance model used in France for decision support

Annie Duparque[1], Jean-Louis Dinh[1], Bruno Mary[2a]
and Alain Bouthier[3], Bénédicte Blin[4], Pascal Denoroy[5], Flora Ganteil[4], Sabine Houot[6], Maxime Levert[1], Stéphanie Sagot[4], Robert Trochard[3]
[1] *Agro-Transfert Ressources et Territoires, 2, Chaussée Brunehaut, F-80200 Estrées-Mons, France a.duparque@agro-transfert-rt.org, +33 (0)3 22 85 75 89*

[2a] *INRA, Unit AgroImpact, Laon*
[2b] *INRA UMR TCEM Bordeaux*
[2c] *INRA UR EGC Grignon*
[3] Arvalis Institut du végétal, Boigneville
[4] Laboratoire d'Analyses et de Recherche (LDAR), Laon

1 - Description of the current version of AMG model

AMG model was created in 1999 (Andriulo et al , 1999). It is derived from the first SOM balance model established in France by Hénin and Dupuis (1945), which has been widely used by agricultural advisors and teachers, and also by agricultural researchers until recently.

The Henin-Dupuis model is one the simplest models simulating C balance in soil and is comparable to ICBM family models (Andrén and Kätterer, 1997). It considers two compartments of organic carbon (OC): fresh carbon inputs (from aerial and root crop residues and organic amendments) and the soil organic carbon (SOC).

Using this model, several authors such as Mary and Guerif (1994), Wylleman et al (1999; 2001) found that the model tends to under-estimate the actual variations of SOC in the short-term and over-estimate them in the long-term. Furthermore, the fitted values of k1 did not correspond to the estimates which can made using long-term incubation in the laboratory.

In AMG model, the humified SOC pool is divided into two parts: an active compartment C (Ca) and a stable one (Cs) which is considered totally inert on the short and mid terms (i.e. that its turnover time is millenary). The active pool is the only pool fed by fresh C inputs and affected by the annual mineralization (outputs).
This transformation has signed the creation of AMG which takes into account the generally accepted result that the humified SOC pool is not homogeneous.

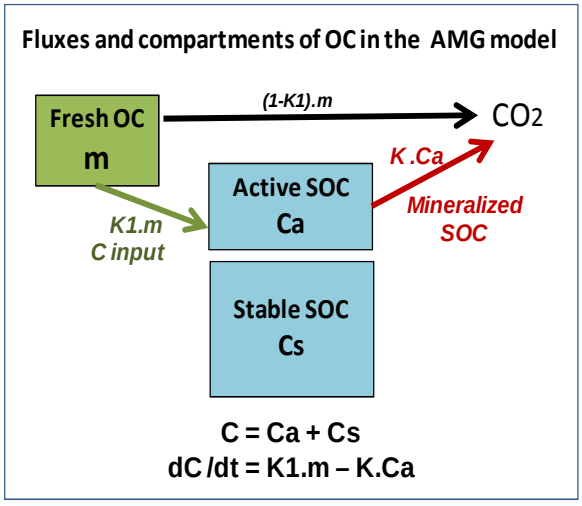

Figure 1: Diagram of AMG model

The current version of AMG model has three compartments of OC (fresh exogenous OC, active SOC and stable SOC)).
It has three main parameters:
k1 = "humification coefficient", *ie*. the conversion efficiency of the fresh carbon inputs into humified SOC;
k2 = annual rate of SOC mineralization.
Cs/Co = initial proportion of stable carbon
(Co = initial SOC content)
k1 is supposed to depend only on the nature of the fresh organic inputs, whereas k2 is supposed to depend on the soil (clay and lime contents), soil tillage (type and depth) and the meteorological conditions (mean air temperature and water balance)

Compared to Henin-Dupuis model, the predictive value of the AMG model is significantly improved. Compared to more complex models such as Century, it remains a simple model, well adapted for developing decision support systems (see below with Simeos-AMG), and which may perform as well for applied purposes. AMG concepts are embedded in the crop model STICS which simulates C and N balances at a daily time step (Brisson et al, 2008).

2 - Evaluation of AMG model

2.1 Description of the research tool : AMG-Research

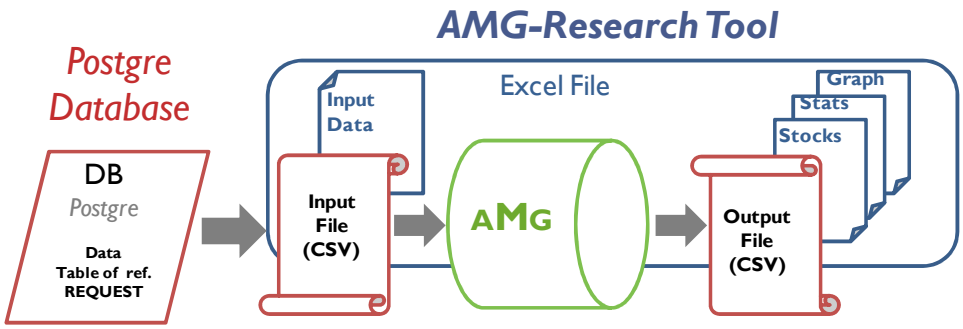

Figure 2: Diagram of AMG-Research model

- A calculation tool called "AMG-Research" was developed to test the model and allow the optimization of its parameters using multiple series of long term experimental data. It combines two complementary calculation functions
- The data processing chain is shown at Figure 2. The AMG-Research model can be run either separately in an Excel file or associated with a Postgres database, provided that the input data CSV file is available. It can be used in different computer environments (Windows / Linux).

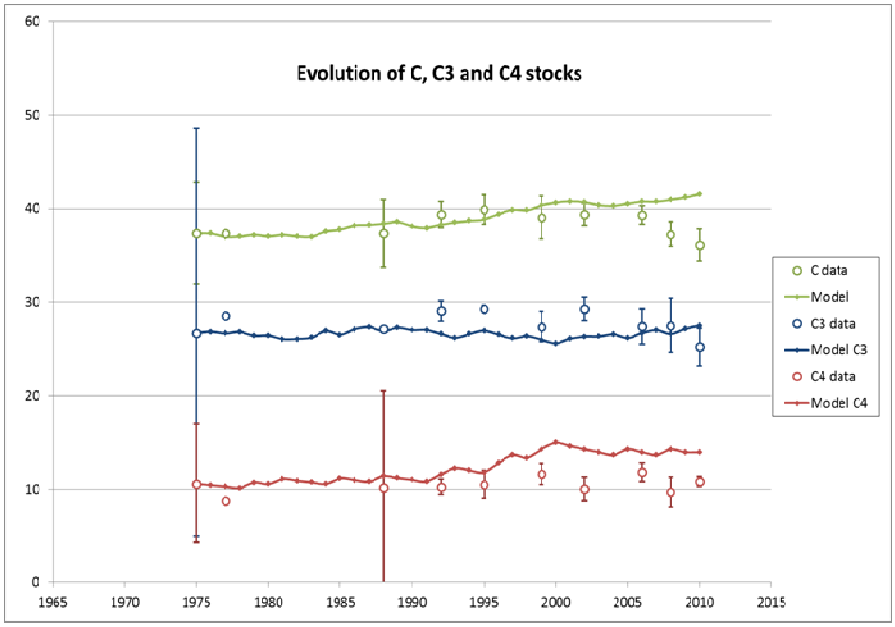

Figure 3: Example of simulation of SOC changes versus time (C3, C4 and total C)

- The model simulates the evolution of SOC stocks in each experiment, displaying the observed and simulated kinetics; it provides the statistical parameters for evaluating the differences between observed and simulated stocks.
- It proposes an optimization procedure of model parameters using a Bayesian method (Monte Carlo Markov Chains). The user may choose any combination of parameters to be optimized.
- The data are collected in CSV files (input data, parameters, output simulated data, output statistics including *a posteriori* distributions). An Excel file provides the interface between these CSV files and the calculator. This file includes macro-functions performing: (i) the import of input data and simulation configuration; (ii) the optimization configuration (choice of variables to be optimized, *a priori* distribution, and number of iterations) and the launch of calculation; (iii) the set up of graphics to display the results of simulations and optimizations.

2.2- Test on a regional database

A database was created by selecting data derived from in a regional soil analysis laboratory. We gathered soil analyses and technical information concerning the management (crops, yields, residues management, …) of the agricultural fields. We selected data which were measured at several dates in the same fields. The selection provided 391 fields monitored during 10-25 years.

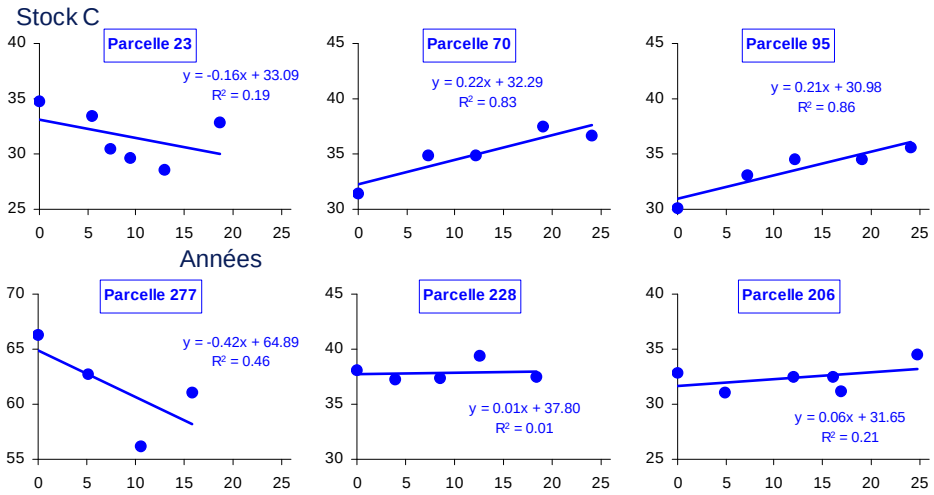

Figure 4: Measured and fitted (linear regression) SOC stocks versus time in 6 fields

The measured SOC stocks were fitted to a linear regression versus time, giving the mean rate of SOC change. This observed change was compared to the simulated change (Figure 4). evolution A good global prediction was found, although the model underestimated the frequency of the situations of positive rates of SOC variation.

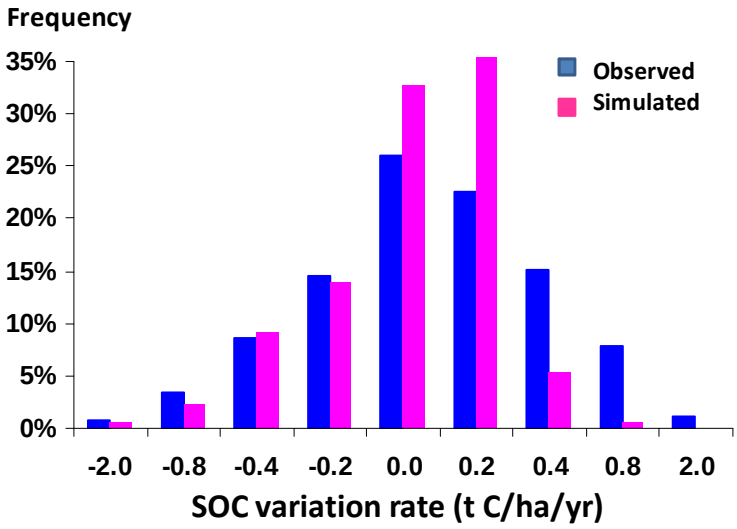

Figure 5: Observed and simulated distributions of the rates of variation of SOC content

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2.3 *Test on long term field experiments with or without straw return*

AMG model was tested in 9 long-term field experiments (18–35 yr) comparing straw export and straw return to soil in sites varying between Sweden and Thailand (Saffih and Mary, 2008). These situations differed widely in climate, soil type, carbon content and carbon input.

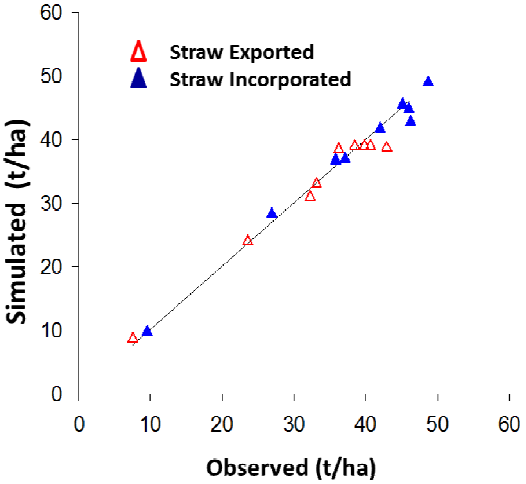

Figure 6: Simulated vs observed SOC stocks

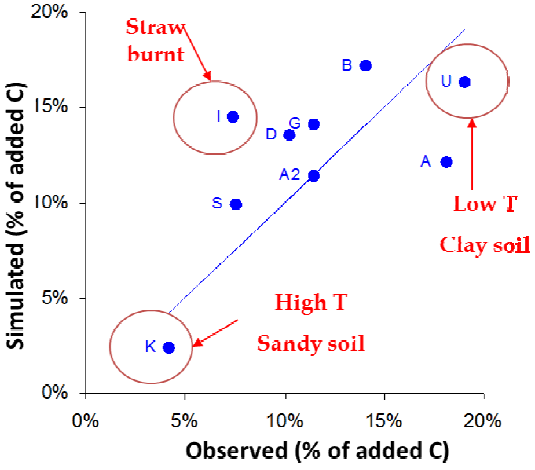

Figure 7: Simulated vs observed changes in SOC due to straw return

The model was able to provide satisfactory simulations of SOC evolution in most experiments with a unique set of parameters. Sensitivity analysis indicated that the quality of fit was very sensitive to humification coefficient, moderately sensitive to the size of the stable SOC pool and weakly affected by the ratio of belowground to aerial C inputs. The dependence of model parameters on (clay content and temperature was analyzed and compared to those proposed in other models.

2.4 *Test on a national database* *("AMG" project)*[1]

A database was constituted by collecting and selecting the results of long term field experiments carried out in France for 10 to 41 yrs. Most experiments had not been established with the aim of studying typically SOC, so that a selection of the most appropriate datasets was required. It was made according to: i) the consistency of SOC content kinetics and ii) the available information on crops and cropping systems, required to get estimates of fresh C inputs The database includes 23 long term field experiments and 75 treatments spread over the main cropping regions in France.

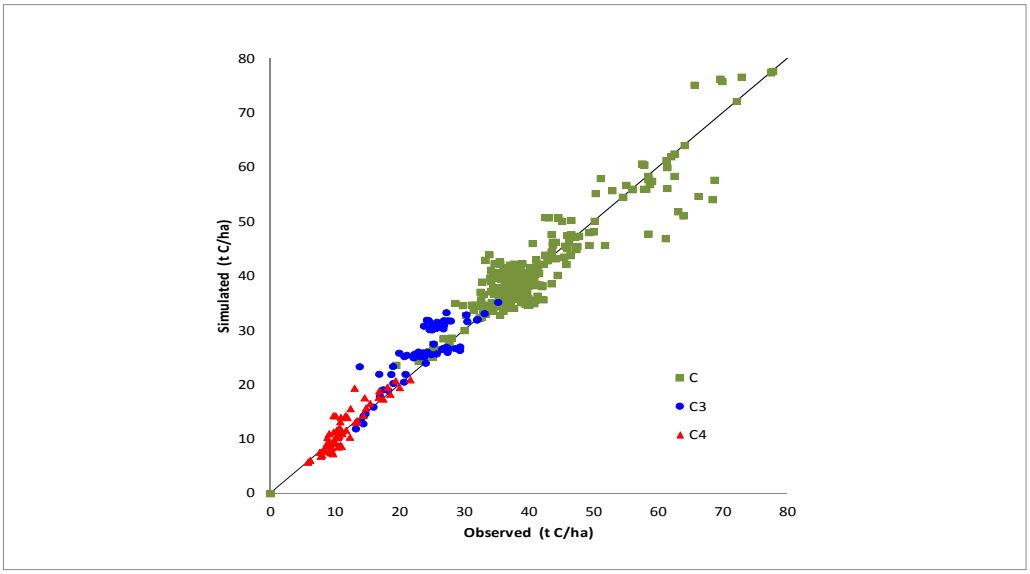

Figure 8: Simulated vs observed SOC stocks (C3, C4, total C) for the national database

[1] AMG : National R&D project (2009-2012) conducted by Arvalis, in collaboration with Agro-Transfert-Ressources et Territoires, INRA and LDAR

Figure 8 shows the model performance using the standard AMG parameterization. The mean difference between observed and simulated values is -1.0 t C ha^{-1} whereas the mean RMSE is 3.4 t C ha^{-1}.

2.5 *Current model limitations*

- the model does not apply to grasslands and other perennial crops (miscanthus, …)
- the effect of soil moisture (through a water balance indicator) must be improved
- the values of humification coefficients of organic wastes (manures, sludges, composts, slurry, …) must be updated using a database of laboratory experiments

These issues are addressed in on going studies in France.

3 - The decision support tool SIMEOS-AMG

The SIMEOS-AMG tool was set up in the course of a regional research-development project on Soil Organic matter management in Picardy region (northern France)[2]. It implements AMG model to perform SIMulations of Soil Organic Status at the field scale and on the long term.

The simulations are performed on the basis of scenarios taking into account the soil type, the local climate and the cropping system. In contrast with AMG-Research, the cropping system is supposed to reproduce identically over the duration of the simulation (true rotation).

The input data and the parameters required for the calculations are either readily available on the farm and entered by the user, or found in various catalogs (soils, regional climates, crops and organic products) integrated in the tool and mobilized through drop-down menus or by consulting reference tables.

The requested input data are the soil contents: initial OC, clay, limestone, pebble content, bulk density; sampling depth for soil analysis; soil tillage type (plowing, no till) and depth for each year; average annual temperature and water balance (precipitation + irrigation – potential evapotranspiration); crops sequence and crop yields; residues management (return or removal); nature, biomass and frequency of catch crops and organic amendments. The output data are:

- SOC stocks over the "depth of topsoil" defined as the larger value between sampling depth of soil analysis and deepest tillage operation during the rotation,
- SOC content and concentration of the deepest tilled layer during the rotation (assuming that tillage homogenizes the concentration of organic materials down to this depth).

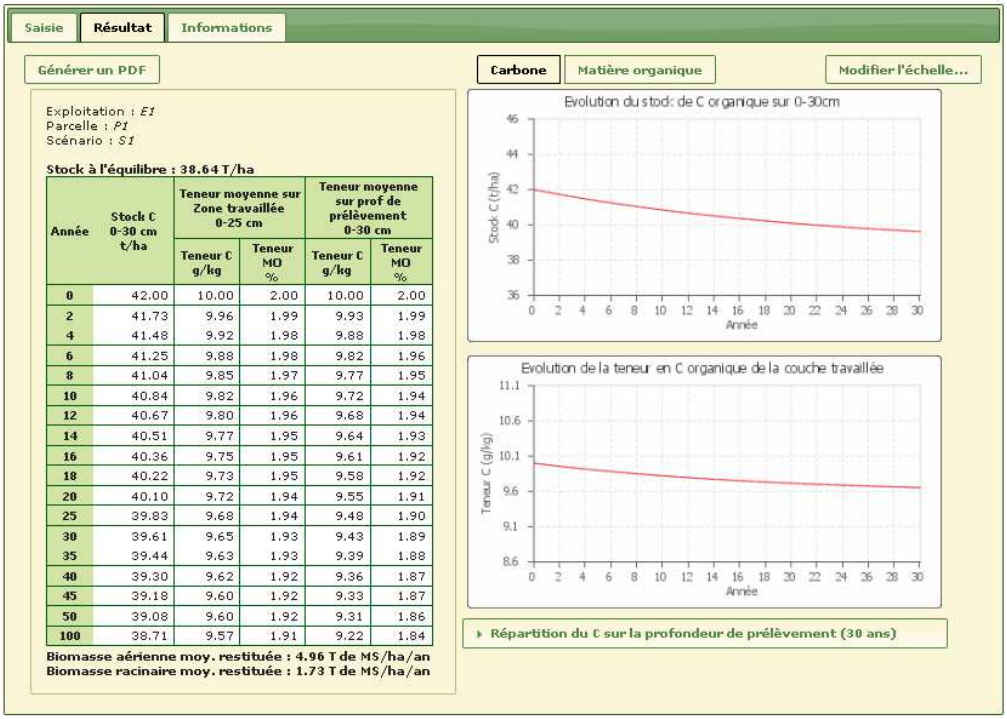

Figure 9: Output screen of SIMEOS-AMG

[2] "GCEOS" regional R&D project (2004-2011) conducted by Agro-Transfert-Ressources et Territoires, in collaboration with INRA, Extension services, a high school of agriculture, LDAR, land experts and cooperatives in Picardy region.

These values are used to trace the evolution of the organic soil conditions over periods ranging from 2 to 100 years. These changes are plotted for periods of time adjustable between 20 and 100 years (Figure 9). The tool also provides the SOC stock attained at steady state and the distribution of the values of SOC content in the profile of the topsoil at a selected date. The simulated scenarios can then be selected and compared graphically.

SIMEOS-AMG is an individual advising tool instrument for the farmer and an educational support for teachers in agricultural schools.
The more classical implementation for advisory or educational support can be described as follows:

- ✓ Starting by actual cases known on the farm and declining them in number of theoretical variants, the simulations allow for understanding how different factors (agricultural practices or natural conditions) can influence soil organic evolution in the long term.
- ✓ Simulations are then used to assess the impact of current practices in different fields of the farm. The diagnosis is mainly based on the dynamics revealed by the evolution curves (increase, decrease or stagnation) and on what the farmer knows about the behavior of the soil examined (crusting frequent or not in loamy soils; difficulty in tillage in clay soils; water infiltration problems, ...).

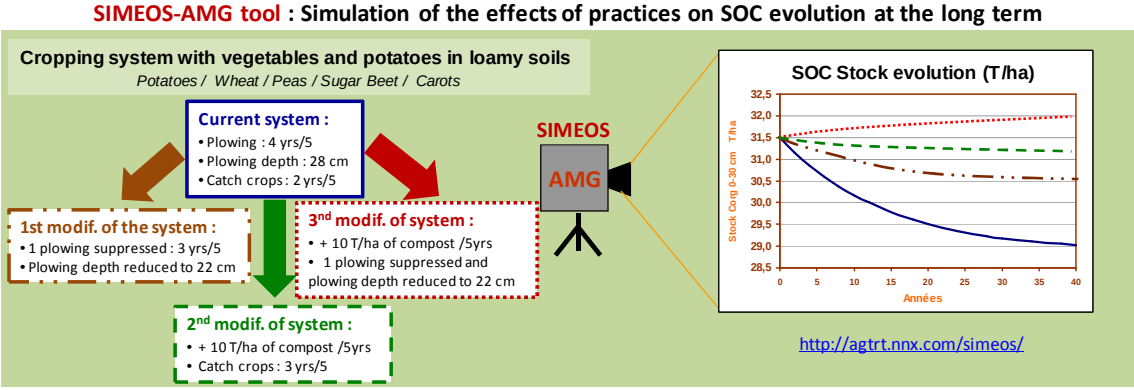

Figure 10: Application of Simeos-AMG tool for decision support (example)

- ✓ Finally, the farmer can see the long term effect of alternative practices compared to those he currently applies. The examination of costs, physical constraints or work organization associated with various technical options can accompany these comparisons and help establish the expected advice, in adapting it to either the context of operation, the means and objectives of the farmer.

SIMEOS-AMG can also be used to establish quantitative prescriptions
This was the case to determine the rate of exportation of cereal straw, without taking a risk for the soil organic status on the long term. The expected output is a quantitative prescription, which implies to quantify the consequences of changes in SOC content on agronomical properties and behavior of the soil. Thus, not only the dynamics of evolution revealed by the simulation curves, but also the levels of SOC attained at the end of the simulation period, has to be taken into account. This principle is applied to several current studies in France where SOC balances or GHG balances with integration of SOC variations are to be performed at a territory scale.

4 Conclusion

AMG is a simple model easy to parameterize and use. The various tests currently realized show satisfactory performances for simulating arable cropping systems in France.
We are interested to compare it to other operational models in Europe.
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