

See discussions, stats, and author profiles for this publication at: <https://www.researchgate.net/publication/50913113>

A Model to Predict Soil Aggregate Stability Dynamics following Organic Residue Incorporation under Field Conditions

Article in *Soil Science Society of America Journal* · January 2008

DOI: 10.2136/sssaj2006.0018 · Source: OAI

CITATIONS

34

READS

264

4 authors, including:



Samuel Abiven

University of Zurich

108 PUBLICATIONS 4,135 CITATIONS

[SEE PROFILE](#)



Denis Angers

Agriculture and Agri-Food Canada

268 PUBLICATIONS 12,463 CITATIONS

[SEE PROFILE](#)

Some of the authors of this publication are also working on these related projects:



Biochar and roots [View project](#)



Soil organic matter persistence [View project](#)

A Model to Predict Soil Aggregate Stability Dynamics following Organic Residue Incorporation under Field Conditions

Samuel Abiven*

Univ. of Zurich
Winterthurerstr. 190
Zurich 8057
Switzerland

Safya Menasseri

INRA
Agrocampus Rennes
UMR Sol, Agronomie Spatialisation
65 Rue de Saint-Brieuc
CS 84215
35042 Rennex Cedex
France

Denis A. Angers

Agriculture and Agri-Food Canada
2560 Hochelaga Blvd.
Ste. Foy, QC G1V 2J3
Canada

Philippe Leterme

INRA
Agrocampus Rennes
UMR Sol, Agronomie Spatialisation
65 Rue de Saint-Brieuc
CS 84215
35042 Rennex Cedex
France

Our ability to predict the effects of various organic amendments on soil aggregate stability is limited due to the complexity of the biological, chemical, and physical mechanisms involved. Based on previous experimental results, this study developed a model (Pouloud) to predict the dynamics of aggregate stability following the incorporation of various organic residues under field conditions. Following Monnier's conceptual model and previously published data, a lognormal function is first used to describe changes in aggregate stability after organic inputs under laboratory conditions. Using principal component analysis, the parameters of the lognormal function are associated with the biochemical characteristics of the organic products such as water-extractable polysaccharide, cellulose and hemicellulose, and lignin contents. To simulate aggregate stability dynamics under field conditions, the effects of soil moisture, soil temperature, and N availability are taken into account by specific functions obtained from the literature. When model simulations were compared with experimental results under field conditions, variations in aggregate stability were generally well reproduced. The sensitivity of the model to climate variations and organic residue characteristics was tested. Soil N availability and the substrate lignin content are major factors that influence the prediction of aggregate stability dynamics. Our results suggest that prediction of aggregate stability dynamics under field conditions using organic substrate characteristics and simple climatic data is possible. More work is required to test the model and broaden its applicability to other soil and climatic conditions.

Several reviews have described the effects of organic matter incorporation on soil aggregate stability for different soils and under varying conditions (Monnier, 1965; Lynch and Bragg, 1985; Six et al., 2002). In most cases, incorporation of organic matter and its decomposition improve soil aggregate stability with an intensity and a duration that depend on the nature of the material incorporated (Martin, 1942; Gerzabek et al., 1995; Martens, 2000) and its rate of decomposition (Abiven et al., 2007). Decomposition

of organic substrates results in the production of biological binding agents such as polysaccharides, lipids, humic substances, and fungal hyphae that influence the stability of soil aggregates (Lynch and Bragg, 1985; Martens, 2000; Six et al., 2002).

From a practical point of view, it would be useful to be able to predict the effects of different organic residues on soil aggregate stability dynamics using organic substrate characteristics. Recently, models were proposed to quantify the dynamics and turnover of water-stable aggregates as influenced (De Gryze et al., 2005, 2006) or not (Plante et al., 2002) by organic matter input. These studies give valuable information on newly formed aggregates and their fate in relation to biological activity and organic matter protection. To our knowledge, however, no models have yet been proposed to predict the stability of existing aggregates as influenced by different organic inputs. Two reasons probably explain this gap in our ability to predict aggregate stability dynamics following organic matter incorporation. First, the direct relationships between aggregate stability and binding agents remain unclear (Metzger et al., 1987; Degens et al., 1996;

Soil Sci. Soc. Am. J. 72:119-125

doi:10.2136/sssaj2006.0018

Received 12 Jan. 2006.

*Corresponding author (samuel.abiven@geo.uzh.ch).

© Soil Science Society of America

677 S. Segoe Rd. Madison WI 53711 USA

All rights reserved. No part of this periodical may be reproduced or transmitted in any form or by any means, electronic or mechanical, including photocopying, recording, or any information storage and retrieval system, without permission in writing from the publisher.

Permission for printing and for reprinting the material contained herein has been obtained by the publisher.

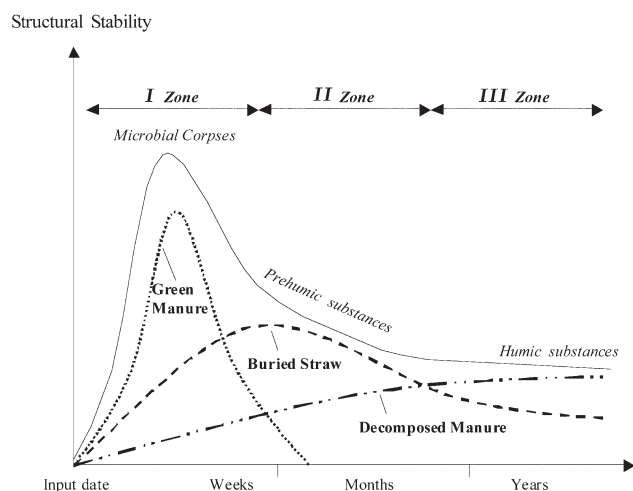


Fig. 1. Monnier's (1965) conceptual model of temporal variations in aggregate stability following organic substrate incorporation.

Martens, 2000). Moreover, these relationships will vary with time after incorporation and will be dependent on climate, soil type, and the nature of the organic substrates. As a consequence, the content of these binding agents in the soil cannot yet be used to predict aggregate stability dynamics. Second, few studies have tried to link the intrinsic characteristics of the organic substrates and their effects on aggregate stability. The few existing correlations (Martin, 1942; Martens, 2000) are valid only for the organic substrates considered and for a few sampling dates.

Monnier (1965) proposed a conceptual model that describes the relative variations in aggregate stability following the incorporation of various organic substrates (Fig. 1). Based on a large experimental database under controlled and field conditions, this model describes aggregate stability dynamics for four broad types of organic substrates: (i) green manure and fermentable substrates, (ii) buried straw and fiber-rich substrates, (iii) decomposed manure and decomposed organic substrates, and (iv) inputs

without a significant effect on aggregate stability (not shown in this figure). As illustrated in Fig. 1, these dynamics were conceptually related to variations in organic compounds such as microbial corpses and prehumic and humic substances. More experimental studies have since confirmed the general shape of aggregate stability dynamics following organic amendments (e.g., Metzger et al., 1987; Abiven et al., 2007) and the effects of organic residue quality (e.g., Martens and Frankenberger, 1992; Abiven et al., 2007), which suggests that this model could be mathematically formulated to predict aggregate stability and organic material incorporation. This study is a first attempt to formalize Monnier's (1965) conceptual model and to apply it under field conditions.

MODEL DESCRIPTION

Aggregate Stability Dynamics under Laboratory Conditions

The model developed in this study was based on the data of Abiven et al. (2007) and is named "Pouloud," a term in the Breton Celtic language that means "aggregate." Its general architecture is presented in Fig. 2. The shape of the curves describing aggregate stability dynamics proposed by Monnier (1965) suggested the possibility of fitting a mathematical function to it. The following lognormal function (Eq. [1]) was chosen from among others for its ability to reproduce all the patterns (time duration and magnitude) presented in Monnier's model. In particular, it was possible to reproduce large variations that could be observed immediately after organic residue incorporation (Fig. 1, Zone I) as well as the dynamics over a longer period of time (Fig. 1, Zone III).

$$AS(t) = A \exp \left\{ -0.5 \left[\ln(t/C)/B \right]^2 \right\} \quad [1]$$

where t is the time in days, A , B , and C are the magnitude, scale, and shape parameters (Fig. 2), respectively, and $AS(t)$ is the aggregate stability value in millimeters as a function of time.

The adjustments of the lognormal function parameters were calculated using data from an experiment performed under controlled conditions (Abiven et al. 2007), briefly described below. In this experiment, aggregate stability was followed after the incorporation of four organic substrates that broadly correspond to the four categories proposed by Monnier (1965) (Fig. 1). These fitted parameters were related to the biochemical characteristics of the organic substrates using a principal component analysis. At this stage, the model simulates the dynamics of aggregate stability under controlled conditions.

Aggregate Stability Dynamics under Field Conditions

To take into account the influence of the organic substrate composition on aggregate stability dynamics at the field scale, three functions describing the effect of soil moisture, soil temperature, and soil N availability on C decomposition were obtained from published studies. These equations are based on principles used in various C and N models, and under various soil and climatic conditions (i.e., Myers et al., 1982; Lloyd and Taylor, 1994; Benbi and Richter, 2002; Paul et al., 2003). These three factors are known to have a significant impact on soil biological activity. As we are considering that the dynamics of aggregate stability follow the same pattern as the decomposition of the organic substrates, and that the intensity and duration of the changes depend on the rate of decomposition of the organic substrates (Abiven et al., 2007), we hypothesized that these factors would have an impact on aggregate stability dynamics.

Rodrigo et al. (1997) analyzed the main mathematical descriptions of the effects of moisture, temperature, and their interaction on microbial pro-

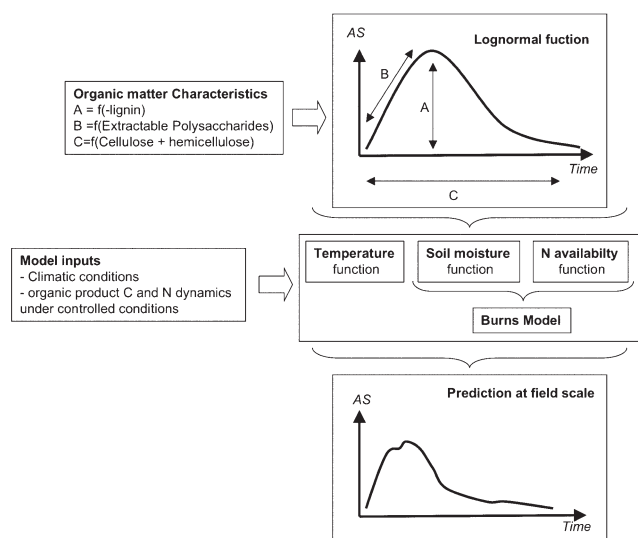


Fig. 2. Description of the Pouloud model structure, describing aggregate stability (AS) dynamics under controlled and field conditions, as a function of time; A , B , and C are the magnitude, scale, and shape parameters of the lognormal function obtained from laboratory results.

Table 1. Input parameters needed to run the model.

Inputs and parameters	Description	Utilization
Lignin, extractable polysaccharide, hemicellulose + cellulose	Description of the organic substrate characteristics	Aggregate stability dynamics under controlled conditions (Eq. [8])
Date of input, quantity of organic substrate	Information about the input applied to soil under field conditions	Aggregate stability dynamics under field conditions (Initial conditions)
Daily rainfall, potential evapotranspiration, average temperature	Meteorological data, measured at a daily step	Soil temperature and water fluxes (Eq. [2] and [3])
Soil moisture at field capacity, saturation, and wilting point	Reference values used to characterize the soil water fluxes	Water fluxes, effect of soil moisture (Eq. [2])
Reference temperature	Temperature corresponding to one normalized day	Effect of soil temperature (Eq. [3])
Dynamics of C and N mineralization	Mineralization of the organic substrate under controlled conditions	N availability (Eq. [4], [5], and [6])
Soil N mineralization	N mineralization of the soil without the effect of the organic substrates	N availability (Eq. [4] and [6])
Initial aggregate stability	Value of the aggregate stability before the input	Initialization of the model (Initial conditions)
Number of soil layers, bulk density	Soil characteristics	N and water fluxes (Burns model)

cesses used in C–N models. From this work, we chose the following equations, which were considered suitable for our soil and climatic conditions.

The influence of soil moisture was considered using

$$F_h = a + \frac{(1-a)(H-H_f)}{H_c-H_f} \quad (\text{Myers et al., 1982}) \quad [2]$$

where F_h is the number of days equivalent to 1 d at field capacity, H is soil moisture, H_f is soil moisture at the wilting point, H_c is soil moisture at field capacity, and a is an adjustment coefficient equal to 0.2, which was developed under conditions comparable to this study (Recous 1994; Rodrigo et al., 1997). The Burns (1974) model was used to distribute water and calculate H in different soil layers.

The following equation was then used to take into account the influence of soil temperature. It corresponds to the Van't Hoff function adapted by Recous (1994) for conditions comparable to those of our study:

$$F_t = \{p + q \exp[r(T - T_{\text{ref}})]\}^s \quad (\text{Recous, 1994}) \quad [3]$$

where F_t is the number of days equivalent to 1 d at the reference temperature, T_{ref} is the reference temperature, and p (−0.566), q (0.62), r (0.9125), and s (1.026) are adjusted coefficients (Recous, 1994). The values of p , q , r , and s were adjusted for data under conditions comparable to this study (Rodrigo et al., 1997). The reference temperature is fixed at 25°C, which corresponds to the temperature of the experiments under controlled conditions.

The calculation of the reduction in decomposition due to N limitation is based on Molina et al. (1983), who proposed a decomposition reduction factor, μN :

$$\mu\text{N} \left(C_p / N_d \right) = 0.2 + 1.26 \exp \left[-0.05 \left(C_p / N_d \right) \right] \quad [4]$$

where C_p is the potentially decomposable C per day (mg C kg^{-1}) and N_d is the available mineral N per day (mg N kg^{-1}). Because (C_p / N_d) can vary each day, μN is calculated every day.

The parameter C_p is the mineralization rate of the organic material C under controlled conditions for the day considered. It is calculated as the derivative value of Eq. [5] at each time step:

$$C(t) = I \exp(-J/t) \quad [5]$$

where $C(t)$ is the cumulative amount of mineralized C from the organic input with time, and I and J are adjusted on measured values for each amendment (Abiven et al., 2007).

As for water transfer, the Burns (1974) model was used to distribute mineral N_d in the different layers of the soils. The parameter N_d is determined using a N budget (Eq. [6]):

$$N_d = N_s + N_p - N_n + N_m + N_o \quad [6]$$

where N_s is the amount of N present in the soil layer, N_p is the amount of N leached from the upper layer, N_n is the amount of N leached to the lower layer, N_m is the mineralization of N from the soil, and N_o is the net mineralization of the organic input. The parameter N_o was measured experimentally with time (data not shown).

The two functions F_h and F_t give results that correspond to the number of days equivalent to 1 d at the reference temperature and moisture. The two values are multiplied at a daily step in each layer to correspond to the equivalent of 1 d under optimized conditions (Rodrigo et al., 1997). Concerning mineral N availability, the limitation implies an irreversible decrease in the decomposition activity (Recous et al., 1995) and, as a consequence, an irreversible decrease in the effects of organic substrates on aggregate stability. When (C_p / N_d) is < 10 , $\mu\text{N}(C_p / N_d) = 1$ (potential conditions). When soil N content is limiting, the aggregate stability calculated using Eq. [1] is decreased by the μN factor. The different inputs needed to run the model are summed up in Table 1.

Statistical Tools

The RMSE was used at different phases of the model construction to assess the quality of the simulations. This value corresponds to the deviation of the aggregate stability values simulated by the model compared with the measured values on the basis of an observed mean value:

$$\text{RMSE} = \left[\frac{\sum (Y_i - X_i)^2}{n} \right]^{0.5} \frac{100}{m} \quad [7]$$

where n is the number of observations, X_i is the measured values, Y_i is the simulated values, and m is the observed mean value. The RMSE was normalized to compare it with the observed mean values.

EXPERIMENTAL DATABASE

The four organic materials (cauliflower [*Brassica oleracea* L. var. *botrytis* L.] residues, wheat [*Triticum aestivum* L.] straw, cattle [*Bos taurus*] manure, and a very mature compost) were chosen to give a wide range in potential decomposability and, as mentioned above, to possibly correspond to the categories illustrated in Monnier's (1965) conceptual model. An extensive

Table 2. Characteristics of the soil used in the experiments.

Clay	Loam	Sand	pH (H ₂ O)	Organic C	Organic N
g kg ⁻¹				g kg ⁻¹	
95	518	387	7.7	10.9	1.0

study of the effects of these organic substrates on aggregate stability dynamics was presented in Abiven et al. (2007). Briefly, two experimental data sets were obtained, one under controlled conditions in the laboratory and the other one under field conditions. Both are based on the same organic substrates applied on the same soil (Table 2) and at the same rate (4 g C kg⁻¹). The soil is an Aquic Dystrudept.

The laboratory data set was obtained from incubations under controlled conditions, which were performed during approximately 4 mo at field capacity moisture and 25°C, and under nonlimiting N conditions for microbial activity. The production of CO₂ was measured on a regular basis to characterize the decomposition dynamics of the substrates, and soil samples were analyzed to determine the dynamics of N mineralization and aggregate stability.

The field experimental data set was obtained from a 2-yr experiment conducted in western France. The mean annual temperature was 11.8°C, and the cumulative annual precipitation and potential evapotranspiration were 746 and 853 mm, respectively, during the study period. Organic materials were applied to the soil in June 2002, and the soil was sampled approximately 1, 5, 12, and 24 mo after incorporation.

Aggregate stability was measured using the slow-wetting test method proposed by Le Bissonnais (1996). This method is believed to involve fragmentation of the dry soil aggregates by partial slaking induced by the slow wetting. An average mean weight diameter is calculated with the resulting fragments and is expressed in millimeters.

The organic substrate characteristics (total C and N concentrations and various biochemical characteristics) were reported and discussed in detail by Abiven et al. (2007). A summary is presented in Table 3.

MODEL PARAMETERIZATION

Calibration of the Lognormal Equation

The parameters of Eq. [1] were fitted to the aggregate stability data for the four different organic amendments: cauliflower, straw, manure, and compost (Fig. 3). The fit for the cauliflower and compost amendments is satisfactory (RMSE = 7 and 9%, respectively). There seems to be an overestimation of the effect of the cattle manure (RMSE = 16%), however, and an underestimation of the effect of straw during the first 30 d (RMSE = 11%). After this period, the fit is acceptable for all the organic substrates. The high RMSE observed for the manure and straw are attributable to the lower quality of the fit during the first 30 d.

A principle component analysis was performed to investigate possible relationships between the biochemical characteristics of the organic substrates and the parameters of Eq. [1]. Axes are

based on organic substrate characteristics, and the adjusted parameters *A*, *B*, and *C* are used as illustrative data, i.e., these values were not used in the calculation of the axes (Fig. 4). Each parameter appeared to correspond to a specific characteristic of the substrates. Parameter *A* is related to the opposite of the lignin content ($A = -0.0068L + 1.143$, where *L* is the lignin content in g dry matter kg⁻¹ dry matter). Parameter *B* follows the same trend as the extractable polysaccharide content ($B = 0.00768EP + 1.486$, where EP is the extractable polysaccharide content in g C kg⁻¹ C). Parameter *C* corresponds to the hemicellulose plus cellulose content ($C = 0.0289HC - 6.947$, where HC is the hemicellulose plus cellulose content in g dry matter kg⁻¹ dry matter).

These statistical relationships can be related to the decomposition potential of the different biochemical components. Organic substrates with a low lignin-like content will decompose more easily than materials rich in this compound (Robin, 1997). In this case, the parameter *A* will be higher and the magnitude of aggregate stability will be higher. A substrate with a high extractable polysaccharide content will decompose rapidly during the first few days. For this kind of substrate, the *B* parameter value will be high and the predicted aggregate stability will also increase rapidly during the first days. Finally, for a high *C* value, the decomposition of a substrate rich in cellulose and hemicellulose will last longer than substrates with lower content, and so will the effect of the substrate on aggregate stability.

The *A*, *B*, and *C* parameters can be replaced in Eq. [1] by these relationships to give an equation for aggregate stability as a function of extractable polysaccharide, hemicellulose plus cellulose, and lignin contents:

$$AS(t) = (-0.0068L + 1.143) \exp \left[-0.5 \ln \frac{t / (0.0289HC - 6.947)}{0.00768EP + 1.486} \right] \quad [8]$$

where *AS*(*t*) is aggregate stability in millimeters with time, *L* is the lignin content, HC is the hemicellulose plus cellulose content, and EP is the water-extractable polysaccharide content.

Sensitivity of the Model to Organic Substrate Characteristics

A sensitivity analysis of the lognormal function was performed to test the influence of all biochemical characteristics of the applied organic substrates (Fig. 5). For each organic substrate (cauliflower, straw, manure, and compost), eight simulations were realized. Each simulation was performed by (i) using as model input the original value of the substrate characteristics (lignin, hemicellulose plus cellulose, and extractable polysaccharides from Table 3) and (ii) by successively varying this original value by -20, -15, -10, -5, 5, 10, 15, and 20%. Only one parameter was modified at a time, i.e., each input parameter was considered independently. The RMSE (expressed as a percentage) was calculated between the result of the simulations and the measured values. To assess the sensitivity of the model to these model input changes, these RMSEs were compared with the average error in aggregate stabil-

Table 3. Chemical characteristics of the organic substrates used in laboratory and field experiments.

Substrate	C/N	Neutral detergent soluble†	Hemicellulose†	Cellulose†	Lignin†	Water-extractable polysaccharides
		g kg ⁻¹ dry matter				g C kg ⁻¹ C
Cauliflower	12.8	615	152	154	78	105
Straw	136.1	173	326	437	64	27
Manure	18.4	487	204	182	127	52
Compost	16.8	415	126	261	198	21

† Van Soest (1963).

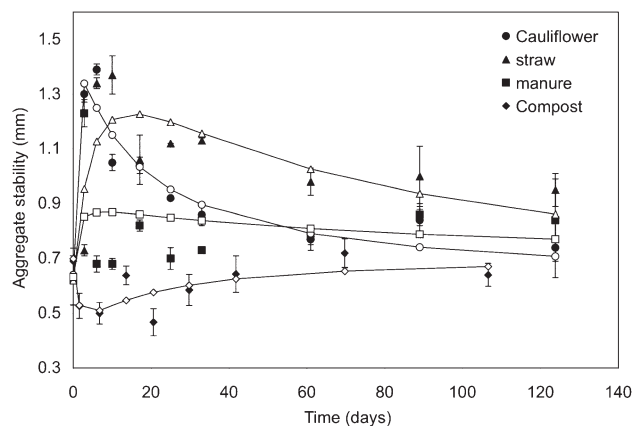


Fig. 3. Aggregate stability dynamics under controlled conditions. Measured values (filled symbols) and adjusted values (empty symbols) were calculated with Eq. [2].

ity measurement observed under field conditions. This value was established at a standard deviation of 0.10 mm, which represents a common average standard variability under field conditions. A corresponding value of RMSE was calculated for each organic product and represented by the dotted lines on Fig. 5. We assumed that the model simulation was accurate when the error calculated by the RMSE was lower than this common average variability.

In most cases, the lignin content was the parameter with the greatest impact on the accuracy of the model, especially for positive variations in its value. The RMSE was increasing when the lignin content was over- or underestimated. This suggests that if the value of the lignin content is not precisely estimated, the quality of the simulation would be lower. In most cases, however, this variation corresponded to a smaller variation than the commonly measured variability (Fig. 5). The hemicellulose plus cellulose fraction was also important for cauliflower, since values lower by 10% than the initial value strongly increased the error (RMSE = 14% at value -10%). Extractable polysaccharide content was not a sensitive parameter in the model. In the four contrasting cases, variations of this model input did not change the result of the simulation and the error was never greater than the commonly observed variability value.

APPLICATION OF THE MODEL TO FIELD DATA

The variations in aggregate stability under field conditions were generally well reproduced by the model for the four organic substrates used in the parameterization of the model (Fig. 6).

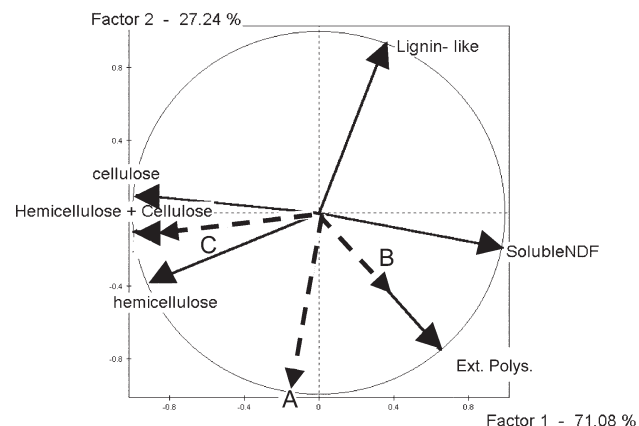


Fig. 4. Principle component analysis relating organic input characteristics and the A, B, and C parameters of Eq. [2]. NDF = neutral detergent fiber, Ext. Polys. = water-extractable polysaccharides.

For each organic substrate, the simulations reproduced the measurements with an accuracy that is comparable to the standard error of the experimental values. This was particularly the case for two (compost) or three (cauliflower, straw, and manure) dates of sampling. The global accuracy of the prediction (for the four sampling dates) was particularly good for the manure (RMSE = 3.3%). For straw and cauliflower, the general trend and three of the four experimental values were well predicted. The relatively high RMSE for these two residues is explained by the difficulty to predict the aggregate stability at the first sampling date. One other data point for which the

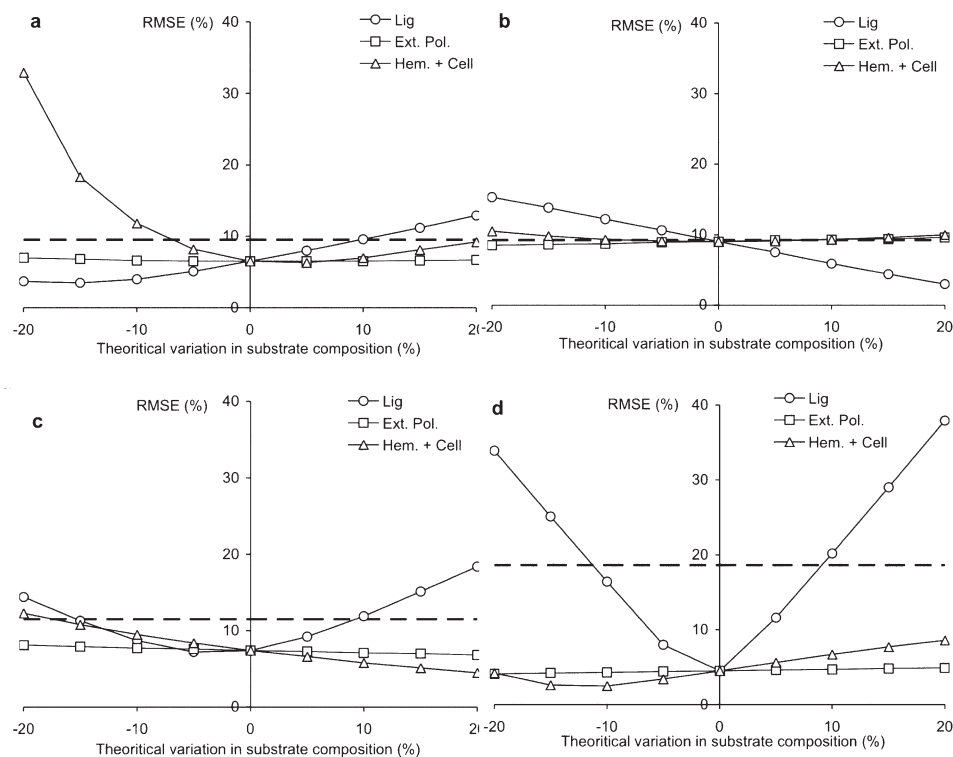


Fig. 5. Sensitivity analysis of the model to theoretical variations in organic substrate characteristics for (a) cauliflower, (b) straw, (c) manure, and (d) compost. Dotted lines represent the standard error corresponding to a variability of 0.10 mm of the aggregate stability value. Lig = lignin, Ext. Pol. = water-extractable polysaccharides, Hem. + Cell = hemicellulose and cellulose.

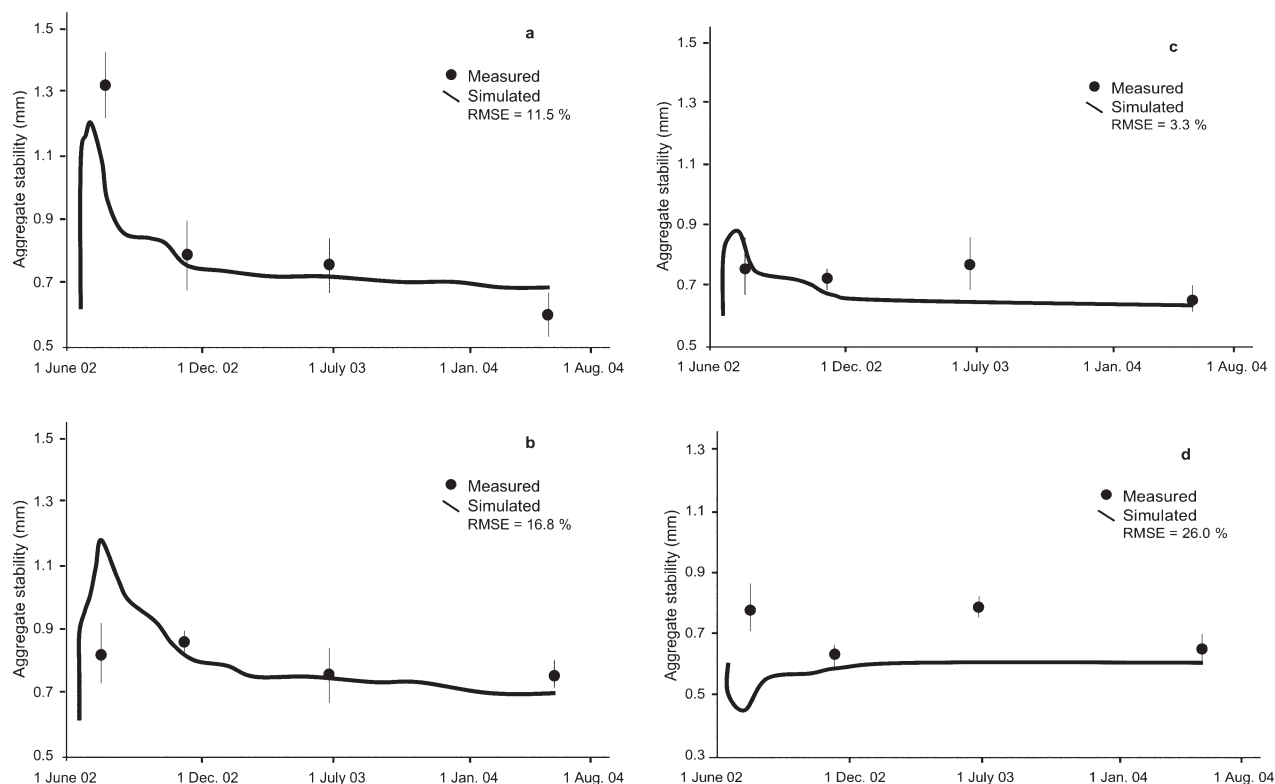


Fig. 6. Simulation of the effect of (a) cauliflower, (b) straw, (c) manure, and (d) compost on aggregate stability compared with field measurements.

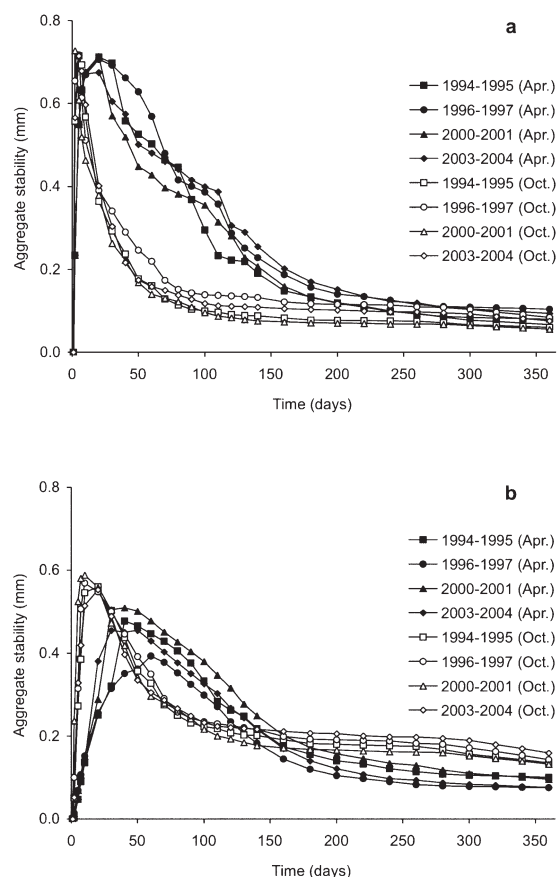


Fig. 7. Simulation of the effect of (a) cauliflower and (b) straw on aggregate stability with 4 climatic yr and two input dates.

model did not perform well is the compost at the first sampling date (approximately 1 mo after incorporation). Under controlled conditions, compost was found to have a small negative effect on aggregate stability (Abiven et al., 2007). Under field conditions, the effect of compost was still small but positive. Difficulties in reproducing aggregate stability during the first weeks after residue incorporation are due to important variations in the decomposition dynamics during this period. Initial conditions that are not taken into account, such as moisture content of the organic substrates or phenomena like priming effects (Kuzakov, 2002) can delay or accelerate the decomposition dynamics. In the model, these rapid variations in the conditions appear to be underestimating aggregate stability with cauliflower residues and overestimating it for the straw.

Influence of Climate and Incorporation Date Scenarios

To test the sensitivity of the model to different climatic scenarios, the effects of two incorporation dates of cauliflower and straw (Fig. 7) were simulated for four contrasting climatic years representing warm or cool summers, and dry or wet winters (Table 4). When organic materials were incorporated in October, the increase in aggregate stability occurred more rapidly and lasted for a shorter period of time than when the incorporation was performed in April. This was particularly the case for cauliflower. The early increase is due to favorable conditions of temperature and moisture for decomposition activity at the beginning of October. The short duration of the effect is due to the increased leaching of mineral N during the winter simulated by the model, which induces a limitation in the decomposition. The longer lasting effect when residues are applied in April is probably due to warmer temperatures, which increased decomposition activity and therefore aggregate stability and N availability.

General climatic conditions of a given year appeared to have less impact on aggregate stability than the date of incorporation of the residue (Fig. 7). When incorporation occurred in October, differences between the years were small. At that date, both residues were affected by the N limitation in the soil. When incorporated in April, the simulated dynamics were different for the two substrates. For instance, the lowest predicted values for cauliflower were predicted for the 2000–2001 period, which was warm and wet. We hypothesized that accelerated decomposition followed by N leaching reduced N availability and aggregate stability. Conversely, the lowest values for straw were predicted for the 1996–1997 year, which was dry and cold. The reduced N mineralization due to these conditions reduced the effect of straw on aggregate stability. Overall, this analysis suggests that N limitation has a major influence on aggregate stability prediction by the model.

GENERAL DISCUSSION AND CONCLUSIONS

The Pouloud model is a first attempt to predict the effect of incorporation of various organic residues on aggregate stability dynamics under field conditions. It is presented here more as a formalization of a preexisting conceptual model rather than a ready-to-use predictive tool. The complete test of the model will need to consider other soil and climatic conditions, as well as a broader range of organic substrates, even though the organic substrates chosen for this study are probably representative of the main categories that exist. In particular, experimental data sets obtained under laboratory and field conditions are necessary to further characterize and understand (i) organic substrate decomposition and its prediction; (ii) the synchrony between organic matter decomposition and aggregate stability dynamics, especially during the early peak of decomposition; and (iii) the accuracy of the temperature, water content, and N functions under different situations. The proposed model is based on the assumption that variations in aggregate stability induced by organic amendments are linked to fluctuations in biological activity. Further improvements of the model will have to take into account both the organic products responsible for these variations (carbohydrates, lipids, fungal hyphae, humic substances) and the effects of these products on aggregate stability mechanisms such as water-entry rate, differential swelling, hydrophobicity, and cohesion.

In conclusion, this approach allows to take into account the dynamic nature of soil aggregate stability with time and to use functions that describe the climatic and soil conditions that will influence the decomposition of the organic substrates under field conditions. Generally, trends in measured aggregate stability are well reproduced by the model and with relatively good accuracy. Differences between simulated and measured values are comparable to the error associated with field measurements. This suggests that prediction of aggregate stability dynamics using organic substrate characteristics and simple climate data is possible.

REFERENCES

- Abiven, S., S. Menasseri, D.A. Angers, and P. Leterme. 2007. Dynamics of aggregate stability and biological binding agents during decomposition of organic materials. *Eur. J. Soil Sci.* 58:239–247.
- Benbi, D.K., and J. Richter. 2002. A critical review of some approaches to modelling nitrogen mineralization. *Biol. Fertil. Soils* 35:168–183.
- Burns, I.G. 1974. A model for predicting the redistribution of salt applied to fallow soils after excess rainfall or evaporation. *J. Soil Sci.* 25:165–178.
- Degens, B.P., G.P. Sparling, and L.K. Abbott. 1996. Increasing the length of hyphae in a sandy soil increases the amount of water-stable aggregates.

Table 4. Characteristics of the different climatic years.

Years	Rainfall	PET†	Effective rainfall‡	Temperature
				°C
1994–1995	1160.5	686.3	474.2	11.6
1996–1997	547	672.3	–125.3	10.6
2000–2001	1346	649.5	696.5	11.3
2003–2004	703	840.5	–137.5	12.0

† Potential evapotranspiration.

‡ Effective rainfall is the difference between the rainfall and PET.

- Appl. Soil Ecol. 3:149–159.
- De Gryze, S., J. Six, C. Brits, and R. Merckx. 2005. A quantification of short-term macroaggregate dynamics: Influences of wheat residue input and texture. *Soil Biol. Biochem.* 37:55–66.
- De Gryze, S., J. Six, and R. Merckx. 2006. Quantifying water-stable soil aggregate turnover and its implication for soil organic matter dynamics in a model study. *Eur. J. Soil Sci.* 57:693–707.
- Gerzabek, M.H., H. Kirchmann, and F. Pilchmayer. 1995. Response of soil aggregate stability to manure amendments in the Ultuna long-term soil organic matter experiment. *Z. Pflanzenernaehr. Bodenkd.* 158:257–260.
- Kuzyakov, Y. 2002. Review: Factors affecting rhizosphere priming effects. *J. Plant Nutr. Soil Sci.* 165:382–396.
- Le Bissonnais, Y. 1996. Aggregate stability and assessment of soil crustability and erodibility: I. Theory and methodology. *Eur. J. Soil Sci.* 47:425–437.
- Lloyd, J., and J.A. Taylor. 1994. On the temperature dependence of soil respiration. *Funct. Ecol.* 8:315–323.
- Lynch, J.M., and E. Bragg. 1985. Microorganisms and soil aggregate stability. *Adv. Soil Sci.* 2:133–171.
- Martens, D.A. 2000. Plant residue biochemistry regulates soil carbon cycling and carbon sequestration. *Soil Biol. Biochem.* 32:361–369.
- Martens, D.A., and W.T. Frankenberger. 1992. Modification of infiltration rates in an organic-amended irrigated soil. *Agron. J.* 84:707–717.
- Martin, T.L. 1942. The effect of composts and compost materials upon aggregation of the silt and clay particles of Collington sandy loam. *Soil Sci. Soc. Am. Proc.* 7:218–222.
- Metzger, L., D. Levanon, and U. Mingelgrin. 1987. The effect of sewage sludge on soil structural stability: Microbial aspects. *Soil Sci. Soc. Am. J.* 51:346–351.
- Molina, J.A.E., C.E. Clapp, M.J. Shaffer, F.W. Chichester, and W.E. Larson. 1983. NCSOIL, a model of nitrogen and carbon transformation in soil: Description, calibration, and behavior. *Soil Sci. Soc. Am. J.* 47:85–91.
- Monnier, G. 1965. Action des matières organiques sur la stabilité structurale des sols. Thèse. Faculté des sciences de Paris.
- Myers, R.J.K., C.A. Campbell, and K.L. Weier. 1982. Quantitative relationship between net nitrogen mineralization and moisture content of soils. *Can. J. Soil Sci.* 62:111–124.
- Paul, K.I., P.J. Polglase, A.M. O'Connell, J.C. Carlyle, P.J. Smethurst, and P.K. Khanna. 2003. Defining the relation between soil water content and net nitrogen mineralization. *Eur. J. Soil Sci.* 54:39–48.
- Plante, A.F., Y. Feng, and W.B. McGill. 2002. A modelling approach to quantifying soil macroaggregate dynamics. *Can. J. Soil Sci.* 82:181–190.
- Recous, S. 1994. Réponse des matières organiques des sols aux changements atmosphériques globaux: II. Effet de la température sur la minéralisation d'un résidu végétal (maïs) et de la matière organique du sol. p. 81–85. *In Séminaire Ecosystèmes et changements globaux.* 17–19 May 1994. Dourdan, France.
- Recous, S., D. Robin, D. Darwis, and B. Mary. 1995. Soil inorganic N availability: Effect on maize residue decomposition. *Soil Biol. Biochem.* 7:1529–1538.
- Robin, D. 1997. Intérêt de la caractérisation biochimique pour l'évaluation de la proportion de la matière organique stable après décomposition dans le sol et la classification des produits organominéraux. *Agronomie* 17:157–171.
- Rodrigo, A., S. Recous, C. Neel, and B. Mary. 1997. Modelling temperature and moisture effects on C–N transformations in soils: Comparison of nine models. *Ecol. Modell.* 102:325–339.
- Six, J., C. Feller, K. Denef, S.M. Ogle, J.C. Moraes Sa, and A. Albrecht. 2002. Soil organic matter, biota and aggregation in temperate and tropical soils: Effects of no-tillage. *Agronomie* 22:755–775.
- Van Soest, P.J. 1963. Use of detergents in the analysis of fibrous feeds: I. Preparation of fiber residues of low nitrogen content. *J. Assoc. Off. Anal. Chem.* 46:825–835.