LOAMY SOILS UNDER EROSION RISK: INTEREST OF THE COMPOST AS A SOURCE OF ORGANIC MATTER TO RESTORE AND MAINTAIN PHYSICAL PROPERTIES OF FRENCH SOILS

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1. ABSTRACT

Manure and compost remain the most important sources of organic amendment. The latter, however, is poorly developed in France. To ensure its development, it is important to determine when organic matter really presents an interest for French soils.

For loamy soils, a decrease in soil organic matter content bellow a threshold value of 2 - 3 % is one of the main controlling factors of the soil's physical degradations like crusting and erosion. This is an increasing problem in France where an estimated 5 millions hectares are suffering from significant erosion. Two solutions can be proposed for this problem:

- reducing the losses of organic matter due to mineralisation by reducing the frequency and the depth of ploughing;
- increasing the input of organic matter by providing exogenous organic matter. This study sought to estimate if the present production of manure would be sufficient to restore and maintain the organic matter contents of loamy soils under significant erosion risk or if the addition of compost would be necessary. And if the latter case prevailed, which amounts of compost would be necessary. These estimates were made for threshold values ranging from 1 to 1.5 % of organic carbon. Results show local deficiencies of organic amendments in a number of French regions : Picardie, Aquitaine, Ile-de-France, Nord-Pas-de-Calais and Midi-PyrÈnÈes. The sensitivity analysis shows that the reliability of predictions is highly dependant from the target threshold value.

2. INTRODUCTION

2.1 Composts : a source of organic matter

France produces approximately 1 million tonnes of urban composts annually, representing 7% of the municipal solid waste treatment in France. However, the organic fraction of solid municipal waste is estimated at 14 millions tonnes (ADEME, 2000) which could represent about 4.5 millions tonnes of composts. There is hence considerable potential to develop this treatment method, which is also being induced by a number of legal measures.

1. Organic fractions should not be landfilled from 2002 (the 1st of July) (13 of July 1992 decree),
2. The regulation of 1996 fixed an objective of 50% recovery (Voynet decree).

But this development would require a lot of efforts, so it is important to know if the compost really presents an interest for French soils.

Used as an organic amendment, the compost provides an important source of stable exogenous organic matter (second after manure). It can be produced anywhere in France, contrary to manure, generally produced in large quantities but in areas of specialised farming (dairy and meat production). It is used in wine growing, orchards and especially in arable land (cereals, beets, oleaginous plants, etc.) where the lack of organic matter induce crusting and erosion. Indeed, the surfaces subject to erosion in France are about 5 millions hectares mainly located in the Nord-Pas-De-Calais, Picardie and the Seine-Maritime as well as in the Rhone-Alpes and Midi-PyrÈnÈes regions (Le Bissonnais et al, 1998).
The question addressed : "how much exogenous organic matter do the French soils need to reach a given organic matter level that might protect them against excessive crusting, and is the manure production enough to respond to this demand?".

2.2 Crusting and erosion in France

The erosion in plain is mainly due to the poor structural stability of the soil. Indeed if the soil structure is not stable, a strong rain (with intensity peaks above 30 or 40 mm/h, Robert, 1996) breaks the aggregates of the soil down. The particles or microaggregates separated from the aggregates clog in the interstices of the structure and so seal the surface. The water can not percolate any more and runoff starts. The structure of soil depends on two main controlling factors :

- a loamy texture : the soil will be subjected to erosion risk if it contains less than 15% of clay (Robert, 1996),
- low organic matter contents (below 2 or 3%, Le Bissonnais and Arrouays, 1997). In France the organic matter contents of cultivated soils decreased during the past decades (Balesdent, 1996). This is due to changes in land uses (Balesdent and Arrouays, 1999) with the specialisation of the agriculture, the suppression of the livestock farming and the substitution of grasslands by crops. Two solutions can be proposed to solve this problem:
- reducing the losses of organic matter due to mineralisation by reduced tillage (Kern and Johnson, 1993) or,
- increasing the input of organic matter by providing exogenous organic matter. Indeed 3 types of organic matter with different actions on soil structure must be distinguished:
- the fresh organic matter which has an intense but very short action,
- the stabilised organic matter which has a long term effect,
- the very stable organic matter.

Fresh organic matter is easy to degrade and thus stimulate the microbiological activity. The secretions of the micro-organisms reduce the wettability of the pores surfaces and so increase the resistance to disaggregation by water. However fresh organic matters are quickly degraded. The stabilised organic matters have a longer effect for two reasons :

- first, because they are longer to degrade, they regularly provide decomposition products, that stimulate the microbiological activity,
- second, they favour the aggregation of the soil particles (LinËres, 1993). Among the different exogenous organic amendments, manure and composts are the largest available sources.

2.3 Objective of this study

The objective of this study is to calculate how much exogenous organic matter would be necessary to restore and maintain loamy soils at a given organic matter sufficient to protect them from systematic or excessive crusting. These estimates are made for threshold values ranging from 1 to 1.5 % of organic carbon.

3. MATERIALS AND METHODS

3.1 Carbon threshold value

The carbon threshold for loamy soil beyond which structural stability may increase is subject to discussion. However most studies give a range of 1% to 1.5 % of carbon (Greenland et al. 1975 ; Grieve, 1980 ; Newbould, 1980 ; De Ploey and Poesen, 1985 ; Albrecht et al, 1992 ; Le Bissonnais and Arrouays, 1997). That is the reason why we did the calculation for 6 different carbon values : 1 - 1.1 - 1.2 - 1.3 - 1.4 - 1.5%

3.2 Estimation of the concerned area

We focused on the arable loamy soils with low organic matter content and exhibiting a significant erosion risk. Estimate and mapping of these areas were made by overlaying maps of parameters from several databases.

- the CORINE Land Cover map (Collectif, 1993),
- the French soils erosion risk map (Le Bissonnais et al, 1998),
- the French soils geographical database (1 : 1 000 000) (Jamagne et al, 1995; King et al, 1999),
- the French soils carbon database (17 000 points, Arrouays et al, in press).

Then for each soil type we calculated :

- the average of the carbon content and
- the percentage of the values inferior to the carbon threshold. We used this percentage as an assessment of the percentage of surface concerned.

3.3 Estimate of the quantities of exogenous organic matter necessary

3.3.a Hénin Dupuis formula

We used the HÈnin-Dupuis model (HÈnin and Dupuis, 1945) in its exponential form (Van Dijk, 1980). This model calculates the organic matter content as following :

$$y_t = \frac{K_1 x}{K_2}\left(1 - e^{-K_2 t}\right) + y_0 e^{-K_2 t}$$

Where :

- y_t is the quantity of stable organic matter at time t,
- x is the input of organic matter,
- K_1 is the humification coefficient,
- K_2 is the mineralisation coefficient.

K_1 represents the ratio of the quantity of organic matter that increases the soil organic matter rate (equal to the stable organic matter) on the total organic matter quantity. K_2 represents the annual rate of destruction of the organic matter. We used the following values for our calculation (RÈmy and Marin-LaflËche, 1976).

Soil	% clay	% limestone	pH	K_2
Neutral sand	50	2	7	0.020
Acid sand	50	0	5	0.010
limestone sand	50	100	8	0.17
Average silt	150	2	7.5	0.16
Clayey silt	220	2	7.5	0.13
Limestone silt	100	300	8.1	0.009
Clay	380	2	7.5	0.10
Clayey-limestone	300	150	8	0.007

Table 1 : Organic matter mineralisation coefficients (R˚ my and Marin-Lafl˙ che, 1976)

We did the calculation with the following hypothesis :

- Ratio organic matter/carbon : 1.724, … Bulk density : 1.4,
- Depth of soil concerned : 30 cm
- We calculated for each year the final organic matter yt with an input of organic matter x equal to :
- the part of the crops residues returned to soil calculated below and,
- a spread of 1.25 t/ha/y of stable organic matter (equivalent to a spread of 40 t/ha of manure every 2 years or a spread of 30 t/ha of compost every 3 years).

We used the following coefficients for the calculations:

	Manure	Composts
Isohumic coefficient : K1	0.34*	0.5 **
Percentage of fresh organic matter	18%.	25% ***

Table 2 : organic amendments coefficients
* Boiffin et al, 1986, ** close to the values of biowaste or green waste composts (Le Bohec et al, 1999 ; Houot et al, 2000), *** ADEME, 1998.

In both cases, we intentionally used coefficients that minimise the quantities of organic matter necessary.

3.3.b Crop residues returned to soils

The fractions from the crop residues returning to soils are :

- the roots (compulsory part),
- the aerial parts that could be let in the field and buried or exported (optional part).

We calculated the quantities of stable organic matter brought to soil by the crop residues from :

- the total areas of each crop in each department (Agreste, 1999),
- the yield of stable organic matter (CERES software, Jones and Kiniry, 1986).

To avoid to count twice the cereals straw, we calculated the straws returned to soil from :

- the departmental cereal area (Agreste, 1999),
- the quantities of straw gathered in (from SCEES / BCPF),
- an average straw yield of 0.7 tonnes / hectare (Messmer, 1996; Agreste, 1999). With these hypothesis the crop residues returned to soil represent nearly 16 millions of tonnes of stable organic matter.

3.3.c Sources of exogenous organic matter

The main source of exogenous stable organic matter is manure which is generally produced locally and most often on the farm itself.
It was estimated that this source accounts for more than 86 millions of tonnes (fresh matter). We calculate the national manure production by French department from :

- the cattle estimation (Agreste, 1999),
- the percentage of manure and slurry produced by each species (Pflimlin, 1999),
- the dejection production for each animal (CORPEN, 1998).

We applied a coefficient 0.5 to the result of bovine manure to take into account the time spent in grazing.

4. RESULTS AND DISCUSSION

4.1 Concerned areas

The surface concerned by this study is 3.4 million hectares (Mha), accounting for 6% of the national surface and 17% of arable land. This area declines to 2.7 Mha and 1.3 Mha respectively if we only consider the surface for which the carbon content is less than 1.5% and 1% respectively.

4.2 Amounts of organic matter necessary to restore and maintain threshold values

The quantities of stable organic matter necessary for restoration and upkeep expressed in amounts of composts are illustrated in figure 1.

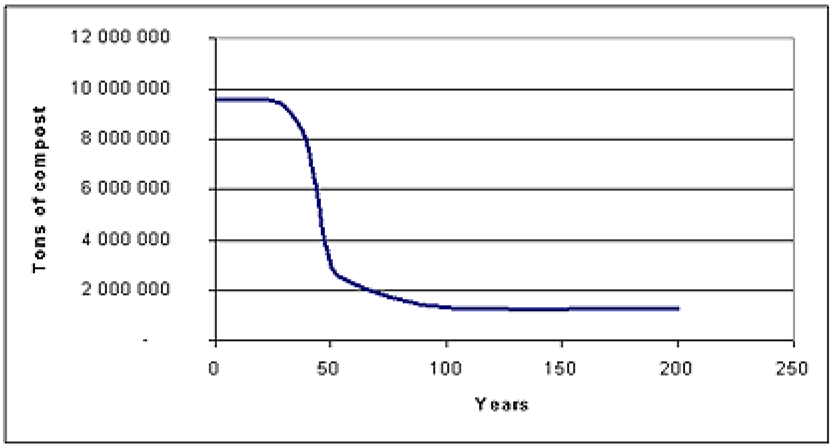


Figure 1 : Amounts of composts

A first plateau corresponds to the minimal duration of restoration for all soils. This stage is followed by a sharp fall that corresponds to the progressive reaching of the soils carbon content to the threshold fixed. The last stage corresponds to the quantities necessary to maintain these soils to the threshold fixed. The table 3 presents the tonnes of compost that would be necessary to restore and maintain the soils to different carbon thresholds. It also present the duration of the first stage.

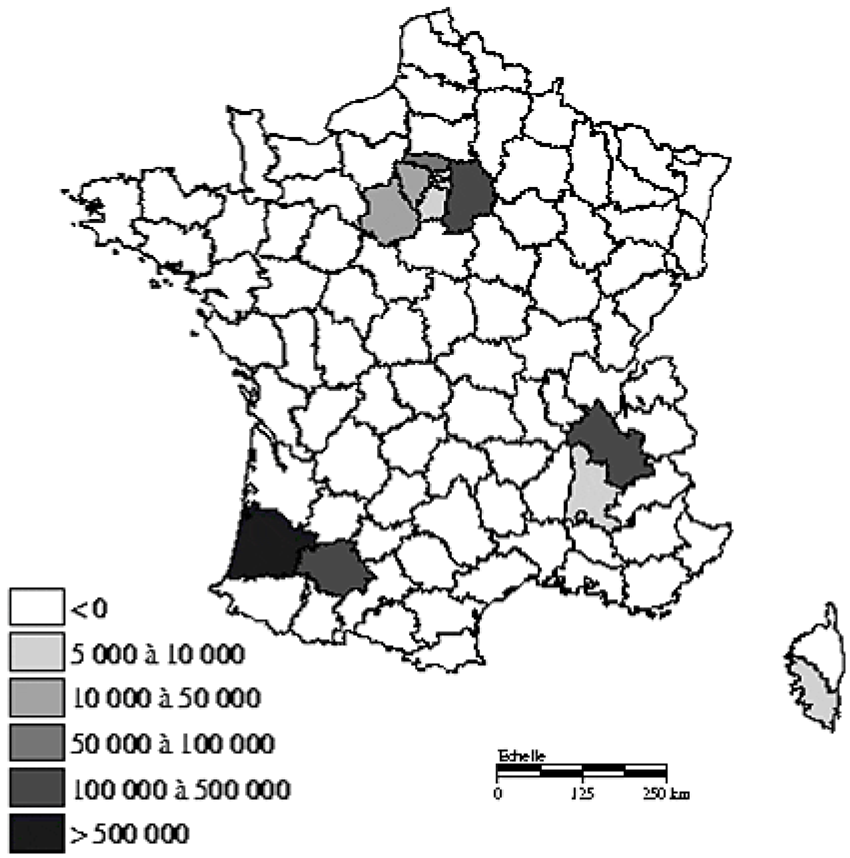
Carbon thresholds (%)	Tonnes of composts necessary in restoration	Tonnes of composts necessary in maintain	During of the first stage of the graph (in year)
1	2 180 000	0	5
1.1	4 120 000	460	10
1.2	6 000 000	120 000	10
1.3	7 260 000	300 000	20
1.4	8 300 000	670 000	20
1.5	9 580 000	1 300 000	40

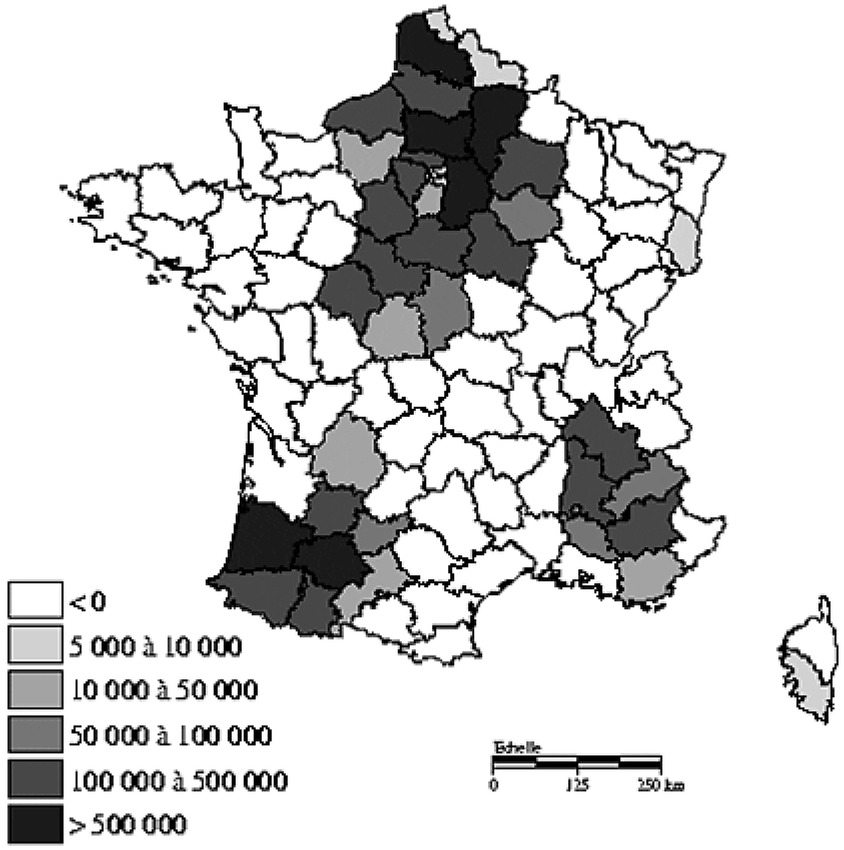
Table 3 : amounts of composts necessary to restore and maintain the soils to different carbon thresholds

According to this estimate, the local use of manure would not be enough to restore the carbon stocks of the soils concerned, but would be enough to maintain the soils at a threshold of 1% of carbon.

4.3 Districts concerned

The maps 1 and 2 represent the departments which would be concerned by the need of composts in restoration (map 1) and in maintain (map 2).





Map 1.&Map2.

The regions concerned are :

- For restoration : Picardie, Aquitaine, Ile-de-France, Nord-Pas-De-Calais, Midi-Pyrénées and Rhone-Alpes,
- For maintaining : Aquitaine, Ile-de-France, Midi-Pyrénées and RhÙne-Alpes.

4.4 Discussion

4.4.a Comparison with the compost production

The compost production is distributed accordingly:

- Sludge compost : more than 110 000 tonnes (CarrÈ, 1995),
- Green waste compost : 240 000 tonnes (ADEME, 1999),
- Biowaste compost : 33 000 tonnes (from ADEME, 2000),
- Mixed municipal solid wastes compost : 630 000 tonnes (ADEME, 2000).

The present production of compost would not be enough to restore the carbon stocks of the soils concerned. However after restoration it would be enough to maintain the soils at a threshold of 1%, 1.1%, 1.2%, 1.3%, 1.4% of carbon, but not at 1.5%. This threshold of 1.5% was demonstrated for the silty soils of South of France (Le Bissonnais et Arrouays, 1997).

4.4.b Model accuracy

These estimates were made using the HÈnin-Dupuis model, which is widely used in France, but fails to take into account a number of important variables and kinetic processes which require a multi-compartment model (Mary and GuÈrif, 1994). We recommend that this study be reviewed and new conclusions drawn based on the work currently being performed on bicompartimental models (Mary and GuÈrif, 1994), or multi-compartment models.

4.4.c Organic matter deficit

This study is based on the hypothesis that the soils exhibiting a high erosion risk and low organic matter content present a deficit of organic matter. This deficit can be compensated in different ways: crop system adaptation, modification of cultivation practices or exogenous input. But other actions can be engaged to reduce the erosion risk : installation of anti-erosion systems or modification of cultivation practices.

5. CONCLUSION

T The objective of this study was to calculate the amounts of organic matter necessary to restore and maintain at a given level the organic matter content in soils exhibiting a high risk of crusting and erosion. The results suggest that the amounts of manure locally available are inadequate to restore and maintain the soils concerned. For a threshold of 1.5%, 10 million tonnes of compost would be necessary for restoration, and this declines after 40 years to 1.3 million tonnes annually once the threshold of organic content is reached. In the light of such findings, it appears that composting has much potential for development in France. But only a very good quality of compost will be able to guaranty the future and commercial viability of this activity. This estimates must also bear in mind the limitations of the model used as described in section 4.4 above. Further improvements should include :

- Elaborating accurate references for the calibration of organic matter evolution model : long term field experiment (Houot et al, 1999),
- Improving database accuracy ,
- Developing more mechanistic models of organic matter evolution.

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