

# Organic carbon in soils

Meeting climate change  
and food security challenges



Local authorities and farming sector

## KNOWLEDGE AND ACTION



# Editorial



## *Soil carbon: what are the issues for climate and agriculture?*

**Jérôme Mousset**

Head of the agricultural and forestry service, ADEME

Soil is the living base for agricultural and forestry production and a limited resource which cannot be renewed at the human scale. Increasingly, land is in demand and there is tension between different land uses. Changes in production practices, ploughing up of grassland, loss of arable and wooded land for urbanisation, increased use of biomass... There are so many changes which, if not taken into account, could affect soil quality and lower soil carbon stocks. Nevertheless, soil is a considerable asset in strategies for mitigating climate change. But this issue lacks visibility and, in order to raise awareness among territorial administrators, decision makers, farmers and foresters, ADEME has enlisted the help of experts, scientists, advisers and representatives of public authorities to produce this brochure.

This brochure aims to clarify the role of soil in mitigating the greenhouse effect and, furthermore, to highlight the environmental benefits of better management of organic matter. A healthy, living, well-balanced soil containing organic matter can increase production potential, contribute to optimising the use of agricultural inputs, filter water from these pollutants and increase biodiversity. This idea of environmental and economic services chimes exactly with the principles of agroecology. ■

## **GIS Sol in brief**

Created in 2001, GIS Sol (sol being the French word for soil) is a French scientific network focused on soils. The network includes the French National Institute for Agricultural Research (INRA), the French Environment and Energy Management Agency (ADEME), the Ministry of Agriculture, Food and Forests, the Ministry of Ecology, Sustainable Development and Energy, the Institute of Research for Development (IRD) and the National Institute for Geographical and Forestry Information (IGN).

GIS Sol is seeking to create and manage an information system on French soils, including data about their spatial distribution, their characteristics and changes in their quality. It works in the knowledge that soil is a limited and non-renewable resource at the human scale.

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# Soils, a carbon pool essential for the climate

*In the form of organic matter, soils store two to three times more carbon than the atmosphere. Therefore their use creates fluxes in CO<sub>2</sub> and has consequences on climate change. Today, the challenge is to limit carbon losses linked to changes in land use and to increase carbon stocks by promoting suitable agricultural and forestry practices.*

Carbon dioxide (CO<sub>2</sub>) is the main greenhouse gas (GHG) linked to human activities. At the global scale, nearly 35 billion tonnes of CO<sub>2</sub> were emitted in 2013 through the consumption of fossil fuels such as oil, gas and coal, and through cement production. Terrestrial ecosystems mitigate these emissions by capturing more than a third through photosynthesis.

### **PRESERVING STOCKS OF ORGANIC MATTER**

Organic matter in the soil is the largest reservoir of organic carbon, even greater than plant biomass. Worldwide, the first metre of soil contains between 1,500 and 2,400 billion tonnes of organic carbon. Losses of these soils and the organic matter they contain throws into question their role as a carbon sink and increases emissions. A reduction of only 5% in carbon stocks represents the

equivalent of two to four years' carbon emissions. In France, 3 to 4 billion tonnes of carbon are stored in the first 30cm of soil, which is three times more carbon than is present in forestry woods. The levels of carbon stocks are highly variable, depending on land use, soil type and climate. The trend shows a general reduction in organic matter in agricultural soils, though there are large regional and territorial differences. The evolution of carbon stocks in French soils remains very uncertain because of the many mechanisms involved and the difficulty of measuring them: the extension of forest areas, development of urban areas, conversion of grassland into cultivated areas and changes in agricultural practices. And to this we can add climate change, a phenomenon which encourages plant production and boosts the degradation of organic matter.

### **TAKING CARBON FLUXES INTO ACCOUNT**

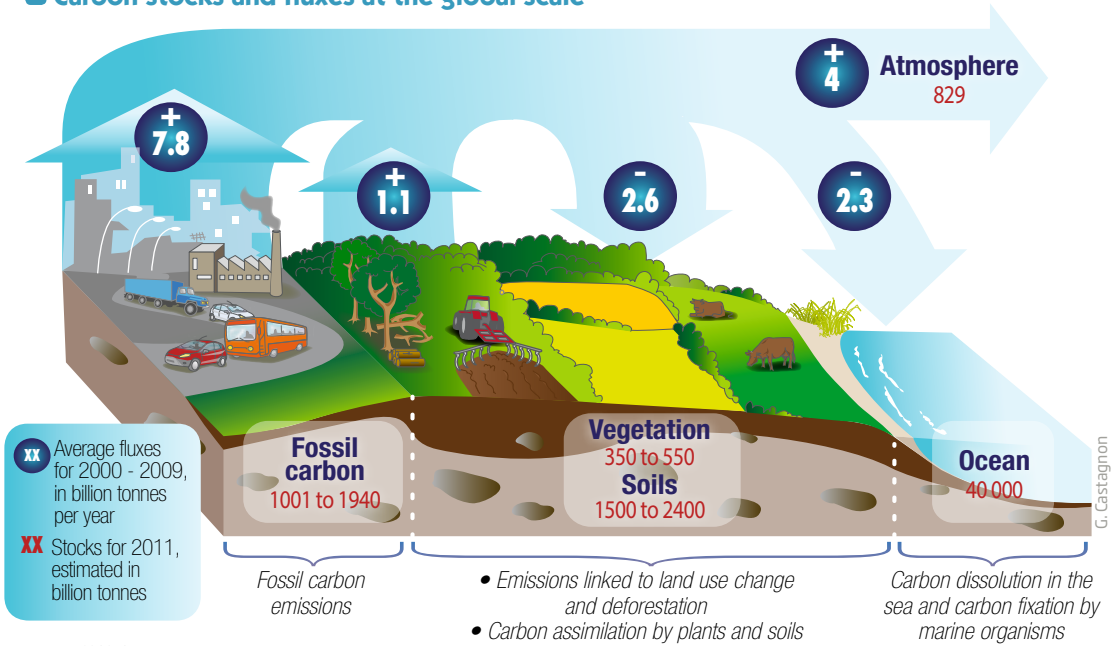
With the adoption of decision 529/2013/EU in 2013, keeping accounts of GHG emissions and

**4 per 1,000**  
A '4 per 1,000' annual increase of organic matter in soil would be enough to compensate for the global emissions of greenhouse gases (see page 27)

storage, integrating changes in soil carbon stocks, has become compulsory for European Union Member States. From 2013, this has included variations linked to forestry practices and, from 2021, will include those linked to the management of cropland and pastures. This decision is evidence of the first step towards the future integration of land use issues in European Union commitments to reducing GHG emissions. Within carbon markets, voluntary carbon offsetting schemes represent a way of valuing carbon storage in soils. Currently, at the international scale, the number of such initiatives and reductions in GHG emissions are very limited because of the diverse nature of emissions and uncertainties over storage levels. More reliable and cheaper evaluation methods are needed. ■

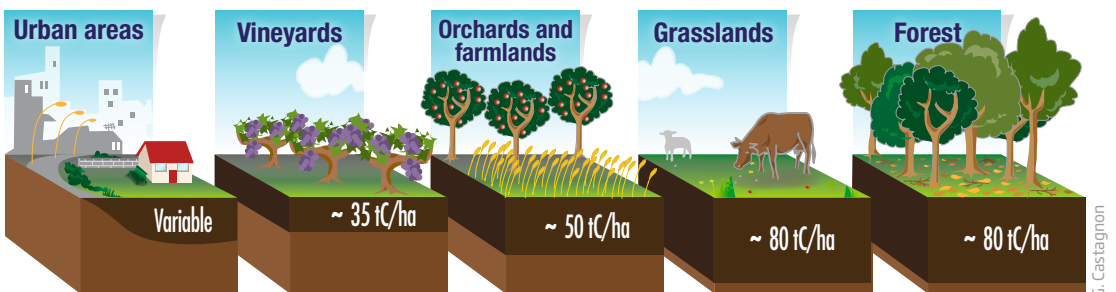
**3 to 4 billion tonnes**  
of carbon are stored in the first 30cm of French soils

## Carbon stocks and fluxes at the global scale



The atmosphere contains 829 billion tonnes of carbon, among which 240 result from human activities, starting from the year 1750. The most important annual flux is linked to industrial and urban areas with 7.8 billion tonnes, to which is added the flux linked to land use change and deforestation, up to 1.1 billion tonnes. These emissions are partially compensated by carbon assimilation through photosynthesis, as well as carbon dissolution in the oceans (2.6 and 2.3 billion tonnes respectively). Some 4 billion tonnes of carbon are added in the atmosphere every year.

## Variations in organic carbon stocks depending on land use in France



### **XX** Estimate of carbon stored within the 30 first centimetres of soil

Organic matter stocks in forests, grasslands and low vegetation growing in highlands are large, whereas stocks are quite low in vineyards, farmlands and Mediterranean zones. Quantifying stocks is difficult in urban areas; nevertheless, a significant amount of carbon could be stored under green spaces. Carbon stored in forest litter is not taken into account.



# Continuously providing soil with **organic matter**

*Soil organic matter can be defined as 'everything that is alive or was alive in the ground'. Organic matter undergoes a degradation which leads to mineralisation. Carbon contained in organic matter is largely released into the atmosphere in the form of a gas. So, in order to maintain carbon stocks, there must be compensation for these losses. Here we explain further...*

Organic matter enters the soil in a 'fresh' form: plants (fallen leaves, crop residues, root exudates etc.), micro-organisms or dead animals. A large part is quickly decomposed: in a few months, organic matter is mineralised by decomposers such as fungi and bacteria, and transformed into carbon dioxide (CO<sub>2</sub>) which is quickly

released into the atmosphere\*. To a lesser extent, losses of organic matter are also due to leaching of dissolved organic matter, water and wind erosion, and fire.

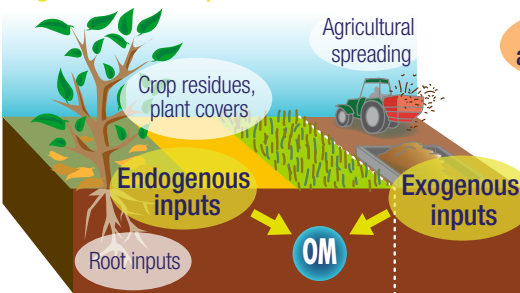
## THE INFLUENCE OF CLIMATE AND SOIL CHARACTERISTICS

In the soils of some large ecosystems, such as African savannas

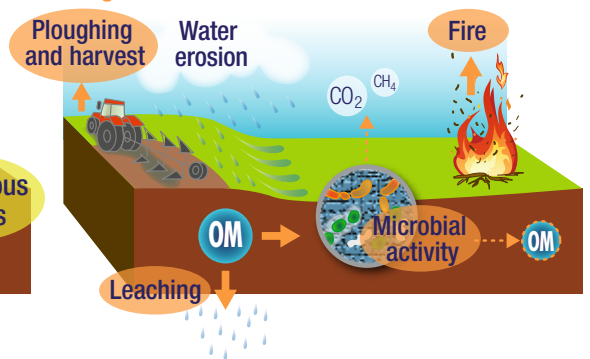
and tropical forests, the storage of organic matter in the soil happens with the same rapidity as its degradation. In agro-ecosystems this balance can be disturbed by many factors, which can favour the accumulation of organic material or, on the contrary, its mineralisation. Rainfall and temperature play a major role. For example, low or high humidity levels can hinder

### ■ How is organic matter formed and degraded?

#### Organic matter inputs



#### Organic matter losses



Apart from root inputs, the major source of organic matter inputs is from the surface. On the other hand, organic matter degradation is mainly an underground mechanism, ensured via microbial activity. Possibilities for action can involve both increasing inputs and reducing losses.



A.D.

Roots contribute a lot to carbon storage in soil

the activity of decomposers in soils which naturally accumulate more organic matter than others. Conversely, a 10°C increase in temperature can double or even triple microbiological activity. Climate change, which currently stimulates plant productivity (temperature and CO<sub>2</sub> concentration in the atmosphere) and mineralisation of organic matter, has an impact on carbon storage which is difficult to assess. Finally, the physical and chemical characteristics of soil reduce mineralisation through their ability to 'protect' organic matter (see box).

### FARMERS: MANAGERS OF ORGANIC MATTER

When harvesting, farmers remove large amounts of plant material. This means the quantity of organic matter returned to the soil is limited. Furthermore, practices such as ploughing aerate the soil and encourage microbial activity and, there-

## Expert opinion



**Éric Blanchart**  
Research director  
French Institute of  
Research for Development

***Structure and nature of soils influence organic matter stability***

*"While the major share of organic matter is quickly mineralised, a more modest quantity can undergo three mechanisms which can help it stabilise and resist mineralisation. First possibility, a chemical transformation: some microbes can transform organic matter into complex carbon molecules, difficult to degrade chemically. The second option consists in integrating organic matter in aggregates, in order to create a physical barrier against microorganisms' action. Third possibility: if soils are rich in clays and carbonates, these elements can react with organic matter, creating a physico-chemical protection against mineralisation. Finally, even if organic matter can be protected and remain stable for a long time - up to several thousand years - it always ends up mineralised."*


fore, mineralisation. Given the important role of organic matter and its positive influence on the environment, the idea is to maintain high inputs of organic

matter and adapting losses to a minimum. ■

\*Some organisms (autotrophic, anaerobic) can consume CO<sub>2</sub> before it is released in the atmosphere. However, they are very few of them and so this mechanism is considered as minor.

# Organic matter: providing environmental services

*Organic matter in soils is essential for the proper functioning and sustainability of agricultural and forest ecosystems. Organic matter ensures soil stability, carbon storage, water quality, biodiversity etc. Some of these services depend on the quantity of organic matter contained in the soil while others depend on the mineralisation of organic matter.*

rganic matter provides multiple environmental services. First of all, organic matter is a food source for organisms living in the soil, microorganisms and fauna. A soil with a high organic matter content encourages the presence of these animals and plants, which are both numerous and varied, and therefore enhances biodiversity.

## *Bio-indicators to evaluate organic matter dynamics*

Bacteria and fungi degrade organic matter, nematodes regulate microorganism populations and earthworms structure soils...The ADEME 'Soil quality bio-indicators' programme aims to provide a better understanding of the role of soil-living organisms, in order to supply public and private stakeholders with tools for monitoring and characterising soil quality. The monitoring of many variables linked to soil ecosystems, in different agro-climatic conditions, has made it possible to evaluate the impact of managing soil organic matter on biodiversity. The abundance of fungi and microbial groups and the diversity of nematodes have been identified as early indicators of changes in a soil's organic quality.

## **MINERALISATION, POSITIVE FOR PLANT NUTRITION...**

Organisms living in the soil feed on organic matter, and hence contribute to its decomposition and mineralisation. Yet, organic matter acts as a sponge in the soil: it adsorbs and contains various elements which are released once mineralised. In agricultural and forest ecosystems, plants benefit from the cations and mineral elements released as they contribute to their nutrition.

## **... THOUGH COMPENSATION IS NEEDED TO MAINTAIN CARBON STOCKS AND LIMIT CONTAMINANT TRANSFERS**

The mineralisation of organic matter has other effects. First of all, it produces simple molecules such as greenhouse gases (CO<sub>2</sub>, N<sub>2</sub>O or CH<sub>4</sub>, depending on the degradation conditions), which are mainly released into the atmosphere\* and therefore contribute to the greenhouse

effect. Nitrate and phosphate ions released represent profitable nutrients for plants but, if not assimilated, they can be transferred to water flows. Mineralisation can also free organic and metallic contaminants which were trapped in organic matter. Therefore it is important that stocks of organic matter are progressively replenished, through plants or exogenous inputs which comply with regulations. If these stocks are maintained, the services provided by mineralisation





© CLUZEAU Daniel/INRA

A soil profile made of soil clods and aggregates is a complex living system, providing habitat for soil microflora and fauna.

can be ensured, carbon stocks remain constant and contaminant transfers can be limited.

**PROVIDING STRUCTURE FOR SOIL**

Finally, the maintenance of a certain quantity of organic matter is essential to soil structure, as well as its stability when faced with rainfall. In effect, organic matter acts like ‘glue’ in the soil. It aggregates mineral particles and also provides a food supply for organisms (microorganisms, earthworms) whose activities are also beneficial for soil structure. Therefore, organic matter contributes directly and indirectly to soil structure, which profits both agriculture and the

environment. Indeed, crop roots benefit from aerated soils and the infiltration of water is enhanced, avoiding problems such as runoff and erosion. ■

\* Very few microorganisms are able to consume these gases in the soil.

**Expert opinion**

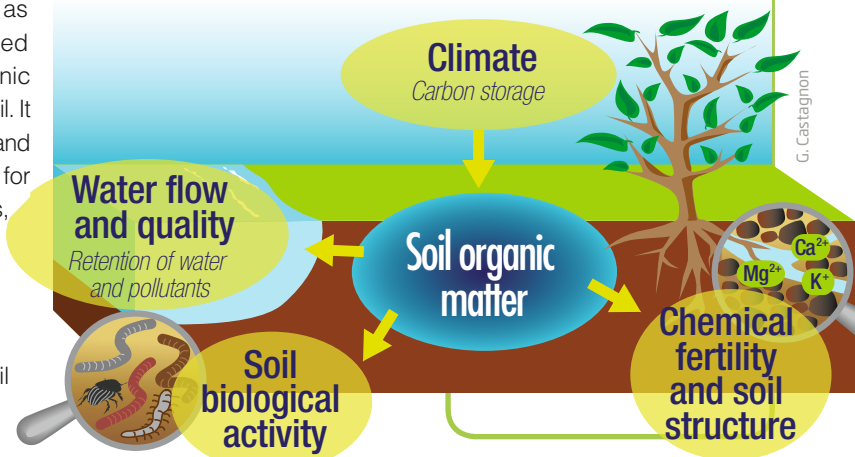
**Claire Chenu**

Teacher-researcher and  
FAO soil ambassador  
AgroParisTech



**Multifunctional**

Both the presence and degradation of organic matter are very important. It is a real ‘turntable’ for the cycles of major elements (carbon, nitrogen and phosphorus) and pollutants in soil ecosystems. It acts as a filter for the environment by storing natural contaminants, not only organic but metallic and synthetic. When degraded, organic matter benefits the environment in a different way, by providing a nutrient supply for plants and enhancing soil biodiversity.



G. Castagnon

# Carbon storage in soils: rising awareness

*Research and public policy are joining forces to boost carbon in French soils and therefore better combat climate change.*



**Dominique Arrouays**,  
Research engineer and  
scientific coordinator of the  
Global Soil Map Programme,  
Infosol Unit of the National  
Institute for Agricultural  
Research (INRA), Orléans.



**Joseph Lunet**, project leader  
responsible for agriculture  
and forest in the Ministry of  
Sustainable Development  
(Energy and Climate Head  
Office, Greenhouse Mitigation  
Department).

The general public may not yet be fully aware of the importance of soils as a carbon pool and a tool for mitigating climate change. However, the business community and the political sector have started to show an interest. “In the agricultural and forestry sectors, awareness is rising,” explains Dominique Arrouays, an INRA researcher specialising in soil. He adds: “It probably isn’t so true for actors in the parks sector and those working in regional planning.” At the Ministry of Sustainable Development, Joseph Lunet confirms that present policies do consider the major role played by soils. According to him, public authorities are especially prominent

in improving knowledge about the mechanisms and amounts of carbon involved. He explains: “The French state supports public research programmes which aim to improve our knowledge, under the supervision of GIS Sol<sup>(1)</sup>. Working on a better knowledge of carbon fluxes in farmland and forest soils is essential.”

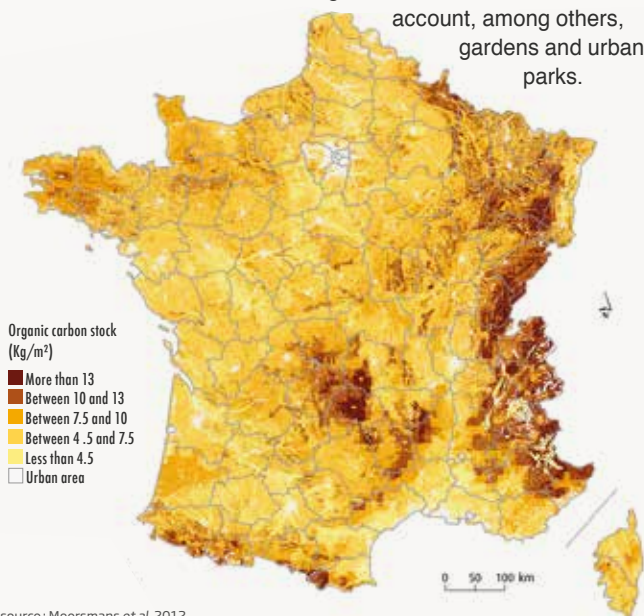
## **MAINTAINING OR ENRICHING ALREADY LARGE STOCKS**

For the moment, Dominique Arrouays considers present

and past land use, climate, clay content, soil depth and agricultural and forestry practices as the main sources of variations in carbon levels in French soils. “The potential for increasing stocks is not necessarily found in the most carbon-weak areas,” he explains. “It might be more useful to preserve or increase already high stocks, rather than try and create new ones in areas where the potential for stabilisation is low. Furthermore, region-specific actions exist, depending on the business sector.”

### Map of carbon stocks in French soils

Thanks to the Soil Quality Measurement Network (known by its French initials RMQS – [www.gissol.fr](http://www.gissol.fr)), soil carbon stocks have been mapped. They seem greater in highlands and livestock areas. The network does not provide a value for carbon stocks in urban areas (shown in white on the map). However, the inventory of national greenhouse gas emissions suggests that urban areas could contain half the stocks of grassland areas. It takes into account, among others, gardens and urban parks.



source: Meersmans et al. 2012

### GROWING IMPORTANCE OF INCENTIVE MEASURES

According to Joseph Lunet, support measures which aim to preserve or increase carbon stocks in agricultural soils are increasingly important, especially with the new 2014-2020 CAP (Common Agriculture Policy), and through France's 'Loi d'avenir' legislation for agriculture and forests. Indeed, these policies support incentives for the preservation of permanent grassland

“ In the agricultural and forestry sectors, awareness is rising. It needs to be developed in the parks sector and regional planning.



“ France would like to see the land-use sector included in future international climate agreements.

”

and ecologically important areas, ban the destruction of some natural meadows, limit clearance of wooded areas and tackle urban sprawl etc.

The representative of the Ministry of Sustainable Development adds that the issue of carbon and soil is not currently at the heart of climate-related policies, “because soil carbon is poorly taken into account within the framework of the Kyoto Protocol”. According to him, France would like to see that the land-use sector is “included in future international climate framework agreements, post 2020”. That way, policies could take greater account of incentive measures to protect or increase soil carbon stocks. ■

(1) Group of scientific interest including INRA, ADEME, IGN, IRD and the Ministries of Agriculture and Environment.

# Changes in land use: the need to preserve carbon-rich soils



© A.D.

Ploughing up grasslands for crop cultivation causes carbon losses. The Common Agricultural Policy encourages farmers to preserve grasslands.

*The reconstruction of organic carbon stock in the soil takes several decades. This means we should focus on protecting those areas which contain the highest stocks, and on controlling urbanisation.*

Turning grassland into cropland leads to a depletion in soil carbon, while afforestation of cropland increases carbon storage. According to the Ministry of Agriculture's annual agricultural statistics, the main land-use changes in France between 1990 and 2010 included a 0.6 million hectare (Mha) increase in afforested land, but also an increase in urbanised land of 1.4Mha. These land-use changes have been to the detriment of farmland, causing a net loss of 1.3Mha over 20 years, and a 0.7Mha loss of natural land. Within agricultural

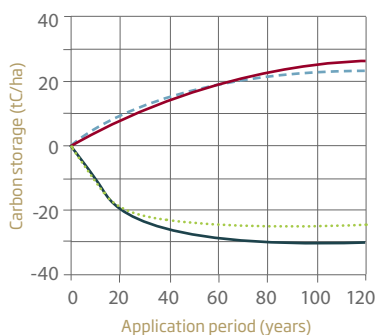
land, permanent grassland has seen the biggest impact, with a loss of 1.6Mha, mostly for conversion to crop cultivation.

### CONTROLLING LAND USE

Although afforestation increases carbon stocks, urbanisation and, in particular, soil sealing leads to a loss of organic matter and soil functions which are very difficult, if not impossible, to reverse.

In all cases, in order to preserve French soil carbon stocks and maintain ecosystems which act as carbon sinks, natural environments should be protected and

### Carbon stock evolution, depending on land-use change



During the first twenty years which follow a change in land-use, carbon is lost twice as fast as it is stored. Only after several decades or even more than a century can carbon storage compensate carbon losses.

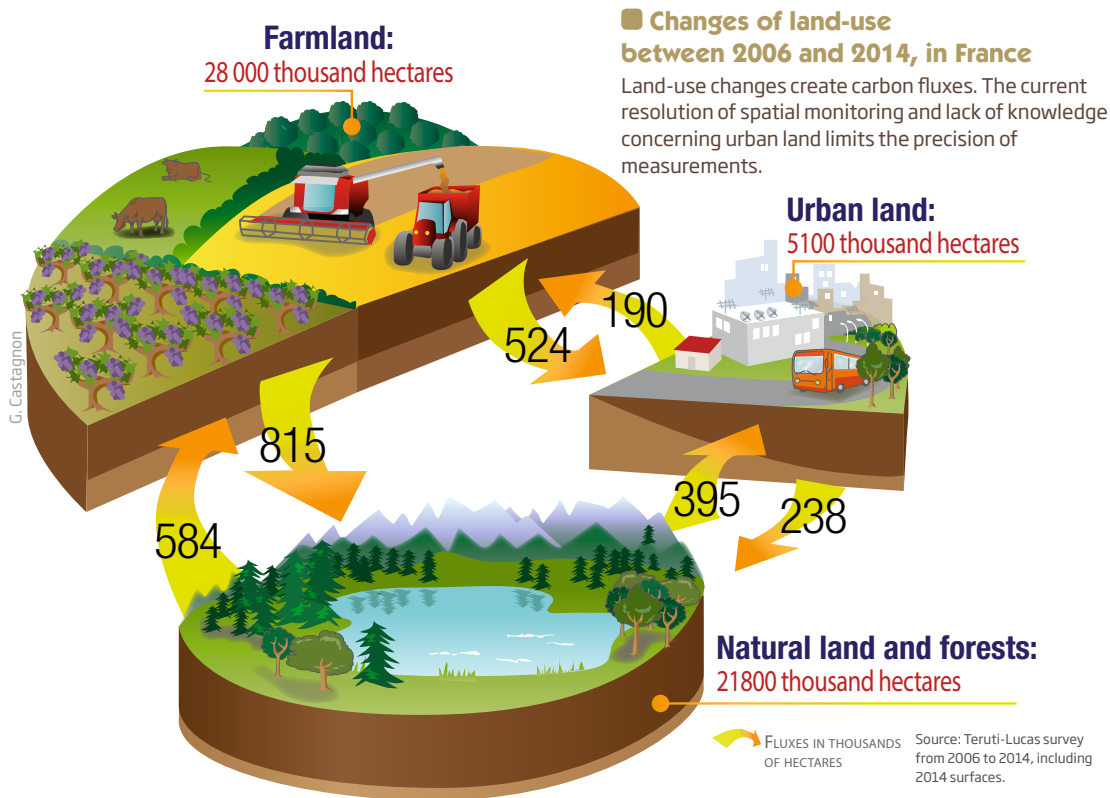
Source: Arrouays and al. 2002

More than **400,000ha** of grassland have been ploughed in France since 2000, and 1.6Mha since 1990.

(source: Agricultural Statistics).

In France, **70,000ha** farmland hectares have been lost between 2006 and 2014, according to Teruti-Lucas.





livestock systems should preserve grasslands. Regarding agriculture, agro-environmental measures deter the ploughing of grassland after five years. The French Safer<sup>(1)</sup> group can also intervene to pre-empt lands threatened by urbanisation. Other regulatory levers are foreseen in the codes dealing with urbanisation, rural areas and the environment, and within the framework of the ALUR law<sup>(2)</sup>. They involve various mechanisms, such as protection zoning, pre-emption and norms on urban densification. ■

(1) Real estate development and rural establishment companies  
(2) Law for access to housing and renewed urban planning.

## Expert opinion



**Antonio Bispo**  
Soil and environment engineer at ADEME

### **Integrating carbon stocks in GHG environmental assessments in land-use policies**

“Any change in land use, whether it is for non-food crops or for urbanisation, can have consequences, not only in France but also in developing countries. So, deforestation may intensify in order to maintain the offer of raw materials on world markets. Within the framework of a working group launched in 2010, the impact of French policies promoting bio-fuels on farmland use and CO<sub>2</sub> emissions has been evaluated. This research is now being extended and is integrating different scenarios and drivers in land-use changes, such as urbanisation and agricultural objectives, both at a national scale and worldwide. Competition for different land uses is a major issue for public policies.”



# Forest soils: rationalising the increase in harvested wood



*The demand for and disruption of forest soils is lower than for farmland, and they evolve slowly. Nevertheless, their fertility is limited and very dependent on natural flows of elements and organic matter. An increase in wood demand for energy purposes needs to be accompanied by measures seeking to protect them.*

The medium and long-term effects of wood harvesting intensification on carbon stocks are not well known. The impacts of different practices strongly depend on soil characteristics.

In chemical terms, forest soils are generally the poorest within a territory, or those whose physical characteristics are the most unfavourable to agriculture. Unlike agricultural soils, they undergo no or very little alteration due to human activity. As a result, organic matter is highly accumulated in the litter and surface layers of soil. In temperate forests, there is approximately as

much carbon stored in the soil as there is in the trees.

## **SUSTAINABLE FORESTRY PRACTICES**

Carbon stocks evolve more slowly in forest soils than in agricultural soils. Usually, they are assumed to be stable, but very little monitoring has been conducted to make it possible to know their true medium and

long-term evolutions, especially under the influence of changes in forestry practices.

In the future, the foreseeable increase in wood demand - for energy or material needs - will encourage the intensification of forest harvesting. The impact of this intensification on stocks is uncertain; it could lead to opposing effects on litter production and the integration of harvest

waste in the soil. Nevertheless, a greater harvest of forest residuals, which includes young trees and branches remaining on land after harvesting and pruning of trees, for energy needs, directly decreases soil intakes of carbon. The ADEME guide\* on 'The sustainable harvesting of forest residuals' recommends that not all of the above-ground biomass should be taken: a portion of the residuals should be left on the ground at each harvest, and residuals should be collected once, maybe twice, in the stand's life. These recommendations were made in order to preserve the mineral chemical fertility of forest soils and reduce soil compaction, but are also valuable in preserving carbon stocks. ■

\* The guide will be updated on the basis of the collective expertise RESOBIO coordinated in 2013 by GIP ECOFOR

## Expert opinion

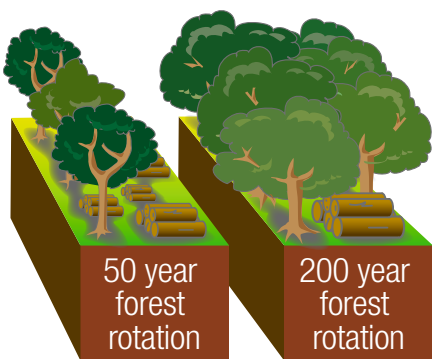


**Laurent Augusto**  
INRA researcher

### Indicators to protect soil fertility

"The challenge for research consists in finding logistical levers in order to mobilise underexploited woodland, but also in finding good compromises to manage forests which are increasingly in demand. The latter have to preserve their various functions, such as wood production, biodiversity reservoirs and carbon storage. In this context, maintaining organic matter stocks in forest soils is essential, because unlike other countries, French forests receive practically no inputs to contribute to soil fertility. Yet, half of the forests are former farmlands reforested in the middle of the 19th century, because they were too poor or difficult to cultivate. In order to preserve this capital, the challenge consists in finding the right balance between exported wood and the wood left on the ground. Today, research projects are seeking to develop indicators so forest managers can improve their harvesting practices."

G. Castagnon



### ■ Elements in the GHG balance in the wood sector

Harvesting larger quantities of forest wood could limit increases in carbon stocks in the soil and trees. For a complete evaluation of the GHG balance in the wood sector, we need to take into account carbon storage in wood products (construction and furniture) as well as substitutions of other materials and fossil fuels.

#### Construction and furniture



- Replaces fossil materials
- Stores carbon

#### Energy



- Replaces fossil energies

# Agricultural soils: acting on organic matter inputs and losses



In order to return higher amounts of organic matter to the soil, it is necessary to favour soil cover by including intermediate crops in the rotation and grassing between the rows in vineyards and orchards.

In France, **less than 1%** of cultivated land is directly sown.

**4.6Mha** is cropped using simplified cultural techniques, a third of the cultivated area.

(Source: Arvalis Institut du Végétal).

*To boost carbon levels in agricultural soils, two specific actions have been identified: favouring practices which increase stocks of organic matter and limiting those which increase losses of organic matter.*

According to INRA estimates in 2002 and 2013, the maximum potential of additional carbon storage in agricultural soils should reach 1 to 3 million tonnes a year over 20 years. This storage could compensate a significant proportion - some 3 to 4% - of France's annual greenhouse gas emissions, but would require a very pro-active approach.

The practices which should be implemented involve either increasing inputs of organic matter or reducing losses.

### **SUPPLYING MORE ORGANIC MATTER**

The first action identified to increase soil carbon stocks is to increase plant production and return more organic matter to the soil. To achieve this, it is necessary to promote the use of soil cover through the inclusion

of intermediate crops in crop rotations, grassing between rows in vineyards and orchards, and extending the lives of temporary grasslands.

The planting of hedges and grass and flower strips enriches the soil in organic matter alongside their role as biodiversity reservoirs, ecological corridors and buffer zones between crops and water courses. With the introduction of rows of trees in fields and pastures, agroforestry techniques lead to an increase of the carbon stocks in soils as well as in wood. In low productivity grasslands (grazing land, high mountain pastures and moorland), moderate intensification practices can be implemented. For crops and grasslands which have already been intensified, the concern is not to increase inputs but to better preserve crop residues. Finally, the application of organic matter from urban

sources or of manure could be an interesting solution at the local scale, provided low-carbon soils are prioritised and it meets existing regulations.

## **SLOWING CARBON LOSSES**

Hedges and soil cover also effect carbon stocks, by reducing runoff and losses due to erosion.

Putting an end to ploughing would lead to an increase in soil-carbon levels as colder and wetter surface conditions and better physical protection in the aggregate slows down the mineralisation of organic matter. According to the Arvalis plant institute, 34.4% of France's cultivated land is currently cropped using simplified cultural techniques (no-till or low-till), mainly autumn crops. Low-till techniques include direct

sowing and more or less deep interventions. Their impact on carbon stocks has often been overestimated.

Based on the monitoring of experiments conducted by the international scientific community, only direct sowing provides an average increase over ploughing (0.15 tonnes of carbon storage per year). This result is highly variable depending on the situation. Moreover, field trials led by Arvalis over 40 years on the Boigneville site in Essonne (south of Paris), show that after a 2t/ha annual organic carbon storage over 24 years, direct sowing does not differ from ploughing after 40 years. Furthermore, ploughing is sometimes necessary for agronomic reasons (see box). According to INRA, occasional ploughing every five years would

preserve part of the possible gain in carbon stocks and, above all, save on fuel. ■

## *Expert opinion*

**Jérôme Labreuche**

Agro-equipment centre manager at Arvalis - Plant Institute



### *Taking better account of practices which enhance organic matter inputs*

The implementation of intermediate nitrate-trap crops (INTCs) during long interculture periods has been encouraged by regulatory obligations. This farming practice improves soil humic balance, especially since carbon storage by INTCs has recently been reappraised. There is also a trend for keeping these crops for a longer time-period, and planting them in areas where it is not necessarily compulsory. Another evolution in practices has been spotted: in cereal production areas, some farmers do not hesitate to add organic inputs to the soil.



### *When ploughing is justified*

According to the Arvalis plant institute, ploughing is most often conducted for spring crops and on soils low in clay content. It provides security for spring crops, as ploughing encourages crop emergence and improves soil structure in situations where there is a significant risk of soil

compaction (late harvesting or loamy soils). It is also the case that for easy-to-plough soils this practice is not often called into question. In a context where weed control is increasingly complex, ploughing is recommended, especially where there is strong pressure from grass weeds.

# Agricultural practices according to their cost and efficacy

In 2013, INRA analysed the potential of agricultural practices for mitigating French GHG emissions. Agroforestry, no-till, extending the life of temporary grasslands and maintaining permanent soil cover appear to be the most effective levers for stimulating carbon storage. Here we present the lessons learned.

Then different actions have been identified by INRA for limiting agricultural emissions of three major greenhouse gases (CO<sub>2</sub>, N<sub>2</sub>O and CH<sub>4</sub>) over the next 15 years. These measures have to be pragmatic and avoid yield losses beyond 10%. Added together, they could lead to a 32 million tonne CO<sub>2</sub>-equivalent reduction per year by 2030. These measures also include economic factors. Those which aim at reducing CO<sub>2</sub> emissions together with increasing farmers' revenues act mainly on economies in the use of fossil fuels and carbon storage in soils and biomass. Regarding carbon sequestration in the soil, the most effective mitigation measures are occasional ploughing (3.77Mt CO<sub>2</sub>-equivalent per year) and agroforestry (1.53Mt CO<sub>2</sub>-equivalent per year). However, the long-term impact of occasional ploughing needs to be clarified (see p.17). The cost-efficiency of these measures remains modest

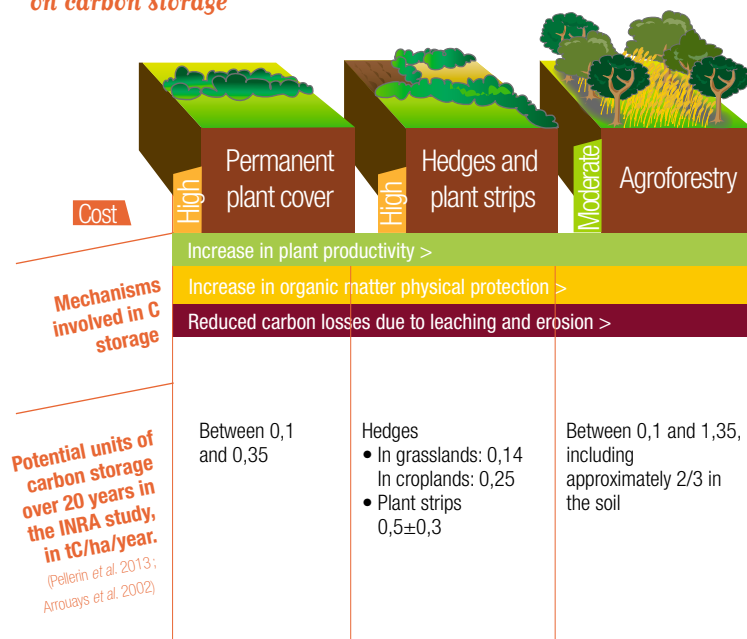
at less than €25 per tonne of CO<sub>2</sub>-equivalent avoided.

## UNDERSTANDING ALL THE BENEFITS

Other moderate-cost measures stimulate the storage of organic

matter: increasing the life of temporary grasslands (1.44Mt CO<sub>2</sub>-equivalent per year) and extending the grazing period. Extending grazing periods also influences other GHGs because part of the manure usually emitted

### Estimation of impacts of agricultural practices on carbon storage



#### Note:

- A tonne of carbon stored is the equivalent of around 3.66 tonnes of CO<sub>2</sub> captured.
- Agricultural land in France covers around 28.2Mha.



## Expert opinion



### Sylvain Pellerin

Coordinator of the INRA study: 'Ten measures to reduce GHG emissions through agricultural practices'

"For the first time, we have measured and quantified GHG emissions mitigation potential, and the related costs. Carbon storage is favoured by moderate-cost measures, such as no-till or agroforestry. In order to improve the carbon-storage dimension of these practices, inventory methods have to progress. Today, only land-use change impacts are measured."

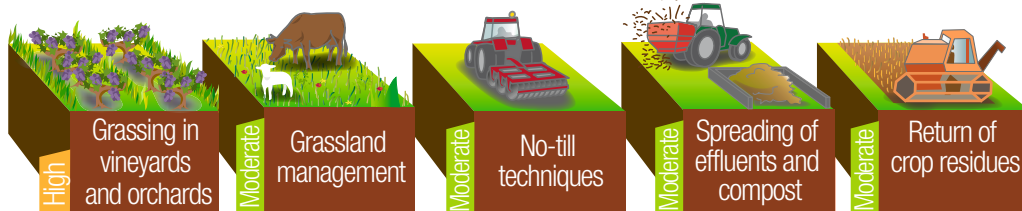
in the barn, and the emissions of  $N_2O$  and  $CH_4$  associated with it, will be reduced. The planting of hedges, intermediate crops, permanent grassing in vineyards and orchards and introducing flower or plant strips (2.77Mt  $CO_2$ -equivalent per year) have a higher cost, mainly because of the working time required. Nevertheless, these measures benefit other

environmental aspects, such as conserving the quality of water, soils and biodiversity, of which the economic impact has not been taken into account in this study.

### CARBON STOCKS CAPPED IN THE MEDIUM-TERM

Overall, the levers relating to carbon storage in soil and

biomass represent 30% of the potential mitigation of GHG emissions, when including their effects on  $CH_4$  and  $N_2O$  emissions, and the substitution of fossil fuels. Beyond the date set in this study - 2030 - carbon stocks will reach a ceiling and net  $CO_2$  fixation will end. However, the other effects of mitigation, such as savings in fuel, will continue. ■



Increase in plant productivity >

Increased return of organic matter to the soil

Reduced carbon losses due to leaching and erosion >

Lower mineralisation if the ratio C/N is high

- For permanent soil covers in orchards:  $0,5 \pm 0,3$
- For permanent soil covers in vineyards:  $0,3 \pm 0,2$
- For temporary soil covers in vineyards: 0,16

- Increase in temporary grasslands' lifetime (< 5 ans): 0,15
- Moderate intensification of poor permanent grasslands: 0,4

- Transition to direct sowing: 0,15
- Transition to ploughing every five years: 0,10
- Shallow tillage: no additional C storage

Between 10 and 50% of the carbon input, according to type of input.

0,15 for 7 tonnes of straw

# Reconstructing carbon stocks

## Many benefits to highlight



**Sandrine Leménager**, project leader on soil subjects at the head office of Agriculture, Food and Territorial Policies (DGPAAT) at the Ministry of Agriculture.

*Practices which favour the storage of organic matter or which preserve carbon already existing in the soil are better perceived in the field if they combine several environmental benefits. Different tools and levers are available to make their implementation easier. Here we explain.*



**Jean-Luc Fort**, head of the agronomy and environment service at the Poitou-Charentes Chamber of Agriculture and coordinator of the 'Sols et Territoires' Combined Technology Network.

Farmers are aware of the importance of carbon storage, particularly in regard to its benefits for biological activity and overall soil fertility. Yet the role of organic matter in environmental assessments is poorly taken into account. "The time required for reconstructing carbon stocks is so long that this issue isn't enough to trigger corrective measures in agricultural practices," says Jean-Luc Fort, manager of the agronomy and environment service at the Poitou-Charentes Chamber of

Agriculture, and coordinator of the Sols et Territoires (soil and land) Combined Technology Network.

"On the other hand, technical bodies, agricultural advisers and cooperatives are involved in plenty of development and awareness-

raising programmes based on the multiple environmental benefits." Sandrine Leménager, project leader at the soil division at the agriculture, food and territorial policies department (known by its French initials DGPAAT) of the Ministry of Agriculture, identifies new opportunities to better take into account issues relating to soil carbon and climate. The timetable provides evidence: "2015 is a pivotal year," she says. "France is hosting the 21st climate conference, Paris Climat 2015 (COP21). It is also the International Year of Soils. The 2014-2020 CAP (Common Agricultural Policy) strongly prioritises measures which ensure greenhouse gas mitigation through carbon storage in soils, such as the preservation of pasture, soil cover, areas of ecological interest... Finally, the fight against the urbanisation of farmland and forest helps to protect the ecosystem services provided by soil carbon storage."



“ Using only the carbon storage angle is not enough to encourage favourable farming systems. We need a multifunctional point of view. ”

### PRIORITISING INCENTIVE MEASURES

According to Sandrine Leménager, approaching carbon issues through agricultural practices which favour its storage is the entry point. The practices identified concern soil cover, notably intermediate crops, flower or grass strips, inputs of organic matter and the development of agroforestry, but also hedge maintenance and afforestation. She insists: “There are tools to encourage the implementation of each measure, particularly within the CAP. Some are incentives, others are statutory, but there is a clear tendency to better take into account soil and carbon issues within agricultural practices.” For Jean-Luc Fort, the agro-environmental measures included in the second pillar of the CAP (Common Agricultural Policy) are relevant levers, because

## Context

### Measures encouraging carbon storage

Measures	Levers
Organic matter inputs	Ongoing discussions about organic residues and current policy promoting farm-sourced organic matter.
Intermediate crops, Grass or flower strips	Nitrates Directive and implementation legislation. CAP - greening: zones of ecological interest
Grassing in vineyards and orchards	CAP, agro-environmental measures
Hedges, Agroforestry	CAP, agro-environmental measures Art. 23 of 2014-2020 rural development regulation CAP - greening: zones of ecological interest
Preservation of permanent pasture	CAP - greening: no ploughing of permanent pasture classed as sensitive, and for other areas if Member State wishes. The diminution rate of permanent pasture must not exceed 5% nationally.

they are based on the environmental benefits and economic compensations obtained, and not only on the administrative management of a problem. “We need to turn this around, to value the agricultural and economic benefits of a better consideration of environmental

“ Measures which encourage carbon storage meet the goals of the French agro-ecological project. ”



aspects. Innovative crop management techniques combining several environmental goals are very welcome since they also include agricultural and economic interests. In our region, lucerne (alfalfa) is a perfect example of positive synergy: we use lucerne as a low-input crop which benefits the rotation with, in parallel, the maintenance of livestock which feed on it and add value to the crop.” This synergy can even go beyond the farming sector. Among the selected measures which increase organic matter, Sandrine Leménager favours the spreading of organic matter inputs, “on the condition that their safety and agronomic value have been demonstrated. The Ministries of Agriculture and of Sustainable Development are working to this end,” she adds. ■

# Measuring changes at the field scale

*At the field scale, the influence of the actions implemented on soil carbon stocks can be assessed through direct measurements and estimated with the help of models. The latter can help agricultural advisers in changing agricultural practices. Below is an overview of the tools and norms available.*

The impact of field management on soil carbon stocks can be quantified using direct measurements, before and after the implementation of new practices.

### DIRECT MEASUREMENTS TO EVALUATE RESULTS

Direct measurement methods require particular caution (see box 'Expert opinion'). We have to

Estimation of	Example of norm	Objective
Organic matter dynamics	NF X31-516, 2007	Isolate particular organic material (plant residues in course of decomposition) and organo-mineral complexes
Soil microbial biomass	NF EN 14240-1 et -2, 2011	Estimate the microbial activity of organic matter degradation
Soil respiration	NF EN 16072, 2011	
Certain enzyme activities	NF EN 23753-1 et -2, 2011	
Earthworms	NF EN 23611-1, 2011	Value the number and diversity of invertebrates involved in organic matter dynamics (e.g. earthworms, nematodes)
Mites and springtails	NF EN 23611-2, 2011	
Enchytraeid worms	NF EN 23611-3, 2011	
Nematodes	NF EN 23611-4, 2011	
Total macro-fauna	PR NF ISO 23611-5, 2010	

### Expert opinion



#### Annie Duparque

Head of agronomy at Agro-Transfert Ressources and Territories, and partner in the RMT Sols et Territoires (soil and land combined technology network).

#### Carbon dynamics: three key points to bear in mind

"In order to assess carbon dynamics, we need a relevant sampling procedure. Different measures have to be made on the same soil amount, and bias must be avoided due to the spatial heterogeneity of organic matter content in farm fields.

"We need to be careful on three different points: recording the samples' locations with a GPS, and returning to the exact same place for further measurements five to seven years later; to rationalise the sample depth according to the depth of tillage, and keeping it unchanged from one measurement to another; if possible, to determine the soil bulk density through the depth of the sample.

"Carbon content analysis of preliminarily air-dried samples is performed by a laboratory. Then, the organic carbon stock (t/ha) can be calculated by multiplying carbon content with the mass of soil, estimated via depth sampling and bulk density."



The evaluation of carbon dynamics in cultivated soils requires the following of a precise protocol.

wait between five and 10 years before the impacts of changes in agricultural practices can be observed. Analytical methods can be used for an early estimation of changes in organic matter (see chart opposite). In order to predict the effects of inputs of exogenous organic matter (liquid manure, fertiliser, compost) on carbon stocks, biodegradability indicators based on the biochemical composition of inputs have been developed and standardised. An example is the organic matter stability indicator (NF XPU 44-162, 2009).

### USING MODELLING TO GUIDE AGRICULTURAL PRACTICES

Thanks to models such as AMG, established in France by INRA in Laon (02), we can also simulate changes in agricultural practices. Agro-Transfert-RT, INRA and partners in the agricultural sector have developed a decision support system integrating this model, called Simeos-AMG. Designed for use in agricultural advisory services, it simulates and displays the expected changes in soil organic carbon stocks in the long-term (20, 30, 50 years etc.), depending on agricultural

practices (crop rotation patterns, residue management, organic inputs, intermediate crops, tillage, irrigation) and on soil and climate characteristics. Specific models are also available for France's overseas territories, such as the Web Mor-Gwanik application developed for Guadeloupe, which are designed to include the specificities of the climate, farming systems and soils found in the country's outermost regions. Used within the framework of energy performance plans, ADEME's tool Dia' Terre® can include soils in farm greenhouse gas assessments. ■

#### Simeos-AMG, a simulation tool for agricultural advice use at different scales

Vegetable production, silt soils (rotation: potatoes/wheat/peas (canning)/beetroot/wheat/carrot)

##### CURRENT SYSTEM

- Ploughing: 2 years out of 3
- Ploughing depth: 28cm
  - Green fertilisers: 1 year out of 3

##### B SCENARIO

- (Inputs of humic substances)
- Input of green waste compost: 10t/ha over 6 years
  - Green fertiliser: 1 year out of 2

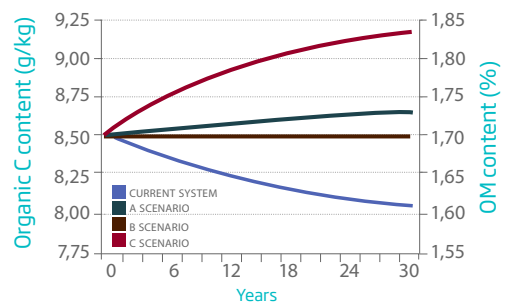
##### A SCENARIO

- (Reduced C losses)
- No ploughing (1 year out of 2)
  - Reduction of ploughing depth to 22cm

##### C SCENARIO

- Input of green waste compost: 10t/ha over 6 years
- One ploughing removed and reduction of depth to 22cm

#### Organic matter content evolution in the tilled layer of the soil



Source agro-transfert RT, Duparque et al, 2011



# Measurement tools at the territorial scale

*Direct measurements, national databases, modelling, etc.: evaluation tools offer the possibility of monitoring the impacts of public policies and predicting changes in soil carbon stocks.*

As for fields, soil carbon stocks can be monitored at the territorial level thanks to direct measurements and modelling. Using direct measurements requires the introduction of sampling networks.

## MEASUREMENT NETWORKS AT THE NATIONAL SCALE

In France, two main networks, complementary in their design, are managed within the framework of GIS Sol: RMQS (soil quality measurement network) and BDAT (soil analysis database).

■ RMQS is based on the monitoring of 2,200 observation sites, divided according to a 16km per side grid across the whole territory. This network supplies average data and representative values of carbon stocks for the main land uses (forests, crops, permanent pasture etc.). Analyses

### Expert opinion



#### Olivier Scheurer

Lecturer at the Institut Polytechnique LaSalle Beauvais, and partner in the RMT Sols et Territoires (soil and land combined technology network).

**Net balance of CO<sub>2</sub> emissions for the cultivated red soils in Vienne, calculated from simulated changes over 50 years.**

	Balance (tC/ha/yr)	Balance (tC/ha/yr)
Red soil - 86	-0.05	0.01
Average depth	-0.10	-0.05
Shallow	0.07	0.13
Deep	-0.10	-0.03
	Without intermediate crops	With intermediate crops

### Modelling offers the possibility of estimating the effects of modifications to cropping systems at small regional agricultural levels

“Within the work conducted in Sols et Territoires<sup>(1)</sup>, we showed that it was possible to apply the AMG model for carbon dynamics in agricultural soils, based on a spatial inventory of ‘soils, cropping systems, and current organic carbon content’. To achieve this inventory, pre-existing databases were used: CAP data, pedological regional references (RRP) and the soil analysis database. Nevertheless, local agronomic expertise is

necessary to group these data. The chart (left) shows a model application in Poitou-Charentes (Vigot, 2012): the introduction of intermediate crops limits carbon losses and even increases stocks depending on the soil type in question.”

(1) [www.sols-et-territoires.org](http://www.sols-et-territoires.org)



A.D.

We can analyse the consequences of changes in cropping systems on carbon stocks thanks to models at the agricultural territorial level.

are also conducted to characterise agronomic parameters, contamination levels and soil biodiversity. Thanks to the first sampling campaign between 2001 and 2011, carbon stocks in mainland France and the French West Indies have been evaluated. Starting from 2015, a new sampling campaign will be conducted in order to observe changes in stocks. All the RMQS samples are conserved at INRA's national soil sample conservatory in Orléans.

■ BDAT is a database which gathers the results of soil analyses conducted by farmers. The database groups around two million samples taken since 1990. Thanks to the data collected, it has been shown that agricultural soils tended to lose approximately 6Mt of carbon per year between 1990 and 1995, and 1999 to 2004. However, these changes are spatially highly variable and

extending these changes to all French farmland comes with great uncertainties linked to the temporal and spatial diversity of the sampling and analytical methods. In France, there are other observation networks integrating soil carbon measurements too. For example, the Renecofor network monitors 102 forest sites in mainland France. The SOERE network (observation and experimentation system for long-term environmental research) brings together different sites chosen to estimate the long-term impacts of climate and agricultural practices.

### **MODEL-BASED EVALUATIONS**

The implementation of observation networks is limited due to their cost and the length of time required. Therefore, in order to evaluate policies which impact on soil management and carbon stocks, modelling is needed to

complete and extrapolate direct measurements. This is the case for the methods developed by INRA, working with Citepa (a technical centre studying atmospheric pollution), based on the GIS Sol database, in order to feed national inventories for GHG emissions. Other tools have been developed for use at the territorial scale. The Simeos-AMG tool made it possible for the AMG model to be implemented at the agricultural territorial level in Loiret and Poitou-Charentes (see box). The ABC'Terre project (Reactif ADEME 2012) continues this work, and will also lead to the development of a calculation method for GHG emissions balances, integrating soil carbon balances at the agricultural territorial level. This project will also improve ADEME's Climagri® tool, used in greenhouse gas diagnoses within territorial climate-energy plans (PCEAT). ■

# Improving and sharing references



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*In order to improve the inclusion of soil carbon in environmental assessments, some uncertainties still have to be resolved. Nevertheless, tools to support the agricultural sector and local communities are being developed.*

soil fertility and biodiversity, particularly through the maintenance or increases in stocks of organic matter. In order to facilitate the inclusion of soil carbon in national and local policies, it is necessary to resolve some uncertainties. We need to expand the references available to provide a better representation of

territorial diversity and different land uses. To achieve this, new experimental data depicting carbon dynamics in the longer term needs to be acquired, and existing data should be pooled. There is important work to be conducted on forest soils, in overseas territories and in urban areas. For a climate-based approach, this work has to

integrate all GHG soil emissions, particularly nitrogen protoxide ( $N_2O$ ) derived from the degradation of organic matter and crop fertilisers.

## **TAKING SOILS INTO ACCOUNT IN DECISION SUPPORT SYSTEMS**

Whether at the field or territorial scale, decision support systems including soil carbon are being developed. Their improvement and distribution will support farmers, agricultural advisers and local authorities in making choices and recommendations. At the supply chain level, including soil in product life-cycle analysis, especially for food and bio-products, would make it possible to include soil carbon in procurement and production system decision making. These tools still need to be created for forest and urban soils. Finally, the focus should not only be on carbon, but include the other environmental services provided by soils. ■

Including soil criteria in life-cycle analysis of food products will help to better guide agricultural practices in the long run.

Soils and the carbon they store are linked to many environmental issues. They play a major role in climate regulation, but also in preserving air and water quality,

# An international dynamic to combine food security and climate change mitigation

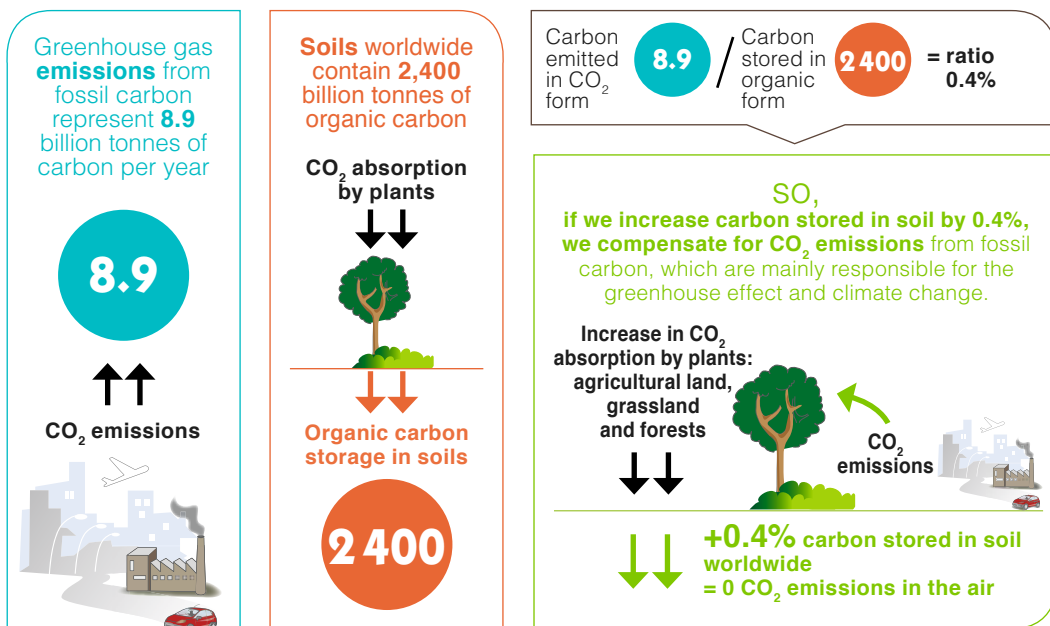
Agriculture can and must be part of the solution to climate change. In 2015, France is launching the '4 per 1,000' carbon sequestration programme for agriculture. This international research programme aims to

adapt agricultural practices with the goal of storing carbon more efficiently in the soil. An annual '4 per 1,000' (0.4%) increase in organic matter in soil would be enough to compensate the global emissions of greenhouse gases. Conversely, a loss of the

same amount would double the emissions. Managing and increasing organic matter in agricultural soil is a way to reconcile soil preservation, food security and climate change mitigation. ■

## The '4 per 1,000' Fighting climate change by storing carbon in soil biomass

"This international research programme combines the objectives of food security and climate change mitigation, and can therefore involve all the countries in COP 21" Stéphane LeFoll, Minister of Agriculture, Food and Forests





# ADEME supports research for better agricultural and environmental management of soil organic matter

Aware of the importance of soil preservation and organic matter management, ADEME has supported science for several decades through research and thesis programmes (for example, the GESSOL programme)\*. In 2010, research actions were launched to provide a better understanding of soil and climate interactions because soils contribute

to the fluxes of three main greenhouse gases (GHG). These gases are nitrous oxide (N<sub>2</sub>O), methane (CH<sub>4</sub>) and carbon dioxide (CO<sub>2</sub>). Research questions linked to the role of soil in climate change have been integrated in the 'REACTIF' call for projects (Research on climate change mitigation through agriculture and forestry) in order to highlight strategies for carbon storage in soil and emissions miti-

gation. Work began in 2012 and 18 projects are currently aiming to provide a better understanding of the effect of land use (agricultural land, grassland and forest) and management of the GHG balance in France and overseas territories. Furthermore, projects for a better integration of soils in climate policies, environmental assessments and ISO standards have also been launched. ■

*The 18 research programmes chosen which include soil as an important dimension in climate change mitigation (REACTIF project) in agriculture and forestry.*

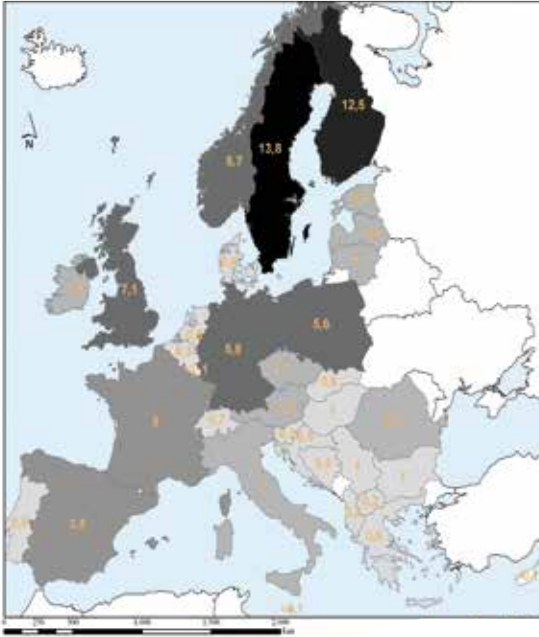
Theme	Coordinator	Title	Deliverables
Crops	Fabien LIAGRE (AGROOF)	AGRIPSOL – Agroforestry for preserving soil	<ul style="list-style-type: none"> <li>• Measuring protocols</li> <li>• Assessment of agricultural practices</li> </ul>
Grasslands	Cornelia RUMPEL (CNRS)	AEGES – Mitigation of GhGs emissions in grasslands.	<ul style="list-style-type: none"> <li>• Assessment of agricultural practices</li> <li>• Modelling</li> </ul>
Crops	Eric JUSTES (INRA)	CICC – Cover crops for mitigating climate change	<ul style="list-style-type: none"> <li>• Assessment of agricultural practices</li> <li>• Modelling</li> <li>• Decision support tool</li> </ul>
Crops	Caroline COLNENNE-DAVID (INRA)	SYSLIM – Crop systems and climate change	<ul style="list-style-type: none"> <li>• Assessment of agricultural practices</li> </ul>
Crops	Joël LEONARD (INRA)	EFFEMAIR N <sub>2</sub> O – Modelling and assessment of the effect of environmentally-friendly practices on microbial activities and N <sub>2</sub> O emissions from soils.	<ul style="list-style-type: none"> <li>• Assessment of agricultural practices</li> <li>• Modelling</li> </ul>

\* The GESSOL programme is coordinated by the French Ministry of Ecology, [www.gessol.fr](http://www.gessol.fr)



Theme	Coordinator	Title	Deliverables
Crops	Catherine HENAUULT (INRA)	SOLGES – Ability of soil to reduce N <sub>2</sub> O.	<ul style="list-style-type: none"> <li>• Assessment of agricultural practices</li> </ul>
Livestock breeding	Safya MENASSERI-AUBRY (AGROCAMPUS OUEST)	ETYC – Integrated assessment of the treatment and the recycling of organic matter in livestock systems designed to mitigate climate change.	<ul style="list-style-type: none"> <li>• Assessment of agricultural practices</li> </ul>
Grasslands	Annette MORVAN-BERTRAND (University of Caen)	P2C – Plant : major actor of the capture of atmospheric carbon and its transfer to grassland soils.	<ul style="list-style-type: none"> <li>• Assessment of agricultural practices</li> </ul>
Crops	Manuel MARTIN (INRA)	CSopra – Accounting methods of soil carbon sequestration in French agricultural soils.	<ul style="list-style-type: none"> <li>• New accounting methods</li> <li>• Modelling</li> <li>• National Inventory</li> </ul>
Crops	Annie DUPARQUE (AGRO-TRANSFERT RT)	ABC'TERRE – Mitigation of GHG emissions from agriculture and carbon sequestration at regional scale.	<ul style="list-style-type: none"> <li>• Regional Inventory</li> <li>• Decision support tool</li> </ul>
Crops and livestock breeding	Cécile BESSOU (CIRAD)	SOCLE – Accounting the effect on soil carbon of land use and land-use changes in Life Cycle Analysis of agricultural products.	<ul style="list-style-type: none"> <li>• LCA Methodology</li> <li>• Decision support tool</li> </ul>
Crops	Pierre TODOROFF (IRD)	C@RUN – Storage/sequestration of carbon in the agricultural soils of the Reunion Island (France)	<ul style="list-style-type: none"> <li>• Regional Inventory</li> </ul>
Crops	Jorge SIERRA (INRA)	TropEmis – Regional assessment of soil carbon sequestration or emission in the tropical soils of Guadeloupe (France)	<ul style="list-style-type: none"> <li>• Regional Inventory</li> <li>• Decision support tool</li> </ul>
Crops	Michel BROSSARD (IRD)	CarSGuy – Soil carbon in French Guyana	<ul style="list-style-type: none"> <li>• Regional Inventory</li> </ul>
Forests	Daniel EPRON (University of Lorraine)	EMEFOR – Effect of soil compaction on CO <sub>2</sub> and CH <sub>4</sub> exchanges in forest soils.	<ul style="list-style-type: none"> <li>• Assessment of forest management</li> </ul>
Crops, Forests, Grasslands	Bernard LONGDOZ (INRA)	CESEC – Analysis of long times series of net exchanges of CO <sub>2</sub> , water vapor and radiation in forests, grasslands and croplands.	<ul style="list-style-type: none"> <li>• Assessment of forest, crop and grassland managements</li> </ul>
Forests	Lauric CÉCILLON (IRSTEA)	piCaSo – Effet of forest management and soil type on carbon stocks in forest soils.	<ul style="list-style-type: none"> <li>• Assessment of forest management</li> </ul>
Forests	Laurent SAINT-ANDRÉ (INRA)	RESPIRE – Harvesting of wood residues : potential, impact and remediation by spreading of ashes.	<ul style="list-style-type: none"> <li>• Assessment of forest management</li> </ul>

## Organic Carbon per country in peta grams (Pg)



### ■ European top soils contain more than 70 billion tonnes of organic carbon.

The European soil database, at a scale of 1:1,000,000, is one of the most homogeneous and comprehensive databases on the organic carbon/matter content of European soils. It also includes information from associated databases on land cover, climate and topography.

### ■ Deep soil carbon: a reservoir not to be neglected!

The first estimates of deep soil carbon stocks in France have been produced by INRA using data from GIS Sol and ISRIC. Soil profiles have been modelled down to 1m across France following the specifications of the GlobalSoilMap programme ([www.globalsoilmap.net](http://www.globalsoilmap.net)). In France, 35 to 60% of total organic carbon could be sequestered deeper than the first 30cm. Biological and human factors predominate at the surface while abiotic factors, such as soil parent material, become more important with depth. These estimates remain highly uncertain. However, they indicate that soil may have a larger potential to sequester carbon than usually reckoned.

## Expert opinion



### Luca Montanarella

Senior Expert, European Commission DG JRC.H5

### Soil organic carbon matters in the European Union

"EU soils contain more than 70 billion tonnes of organic carbon, which is equivalent to almost 50 times our annual greenhouse gas emissions. However, intensive and continuous arable production may lead to a decline in soil organic matter. In 2009, European croplands emitted an average of 0.45 tonnes of CO<sub>2</sub> per hectare (much of which resulted from land conversion)<sup>1</sup>. The conversion of peatlands and their use is particularly worrying. For instance, although only 8% of farmland in Germany is on peatland, it is responsible for about 30% of the total greenhouse gas emissions of its whole farming sector<sup>2</sup>. However, with appropriate management practices, soil organic matter can be maintained and even increased. Apart from peatlands, particular attention should be paid to the preservation of permanent pastures and the management of forest soils, as carbon age in the latter can be as high as 400-1,000 years<sup>3</sup>. Keeping carbon stocks is therefore essential for the fulfilment of present and future emission reduction commitments of the EU. Soil organic carbon is the major component of soil organic matter that improves the physical properties of soil, as it stores a great proportion of nutrients necessary for plant growth."

1 <http://www.eea.europa.eu/publications/european-union-greenhouse-gas-inventory-2011>. 2 [http://ec.europa.eu/environment/soil/pdf/report\\_conf.pdf](http://ec.europa.eu/environment/soil/pdf/report_conf.pdf), p. 17. 3 *Ibid.*, p. 13.

## Expert opinion



**Isabelle Feix**

National soil expert at ADEME

### Organic matter fuels agroecology

"Agroecology returns agronomy to the centre of agricultural practices. Soils, and the organisms living in it, are one of the driving forces of agroecology, with organic matter providing the fuel. Depending on its degradation stage, organic matter supplies nutrients for plants, contributes to soil stability, maintains water reserves, provides a home to soil-living organisms and contributes to good root structure for crops. The good management of soils is essential to improve production systems. A healthy soil makes it possible to rationalise inputs of fertilisers, water and even plant protection products, and also improves crop vigour. To ease the implementation of agroecology, research has to focus on soils and work in a sector-approach, in conjunction with technical institutes and farmers. It has to prove that other sustainable production systems, identified according to the nature of the soil, can be implemented. It also has to guarantee the durability of systems which ensure soil carbon stocks are maintained or increased by assessing their environmental, economic and social impacts. This approach will avoid later problems, for example, a system which provides environmental benefits through carbon storage but creates other problems, such as increased N<sub>2</sub>O emissions or greater use of plant protection products."

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### Organic carbon in soils

Meeting climate change and food security challenges

*Farmland and forests occupy more than 80% of the French territory and currently store 4 to 5Gt of carbon (including 15 to 18Gt of CO<sub>2</sub>), with more than two-thirds of this carbon stored in top soils. Any positive or negative fluctuation of this stock influences national greenhouse gas (GHG) emissions, which are estimated at 0.5Gt CO<sub>2</sub> eq/year (2011). The agricultural and forestry sectors also offer solutions for climate change mitigation through the production of renewable energies and preserving or increasing carbon stocks in soils and biomass. The management of organic matter, which is the principal carbon reservoir in soils, is a key determinant in the capacity of soils to produce food and material and to offer other environmental services such as the regulation of water cycles and air quality etc. Acting on soil carbon stocks also means acting on soil and environmental quality. This is the sense of the '4 per 1,000' initiative proposed by France at COP21. Drawing on data from the GIS Sol database, this brochure highlights the important role of soil carbon in French climate change mitigation strategies. In order to address soil and climate change challenges, the main agricultural and forestry levers for action are presented. An inventory of evaluation tools, from the field to the national scale, will help managers and advisers to better direct practices.*



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