The state of the soils in France in 2011 - A synthesis

Véronique Antoni, Dominique Arrouays, Antonio Bispo, Michel Brossard, Christine Le Bas, Pierre Stengel, Estelle Villanneau, Denis Baize, Enrique Barriuso, Yves Blanca, et al.

■ 2013

The state of the soils in France in 2011

A synthesis



THE SERVICES RENDERED BY THE SOILS   THE PRESSURES TO WHICH THE SOILS ARE SUBJECTED   DIAGNOSIS OF THE STATE OF THE SOILS IN FRANCE

Groupement
d'intérêt
scientifique
sol

List of authors and contributors

Scientific editors

Véronique Antoni, Dominique Arrouays, Antonio Bispo, Michel Brossard, Christine Le Bas, Pierre Stengel, Estelle Villanneau.

Lead authors and contributors

Véronique Antoni, MEDDTL-CGDD-SOeS
Dominique Arrouays, Inra
Denis Baize, Inra
Enrique Barriuso, Inra
Antonio Bispo, Ademe
Yves Bianca, IRD
Line Boulonne, Inra
Olivier Briand, Anses
Michel Brossard, IRD
Yves-Marie Cabidoche, Inra
Giovanni Caria, Inra
Philippe Chéry, Enitab
Daniel Cluzeau, Université Rennes 1
Isabelle Cousin, Inra
Alain Couturier, Inra
Thibaud Decaëns, Université Rouen
Pascal Denoroy, Inra
Samuel Dequiedt, Inra
Nathalie Derrière, IFN
Sacha Desbourdes, Inra
Élodie Dupuits, IRD
Jean-Claude Fardeau, retired
Isabelle Feix, Ademe
Benoït Gabrielle, AgroParisTech
Catherine Gibaud, MAAPRAT
Muriel Guernion, Université Rennes 1
Alain Hartmann, Inra
Catherine Hénault, Inra
Marcel Jamagne, retired
Claudy Jolivet, Inra
Bertrand Laroche, Inra
Christine Le Bas, Inra
Hervé Le Martret, IRD
Sébastien Lehmann, Inra
Blandine Lemercier,Agrocampus-Ouest
Stéphanie Lucas, IFN
Jean-Philippe Malet, CNRS
Manuel Martin, Inra
Raia Silvia Massad, Inra
Jean-Claude Miskovsky, CNRS, Géopré
Joël Moulin, Chambre d'Agric. de l'Indre
Valéry Morard, MEDDTL-CGDD-SOeS
Sylvie Nazaret, CNRS-Université Lyon
Catherine Pasquier, Inra
Guénola Péres, Université Rennes 1
Jean-Luc Perrin, MEDDTL-DGPR-SRT
Patrick Perrin, CTMNC
Lionel Ranjard, Inra
Guy Richard, Inra
Anne Richer de Forges, Inra
Jean Roger-Estrade, AgroParisTech
Nicolas Saby, Inra
Joëlle Sauter, ARAA
Nathalie Schnebelen, Inra
Pierre Stengel, Inra
Marie-Agnès Vibert, MAAPRAT
Estelle Villaneau, Inra
Christian Walter, Agrocampus-Ouest

Graphic Concept: Sacha Desbourdes and Pascale Inzerillo (Inra)

Layout and pre-press: CHROMATIQUES ÉDITIONS

Scientific and medical translation: Helen Le Bras - helenlebras@yahoo.fr

How to cite this document:
Gis Sol. 2013. The state of the soils in France. A synthesis / Groupement d'intérêt scientifique sur les sols, France, 24p.
This synthesis is based on a document edited by the "Groupement d'intérêt scientifique sur les sols" (French Soils Scientific Interest Group):
Gis Sol. 2011. L'état des sols de France. Groupement d'intérêt scientifique sur les sols, 188 p.

Foreword

The creation of the "Groupement d'intérêt scientifique sur les sols", the Gis Sol (French Soils Scientific Interest Group), in March 2001, was an ambitious challenge. It involved catching up, over a few years, with France's lateness in carrying out inventory and monitoring programmes of its soils, in order that it may become equipped with an information system regarding the soils of France and on the evolution of their quality.

After ten years of work, strengthened by the common purpose that drives the ministries and the public establishments from which it is composed*, the Gis Sol is presenting significant advances in soil knowledge and understanding. It wanted to place a document at the disposal of a broad audience; a simple, understandable, general document about French soils: to provide some keys to understanding their extreme spatial variability, and to present the most recent developments in the current thinking regarding their quality and their possible evolution.

In 2012, the productive uses of the soil, its environmental and ecological functions, its role in land use and land planning, still constitute a collective issue for sustainable development. Furthermore, the processes of soil degradation, a non-renewable resource on the human timescale, remain. These assessments on the roles of the soils and the evolution of this resource underline the need for a policy of sustainable soil management. We would like this report on the state of the soils in France, coordinated by the Infosol Unit of Inra, and using the knowledge gained from the programmes followed by the Gis Sol, to become a reference tool, and thus contribute to the emergence of such a strategy.

** The French Soils Scientific Interest Group includes : Ministry for Ecology, Sustainable Development and Energy ; The French Environment and Energy Management Agency ; Ministry of agriculture, agrifood and forestry ; l'Institut de Recherche pour le Développement, www.ird.fr ; National Institute of Geographic and Forest Information ; French National Institute for Agricultural Research*

The microrelief and variability of the sandy soils found in «Les Landes», Gascony.

Introduction

The soil is the superficial layer of the continents' surfaces, formed by the weathering of underlying rock under the action of the climate and of living organisms. Its volume extends from the surface of the earth to the weathered rock, from which it is distinguished by the intimate association of the mineral and organic constituents, as well as by the intensity of the biological activity, notably that of plant roots. In mainland France, its thickness is typically about a metre, whilst it can reach a thickness of several tens of metres in tropical conditions. Its formation results from a slow evolution, the duration of which varies from several millennia to several hundreds of millennia. Taking into consideration the time required to its formation, it is an essential resource to be protected.

The soils are both the product of and the support for plant development. They are a central link in the regulation of the main global cycles, such as water, carbon or nitrogen. They are at the heart of major planetary issues, like food security, climate change, availability of quality water or biodiversity. Their preservation and efficient management is a requirement for feeding the planet and for limiting the extension of cultivated areas into ecosystems precious for their biodiversity.

The soils constitute therefore a natural resource. This resource can be used sustainably for agricultural and forestry production. But its destruction is difficult to reverse and its rehabilitation is very costly. The pressures to which it is subjected engender more or less rapid degradation processes. Its uses and its future represent, therefore, a collective issue for sustainable development.

In order to protect and exploit soils better, it is, therefore, essential to have an objective understanding of their quality. This notion of soil quality cannot be assessed either in absolute terms, or by a single criterion. It can only be assessed in relation to its functions and to the ecosystem services that it is expected to achieve. Among these services, the production of food or materials is the most obvious. But, as an interface, interacting with the other environmental media, the soils also participate in the regulation of the water cycle and of its quality, they recycle organic matter, they can store carbon and mitigate CO^2 emissions into the atmosphere and they are home to an immense reservoir of biodiversity.

The soils are an integral part of our landscapes, but their presence is most often hidden by forests, cultivated fields, dwellings or infrastructures that cover them. Being hidden and often considered as a simple support, they remain, largely, poorly understood. Differing from the air we breathe or the water we drink, the impact of a change in their quality is not directly perceived. Thus, soil awareness is not widespread among citizens, decision-makers or developers.

This situation of a lack of soil awareness, and the need for information regarding the soils by environmental players, led to the creation of the Soils Scientific Interest Group, the Gis Sol, in 2001. After 10 years of work, the Gis Sol wanted to make available, to a broad audience, a document concerning the state of the soils in France. Written as a reference tool, this report lays out an assessment regarding the state of the soils in mainland France and overseas French territories.

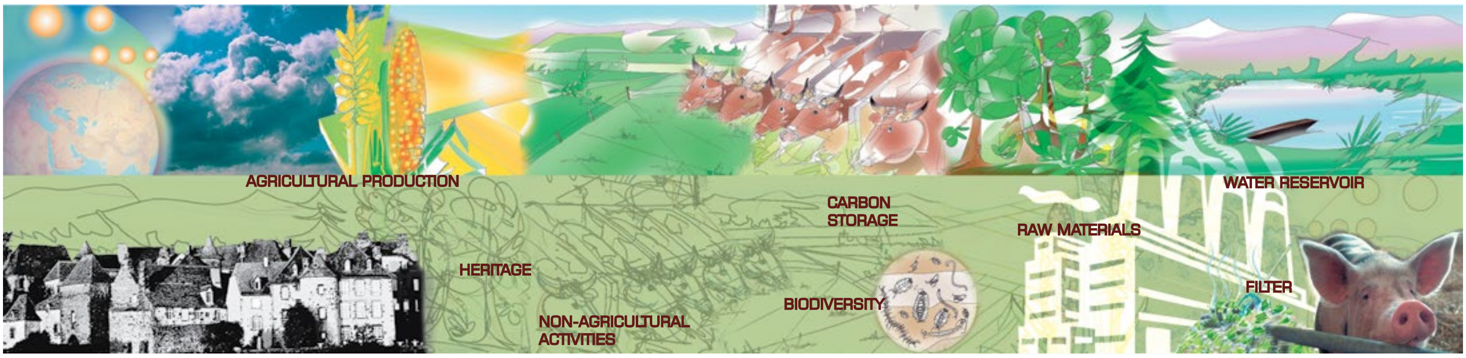
This summary outlines the main conclusions of this report. It lists, firstly, the functions of the soils, the services they render, and the pressures to which they are subjected. Then it lays out an appraisal of their quality, its observed or probable evolution, as well as the uncertainties associated with it.

The services rendered by the soils

Despite the ecosystem services it renders, the soil remains, largely, poorly understood. These services are, however, numerous: support for production, support for the landscape, source of materials, memory of the past, filtration and purification, regulation of water, and of carbon and nitrogen cycles, and a reservoir of biodiversity. The soils are at the heart of major planetary issues, like food security, climate change, availability of quality water or biodiversity. It is therefore vital to protect their essential functions within the context of ever-increasing environmental concerns.

The soil results from pedogenesis, which is the weathering of rocks under the influence of climate, of geological relief, and biological and man-made activities. Among the different environmental components, the soil remains the least familiar. The services it renders to humankind are, however, numerous.

The major functions of the soil



The soil is the support for human activities and notably for agricultural and forestry production. It is the anchoring point of plant root systems and constitutes their supply of water and nutrients. It supplies, therefore, the indispensable elements for plant production used to feed animals and people, and for producing fibres, materials and renewable energy.

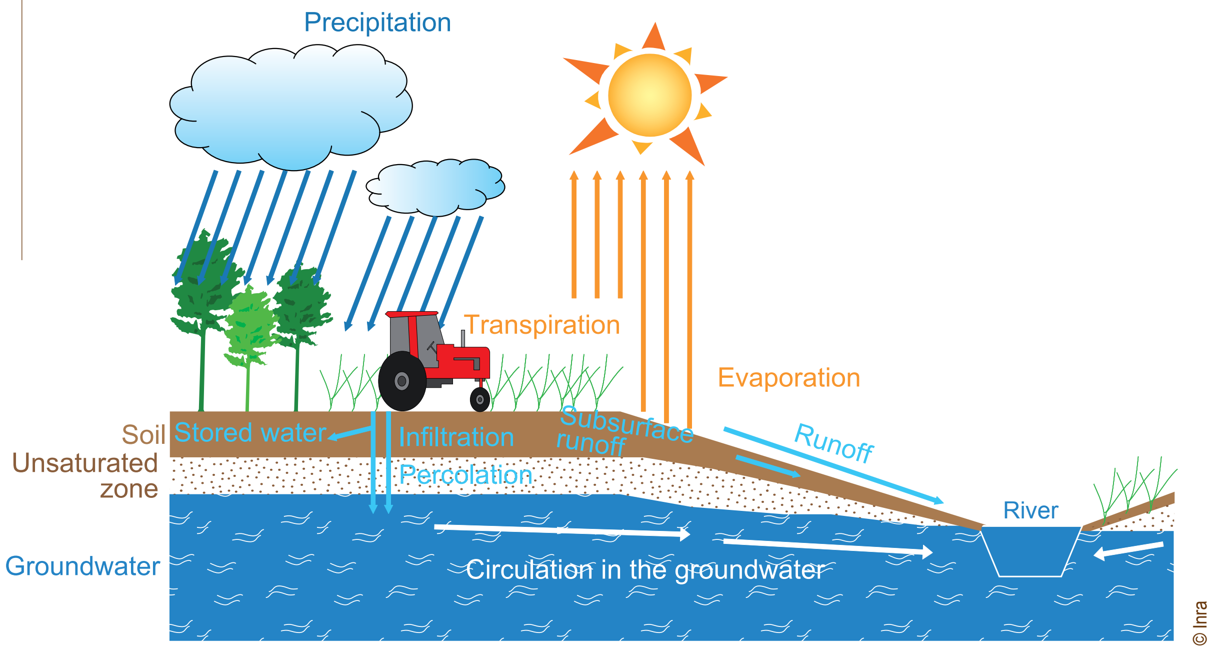
The elements of our agricultural, forest and urban landscapes are supported by the soil. It is the support for the development of infrastructures. Protecting our archaeological heritage, the soil preserves the memory and the imprint of the passage of humankind and human activity throughout the ages.

At the interface between the atmosphere and the aquifers, it filters or degrades pollutants and other substances introduced by human activity: trace elements (cadmium, mercury, lead, etc.), persistent organic pollutants (polycyclic aromatic hydrocarbons, pesticides, etc.), etc. It shelters a biodiversity of fauna, flora and microbes that is remarkable in its abundance, a large part of which is still unknown and represents therefore a considerable genetic and ecological potential. This biodiversity is already the source for medicines: currently, numerous marketed antibiotics originate from soil bacteria. Inversely, the soil can constitute a reservoir of pathogens, notably for plants but also for animals and humankind.

Being the site of intense biological activity, the soil enables organic waste to be recycled (livestock farming or industrial effluents, sewage sludge, various composts, etc). It is a central link in the regulation of the main planetary cycles such as carbon and nitrogen, and thus carries out essential functions in the regulation of greenhouse gases (carbon dioxide, methane, nitrous oxide).

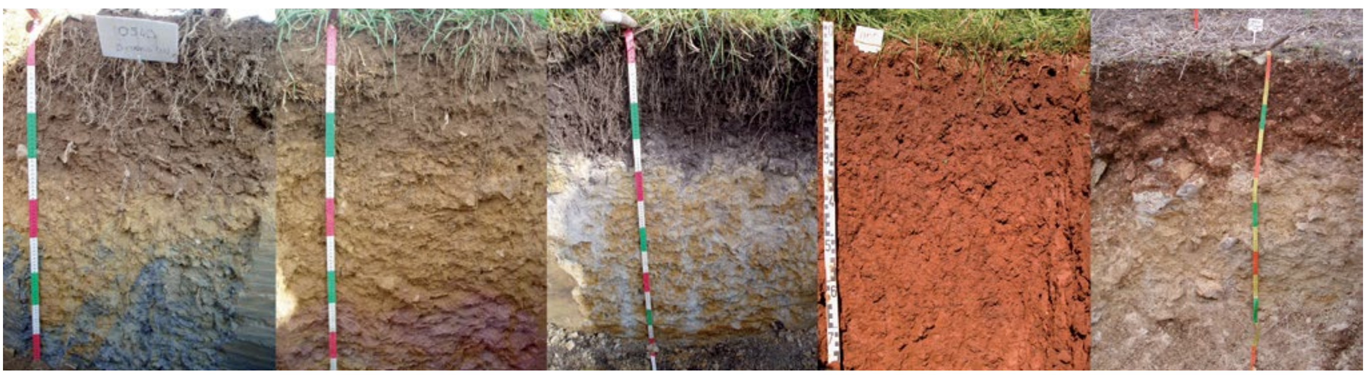
Finally, the soil regulates the hydrological processes in rivers, lakes and the seepage towards groundwater. It determines the distribution between runoff and infiltration of rainfall. It plays a buffering role in relation to water flow, thus bringing about, for example, the lessening of flooding phenomena or supporting the flow in rivers during low water.

Water transfer pathways and the soil



The soil is therefore a complex living system, in an interfacing position and in constant interaction with the other media. A better understanding of the soils by local managers is indispensable, in order to better protect them by limiting the pressures to which they are subjected (agriculture, contamination, etc.)

This knowledge is all the more necessary as the soils are characterised by a very large variability that occurs on all the scales and as they provide multiple services, some of which may be antagonistic. Their quality cannot therefore be judged in absolute terms and the actions needed to protect them or to maintain some of their functions, depend both on the services expected of them and on their intrinsic characteristics.



The variability of the soils in France

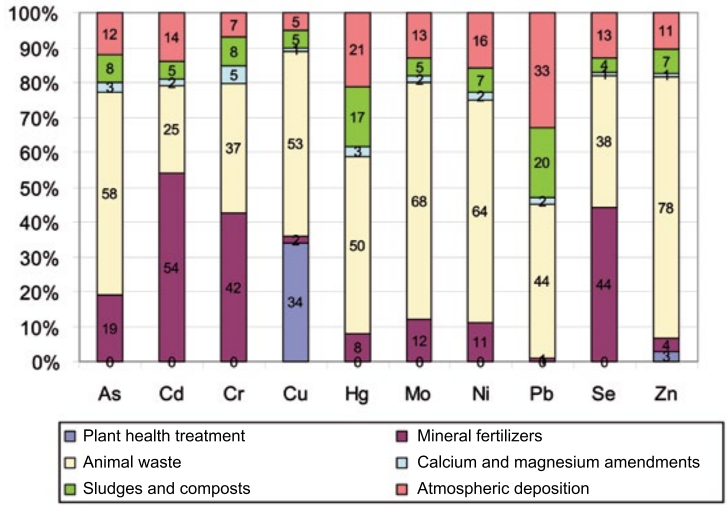
The pressures to which the soils are subjected

The soils are subjected to various man-made pressures that can influence their state, their functions and the exchanges they perform with other media. They can deteriorate very rapidly due to human activity. Demographic evolution, agricultural, industrial and tourist activities, as well as climate change, can also change the functioning of the soils and bring about their degradation. The soils are the subject of numerous issues such as the development of towns and of infrastructures, food and energy production, waste management, the mitigation of climate change, conservation of water quality and biodiversity protection. These issues, being the basis of a competition for the soils, are difficult to reconcile, as the various services rendered by the soils are not all compatible.

All of the services rendered by the soils require the maintaining of a sufficient surface area and thickness. This maintenance is threatened by various natural and man-made pressures: sealing, erosion, extraction, etc. The consumption of space by peri-urbanisation and the construction of transport routes are thus carried out to the detriment of the natural soils and of the cultivated soils, which loose, in this way, their functions of water purification, support for biodiversity and biomass production. Soil loss indicators are necessary in order to better assess their importance and the actions to be taken to combat them (erosion) or, to better manage the processes of selecting soil types that are affected by these pressures (sealing, extraction).

Acting as an interface in the environment, the soils are likely to receive or to emit a certain number of contaminants that are detrimental to human health, *via* their direct ingestion, or their transfer in water systems, plants and the food chain. These contaminants may be transmitted throughout all ecosystems. The treatment of animal waste and the use of certain fertilizers or plant health (phytosanitary) treatment products, the spreading of waste such as the sludge from water treatment plants and urban composts, as well as atmospheric deposition, could be sources of widespread soil contamination, notably of trace elements (TEs).

The distribution of various sources contributing to the provision of TEs in agricultural soils in mainland France



Source: Sogreah-Ademe, 2007.

Therefore, human activities are sometimes the origin of widespread soil contamination or of localised pollution by trace elements, persistent organic pollutants or pathogenic micro-organisms. For certain contaminants, the atmospheric depositions of man-made aerosols (industrial activity, automobile traffic, household rubbish incineration) add to the natural atmospheric depositions (volcanic eruption, forest fires).

The agricultural intensification and some cropping practices can promote physical degradation of the soils, like erosion and compaction. They participate in the decrease of biodiversity and the reduction of organic matter in the soils. They can also cause the emission of greenhouse gases by the soils. The mechanisation of forest management can also generate compaction.

Finally, climate change, accelerated by human activities, might intensify several phenomena of soil evolution and degradation. The increase in extreme rainfall phenomena is likely to accelerate soil loss and the probability of mudflow occurrences. More abundant winter rain might also increase the importance of waterlogged soil conditions. This could affect forest species sensitive to these conditions and some cultivated species. This could also make certain cultural interventions more difficult and worsen their negative effects on soil structure. Climate change could also, in certain cases, precipitate organic carbon stock depletion, by accelerating the mineralisation rate of organic materials in mountain soils or in peaty soils of the humid zones.
A change in water systems might influence, in the long-term, certain processes of pedogenesis. In the situations where these processes are rapid and strongly dependent on climate (like, for example, in the French West Indies), soil properties could evolve rapidly.

More frequent and intense droughts could increase the risks of forest fires and deleteriously affect the cycles of mineral elements and organic carbon, as well as the biodiversity of the soils. They could also affect the dynamics of soil structure, by engendering and promoting deep cracking, particularly in clay-rich soils. In these conditions, it is probable that the phenomena of rapid vertical transfer of water and solutes *via* preferential flows would be more frequent, and consequently, the risks of groundwater contamination would be greater.

A higher frequency of storms could profoundly disturb the vertical structure of soil horizons in forests due to windfall (this is already the case for a large proportion of the soils in Les Landes, Gascony), could accelerate the mineralisation of their organic matter, and could promote compaction linked to the passage of heavy haulage machinery.

Most of the direct climate change effects expected remain, however, very low in comparison to the effects linked to the direct action of humankind. We cannot, however neglect the risks with which they are associated, particularly due to the interactions between both categories of factors. Certain slow evolutions could lead to some soil functioning thresholds being exceeded and certain extreme events are likely to favour this, for example, repetitive forest fires.

Diagnosis of the state of the soils in France

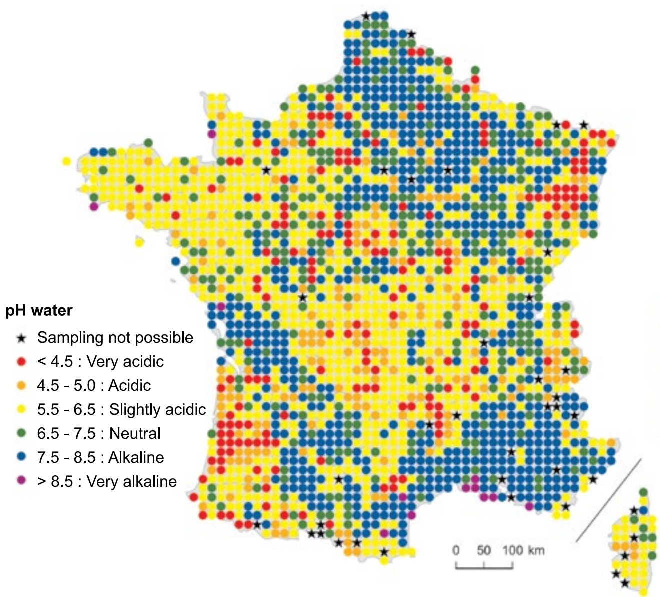
Soil quality cannot be judged in absolute terms. This notion can be understood through its functions, the ecosystem services that it renders and their sustainability. Some of these services can be antagonistic. It is therefore through the uses of the soils, and the functions that the decision-makers and the managers look to promote or to maintain, that the indicators describing this quality are defined here.

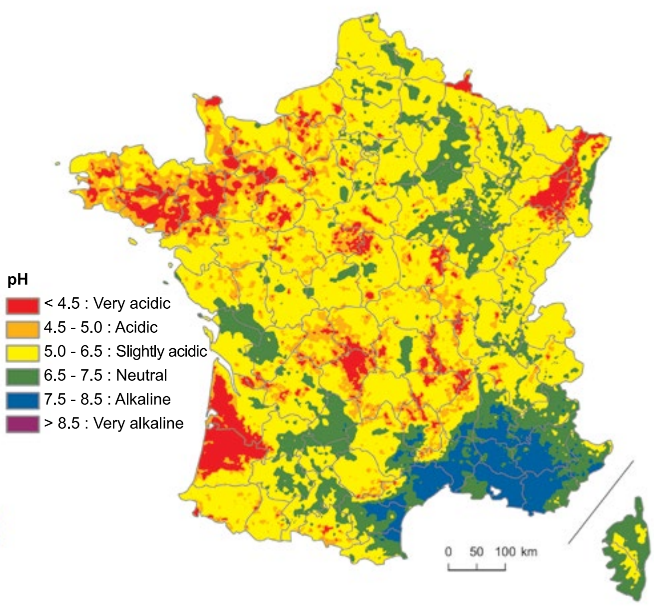
The soils are the support for plant production. The rooting of plants and their supply of water and mineral elements depend on the soils' characteristics. In order to fulfil this function, the soils must possess properties and physical states enabling water storage and infiltration, aeration and root growth. Root formation and aeration depend on the quality of the soils' structure. **Major uncertainties exist on the state of compaction of agricultural and forest soils and on their long-term structural evolution. Furthermore, the evolution of organic matter levels in the soils susceptible to structural degradation remains uncertain.** The variability of the soils' water-retention properties is *a priori* an interesting tool for better managing the water resource in agriculture and for adapting to climate change.

This last point is particularly important for forestry production, the management of which must be planned into the distant long term.

The state of the soils' mineral reserves is a good indicator of their ability to supply the minerals necessary for plant growth and development. It conveys the capacity of the soils to sustain high plant productivity, while minimising the external inputs. **Agricultural soils show no measurable evolution in their acidity.** Their pH values have remained stable over the last 15 years. The acidification of agricultural soils seems therefore to be managed effectively on a national scale, this process being counterbalanced by liming practices in non-carbonated soils

The pH of topsoil horizons in mainland France from sites of the Réseau de Mesures de la Qualité des Sols [Soil Quality Monitoring Network] (measured) and that of forest soils (predicted by the vegetation)





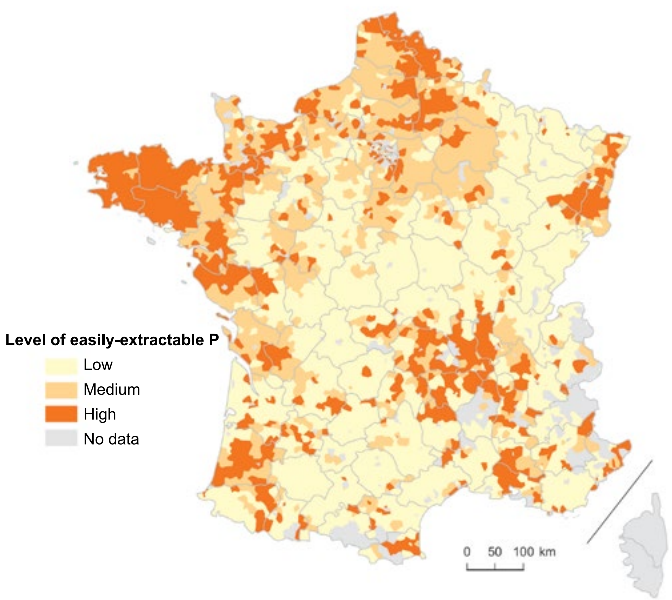
Source: Gis Sol, RMQS, 2011.

Source: © permission AgroParis Tech-Engref (UMR LERFOB) – IFN no 2007-CPA-2-072

In the natural and forest environment, long-term acidification remains uncertain, similar to the evolution of most of the chemical fertility parameters of these environmental soils. In addition, the prospect of a possible increase in uptake from forest biomass (e.g., dead wood, coarse woody debris, branches, etc.) raises the issue of maintaining a sufficient amount of nutrients in these soils.

Agricultural soils do not show a measurable reduction in their potassium contents, in spite of a significant decrease in external mineral inputs. This fact testifies to the progress made in the management of mineral and organic fertilisation, as well as a natural supply, *via* the weathering of minerals in some soils. In the long term, however, the question of a possible reduction in potassium fertility remains pertinent. Finally, **numerous soils show relatively low phosphorus levels**. The large reduction in phosphate-containing mineral fertiliser supply poses the question of compatibility, in the medium term, of agricultural soil phosphorus fertility with current agricultural practices. Inversely, the increase in phosphorus levels in soils where intensive livestock production is practised remains a concern due to its impact on freshwater quality and eutrophication.

The levels of easily extractable phosphorus in agricultural topsoil horizons per canton



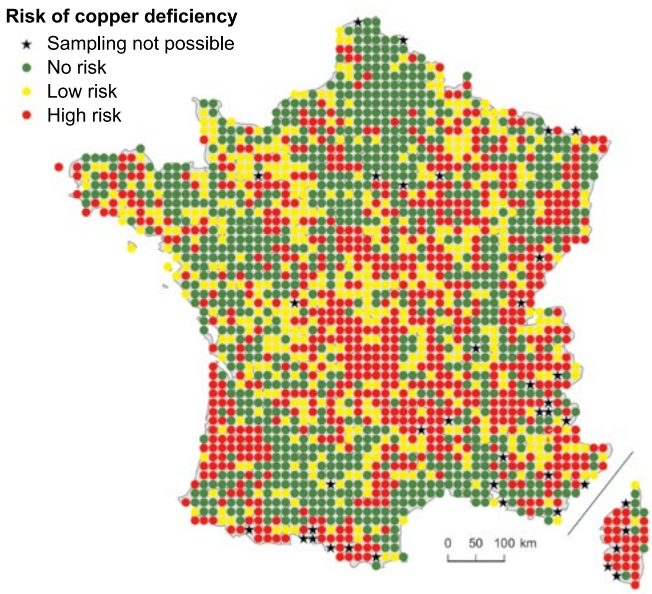
Source: Gis Sol, BDAT, 2011 ; IGN, Geofla®, 2006. Follain *et al.*, 2009.

Note: The high levels in Brittany are linked to concentrated livestock farming. Those found in the North and East correspond to previous contributions from mining waste.

The juxtaposition of excesses and possible deficiencies, in the context of long-term rarefaction of phosphorus, raises the question of better treatment of effluents from livestock farming to correct both of these situations.

Numerous situations seem to be incompatible, such as those for certain oligo-elements (e.g., boron, copper, etc.) with demanding cultures. This fact is not surprising, considering that the practice of balance assessments for these elements is much more recent, and much less widespread, than for the three main elements, which are nitrogen, phosphorus and potassium.

Risk of copper deficiency for a demanding culture



Source: Gis Sol, RMQS, 2011.

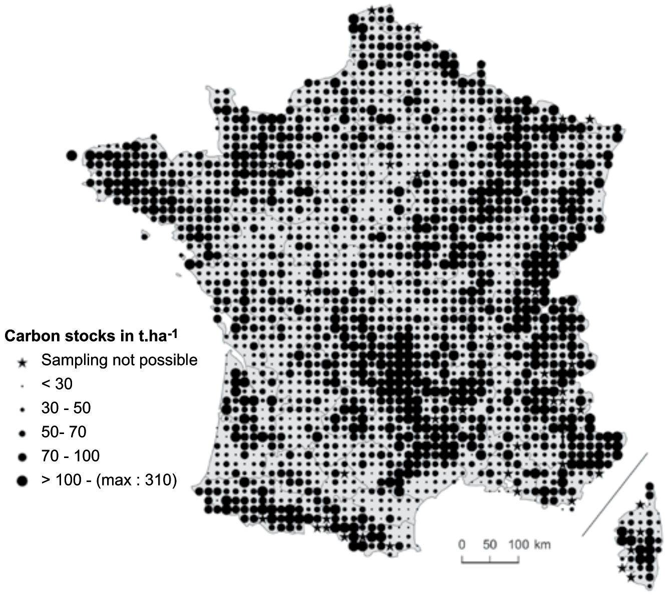
Note: The evaluation of the risk of copper deficiency is based on the relationship between the level of copper extracted with EDTA and the level of organic matter in the soil.

Soils are in an interfacing position between surface and subsurface waters and are crucial to their quality and quantity. Therefore, they are likely to contain, in varying quantities, some elements that are more or less mobile, the transfer of which to water could be accelerated by the effects of climate change. Indeed, the increase of extreme climate events could accelerate lateral transfers by runoff and erosion during periods of very intense rainfall. More generally, the buffering capacity of soils with regard to excess water (e.g., floods, runoff) is threatened by increases in soil sealing. Inversely, an increase in the frequency of droughts could increase the rapid transfer of water and contaminants to certain aquifers by engendering and promoting deep cracking in certain soils. With the data currently available, it remains difficult to assess the possible impact of soils on water quality, except with regard to erosion and the transfer of phosphorus to surface waters.

With regard to climate change, the soils represent both a potential for adaptation and mitigation. The soils of mainland France contain a considerable organic carbon stock, estimated at 3.2 billion [10^9] tonnes in the first 30 centimetres.

This carbon stock is declining in some clearly identified agricultural situations (Bretagne, Franche-Comté, cultivated soils of Les Landes in Gascony, and the Pyrenean foothills), most often due to changes in land uses or practices occurring over the last few decades.

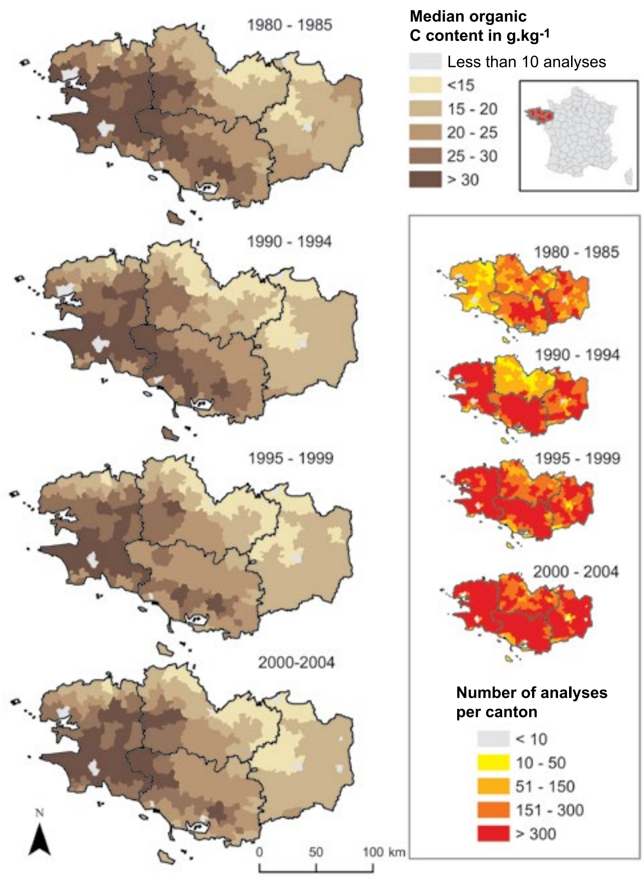
The organic carbon stock in the first 30 centimetres of the soils in mainland France.



Source: Gis Sol-RMQS, 2010, Inra - RMQS, 2010.

Note: The distribution of carbon stocks is mainly controlled by climatic parameters (e.g., effects of altitude), land cover and land use (high stocks in bocage and forest regions, low stocks in regions of intense cultivation and wine production), as well as by soil texture (the greater the level of the carbon stocks, the more clayey the soils are).

The evolution of median cantonal organic carbon contents in the soils of Brittany between the periods 1980 – 1985, 1990 – 1994, 1995 – 1999 and 2000 – 2004



Source: Gis Sol-BDAT, 2004, IGN Geofla®, 2008.

Note: The reduction in organic carbon stocks in the soils of Brittany is most likely linked to changes in agricultural systems, particularly the conversion of permanent grasslands and the development of maize fodder cultivation.

In other situations, carbon stocks appear stabilised, or even slightly increasing. The increase in forest surface area has also contributed to carbon accumulation in France's soils. Afforestation of cultivated soils at 50,000 hectares per year is associated with carbon accumulation of 25 million tonnes over 50 years. The national potential of additional storage with the effects of land-use changes or practices has been estimated to range between 1 and 3 million tonnes of carbon per year over 20 years. **The management of carbon in the soils therefore represents a temporary mitigation of greenhouse gas emissions. However, this storage does not constitute a long-term solution, and its sustainability is very uncertain.** The effects of long-term climate change on the carbon cycle in soils remain very unpredictable with regard to carbon inputs (*via* a possible change in plant production) and outputs (*via* a change in mineralisation kinetics of soil organic matter).

With regard to emissions of nitrous oxide (N_2O) by soils, their spatial and temporal estimation is still impeded by major difficulties in methodology, as well as a lack of scientific understanding. Finally, very little data are available today regarding the movement of methane, but it is probable that the soils of France currently represent a sink, rather than a source, of methane for the atmosphere. Outside of the problems of greenhouse gas fluxes, climate change and increases in extreme events could have diverse impacts on the soils, which remain very difficult to predict and quantify. These probable impacts concern, for example, acceleration in leaching or erosion, disturbance of forest soils from the uprooting of trees during storms, increase in the frequency of floods, and rising levels of marine and brackish waters.

Uncertainties still exist regarding the extent and consequences of climate change on plant production and the soils, but the spatial variability of soil properties, particularly with regard to water retention, represents one of the adaptive solutions to this change.

Soils are the support for terrestrial biodiversity and shelter a multitude of living organisms. They contain an immense quantity of micro-organisms (approximately 10 billion [10^9] individuals per gram of soil), most of which remain unknown, and constitute a considerable genetic pool. The inventory of this biodiversity is a major challenge for the understanding of soil ecological function. **Extractions of microbial DNA in the framework of the "Réseau de Mesures de la Qualité des Sols" (the Soil Quality Monitoring Network), or RMQS, constitute a major step forward.**

These extractions enable, for the first time, the quantification of the role of soils as a reservoir of microbial biodiversity and also the identification of the major factors of variation at the national level: texture; pH; soil organic carbon content; land cover; and land use and agricultural practices. In the current state of understanding, the relationship between soil functions and the abundance or diversity of microbial communities remains an important research topic. It is not yet possible to afford a qualitative judgement on the values observed.

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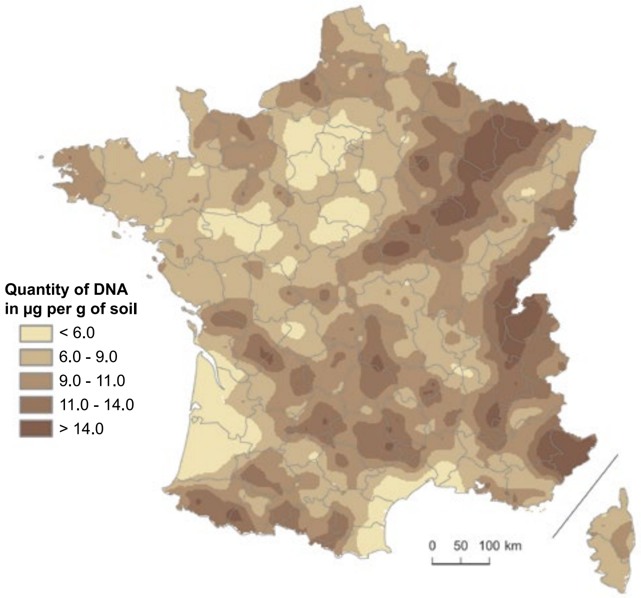
The barcode profiles of the soil bacterial communities can be obtained by analysing soil DNA. These profiles differ as a function of land use: intensive cultivation, natural meadows or forests. More exhaustive studies are currently on-going at a national level in France to evaluate the impact of different land uses and practices on soil microbial diversity (ECOMIC-RMQS programme).

Quantities of microbial DNA extracted from soil samples of the Soil Quality Monitoring Network



Source: ANR Ecomic-RMQS Programme (2010).

Note: On a national level (mainland France), the distribution of microbial DNA quantities contained in the soils is mainly controlled by the soil properties upon which the availability of nutrients for the micro-organisms depend (e.g., clay content, pH, organic matter content).

The long-term future of these populations, as much in number as in diversity, also remains a major unknown. This uncertainty is also the case for other organisms living in the soil, especially micro-, meso- and macro-fauna, in the absence of an exhaustive inventory of their abundance and diversity. The data from a single region (Brittany) affords a first clue regarding the influence of certain types of soil use.

The abundance and diversity of nematodes and earthworms in the RMQS soils in Brittany

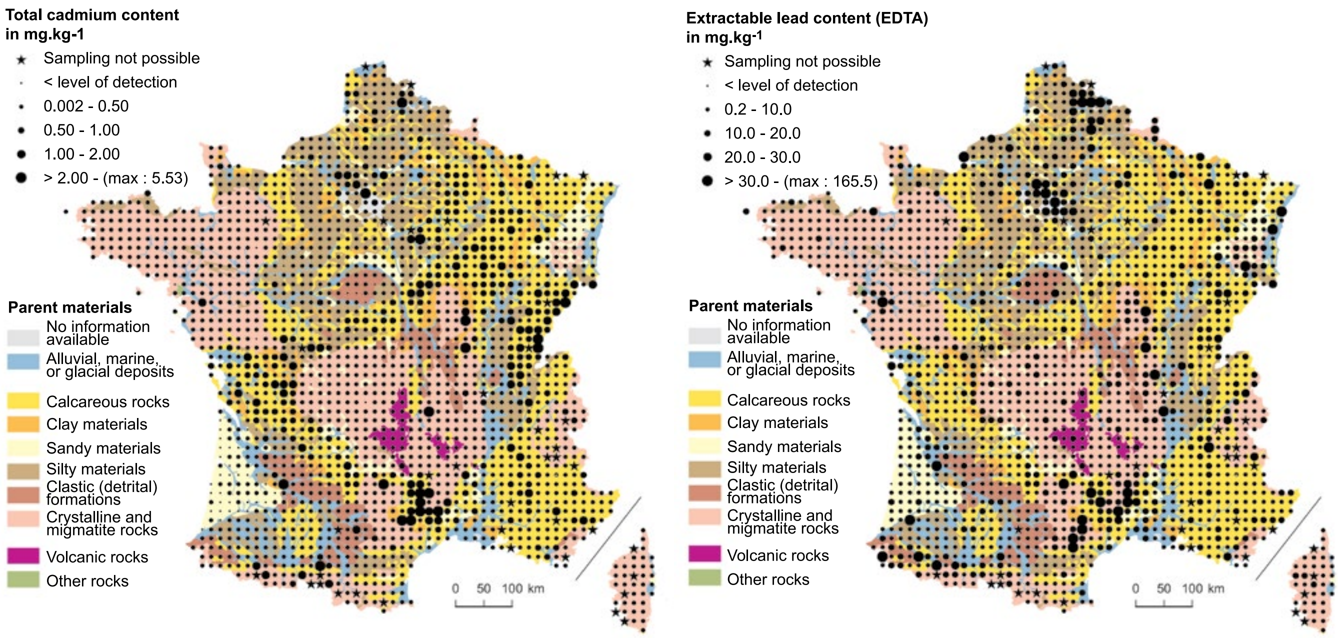
		Value from the 1st and 3rd quartiles	
		52 RMQS sites under cultivation	47 RMQS grassland sites
Nematodes	Abundance (individuals per gram of dry soil)	8 to 16	10 to 30
	Diversity (number of species)	14 to 17	12 to 20
Earthworms	Abundance (individuals per m²)	86 to 320	175 to 447
	Diversity (number of species)	6 to 9	9 to 11

Source: Université Rennes 1, RMQS-Biodiv, 2009.

Note: The first quartile separates the lowest 25% of the data, and the third quartile separates the upper 25% of the data.

As an interface in the environment, soils are likely to receive or emit a certain number of contaminants. These contaminants can be harmful to human health *via* direct ingestion or transfer into water systems, plants and the food chain, and can spread to all ecosystems. **The geographical distribution of some trace elements (TEs), such as lead or cadmium, can be linked to widespread diffuse contamination phenomena.**

The contents of total cadmium and lead (extractable by EDTA) from topsoil horizons (0 – 30 cm) in mainland France

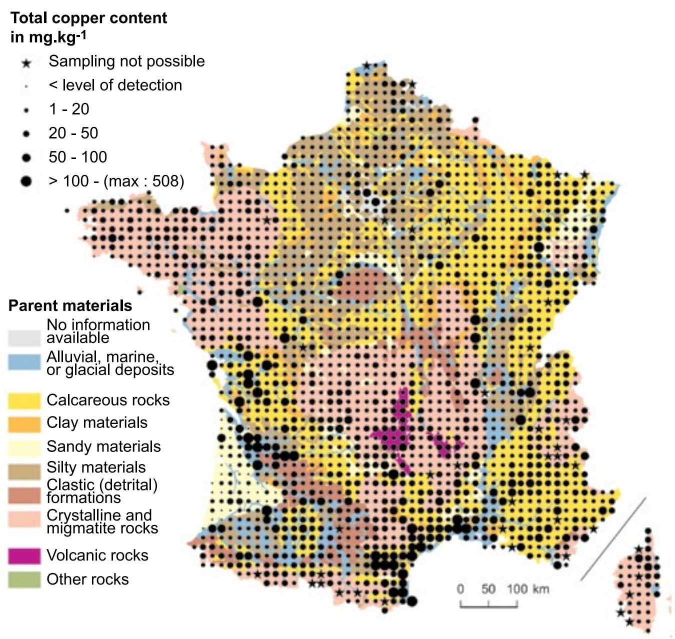


Source: Gis Sol-RMQS, 2011.

Note: The distributions of cadmium and lead in soils depend on natural factors, such as parent material and pedogenesis (this is the case for cadmium in soils coming from Jurassic calcareous rocks and for lead and cadmium bordering, and to the south of, the Massif Central region) and on diffuse contaminations originating from human activity (such as in the Paris and Nord - Pas-de-Calais regions for both elements).

These contaminants mainly affect urban and industrial zones and sometimes demonstrate wide gradients affecting peripheral sectors or much larger rings, such as in the Paris and Nord - Pas-de-Calais regions. Such contaminations also likely exist around smaller urban or industrial centres, but they may not have been observed by the 16 km square reference grid used by RMQS. **Furthermore, certain urban soils have very high levels of some TEs as occasional and isolated events.** In agricultural areas, except for peri-urban and peri-industrial areas, the main sources of soil contamination are linked to agricultural use and practices (e.g., fertilisers, plant health treatments, livestock effluents). In particular, **copper contamination is omnipresent in wine-producing soils.** If copper does not present a danger for the vine itself, it is likely to transfer by erosion and could become an issue if land use is changed. Certain wine-producing soils also have high levels of lead, most likely due to the historical use of lead-containing treatments, which are prohibited today.

Total copper content in topsoil samples (0 – 30 cm) of the Soil Quality Monitoring Network



Source: Gis Sol – RMQS, 2011.

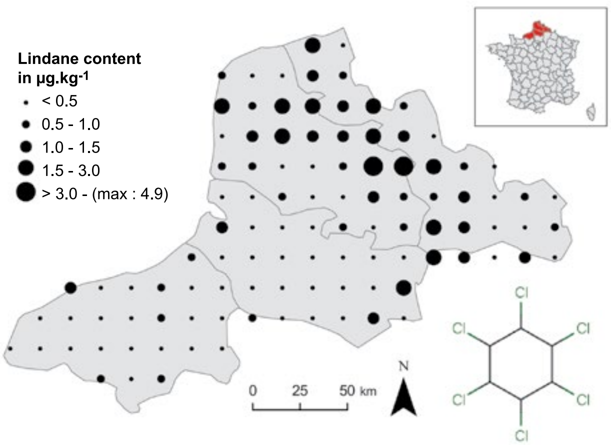
Note: High copper contents are mainly found in wine-producing sectors (Bordelais, Languedoc, etc.). Some vineyards may "escape" from the map-producing process due to the size of the RMQS reference frame. More diffuse contamination is observed, most likely due to industry, around Paris and the Nord-Pas-de-Calais.

In spite of identifying these recognised contaminations, the vast majority of soils in France show TE contents that are quite low (generally <2% are grea-ter than the thresholds used in water treatment sludge spreading activities) or are from a natural source.

For the majority of situations, the risk of transferring TEs into the food chain remains very low. Certain diffuse contaminations can be considered as historic. The diffuse contamination of soils with lead in peri-urban areas is, for example, most likely linked to lead addition into fuels as an anti-knock agent, prior to the selling of unleaded petrols in 1990. Moreover, the reduction of industrial source emissions is a factor in reducing the entry of contaminants into the soils. **The geographical distribution of certain contaminants remains unknown (e.g., arsenic, mercury and selenium).**

A **range of organic pollutants** has been measured in a sub-group of soils sampled by the RMQS. This trial showed some reassuring points but also some points of concern. **Numerous organic pollutants are not – or are only rarely – observed in the soils.** Considering the size of the observation frame, this result does not identify isolated contamination events. However, the dispersal of these contaminants by air into the environment appears to be relatively limited, unless the soils do not store them, or they are rapidly biodegraded in the soils. Inversely, certain contaminants are relatively ubiquitous in the soils; typical examples include DDT and lindane [γ-HCH], two organochlorine insecticides that are now prohibited in Europe but are very persistent in the environment.

Lindane content [γ-HCH] in topsoil horizons (0 – 30 cm) in the north of France

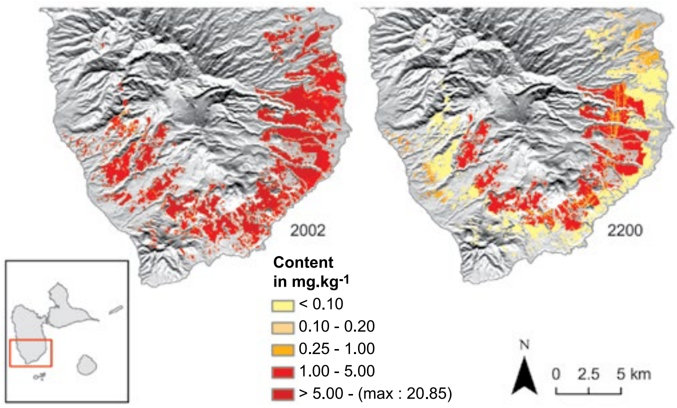


Source: POP-RMQS Programme, Anses, 2009. Villanneau *et al.*, 2009.

Note: The lindane contents were measured in a sub-group of the soils sampled by the RMQS. Lindane was detected in all the samples. It shows, furthermore, a very clear geographical gradient of distribution.

The concentrations remain, nevertheless, low and often close to detection limits. Lindane is present in all of the soil samples analysed, even where it had never been obviously spread. There are uncertainties in the mechanisms of lindane remobilisation, volatilisation and aerial or aquatic transfer. These concerns are linked to the continuation of possible long-distance atmospheric dissemination and the impact that this generalised contamination could have on ecosystems and human health. The case of chlordecone on banana plantations in the French West Indies is **an extreme example of recognised contamination by a particularly long-lasting pollutant of great concern.**

Chlordecone contents in the banana plantation soils in the south of Basse-Terre (Guadeloupe, French West Indies)

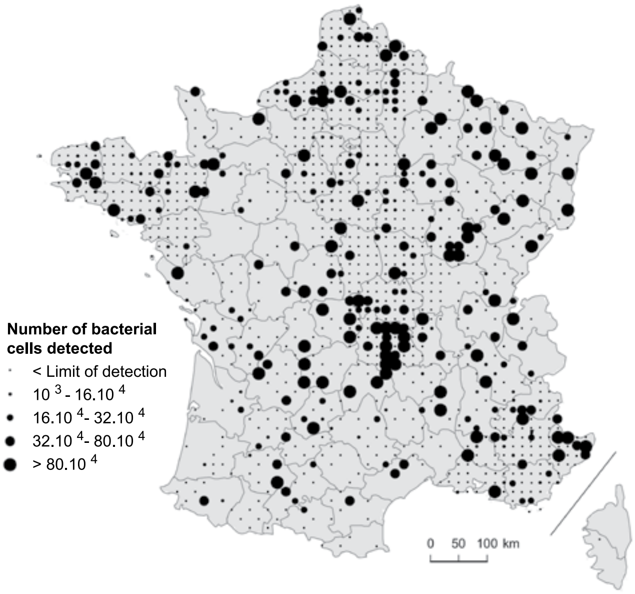


Source: Gis Sol – IGCS 2009 ; Cabidoche *et al.*, 2009.

Note: Chlordecone is a very long-lasting insecticide, prohibited today, which was used in the banana plantations in the French West Indies. Modelling simulations show that certain soils will be contaminated for several centuries.

The characterisation of soils as a reservoir of pathogens is still in its early stages. The results obtained, as well as recent investigations into the origin of certain pathogens, reinforce the idea that the exploration of this potential reservoir should be pursued.

The distribution of the genus Acinetobacter in the soils of mainland France, not including Corsica



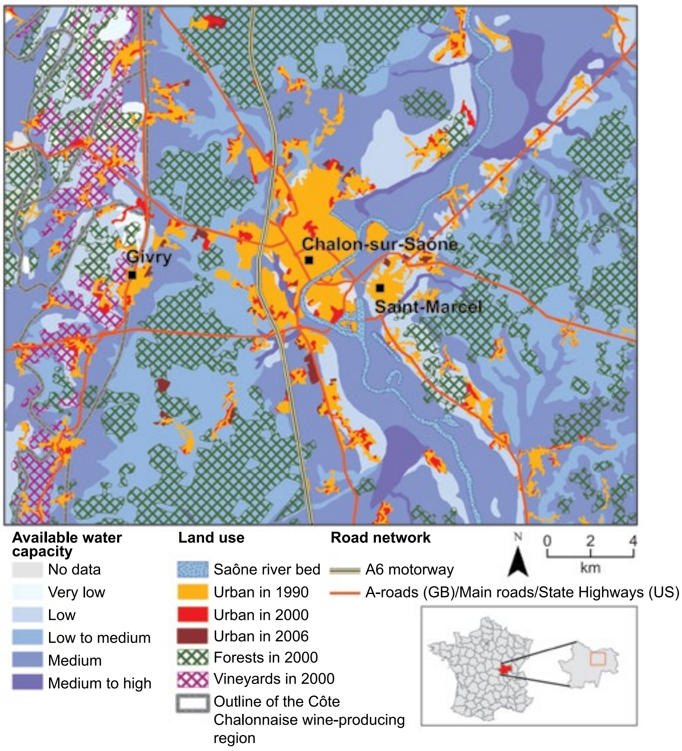
Source: ANR PATHO-RMQS Project, IGN Geofla®, 2008.

Note: The distribution of the genus *Acinetobacter* was analysed for 1,463 sites of the 2,200 that make up the RMQS, within the context of the Patho-RMQS project. The *in vitro* technique of targeted replication, or PCR (Polymerase Chain Reaction), enabled the bacteria to be quantified using DNA extracted from the soil. The genus *Acinetobacter* was detected in 112 of the 1,463 samples tested. Conversely, *Acinetobacter baumannii*, an opportunistic human pathogen, was only found in 8 of the samples.

The whole of services rendered by the soils requires the maintenance of a sufficient "volume of soil", as much in surface area as in thickness. This maintenance is threatened by various natural and man-made pressures, such as sealing, erosion, extraction, landslides, etc. Soil indicators are therefore required to better evaluate the importance of loss mechanisms and mitigation techniques used to combat them (e.g., for erosion), or to better direct the process of choosing soil types for certain uses (e.g., sealing, extraction). **A major concern is soil sealing** which has accelerated over the last decade. Sealing is an obvious threat for most of the functions of the soils, except supporting infrastructures. According to the Teruti-Lucas survey, soil sealing affects a significant portion of French soils (8.9% in 2010). Moreover, it has accelerated between 2003 and 2009, affecting the equivalent of an average French department (6,100 km^2) over 7 years, in comparison to the same surface area over 10 years between 1992 and 2003 (Agreste, 2010). The sealed spaces have spread mainly to the detriment of agricultural soils. More than one third of these events concerned very high quality agronomic soils.

From this point of view, **lthe management of peri-urban soils is an important issue.** These soils simultaneously endure very strong property-related pressures and are affected by widespread or localised contamination that could impair their use. Careful local management presupposes a better understanding of the services they render and the risks associated with their use.

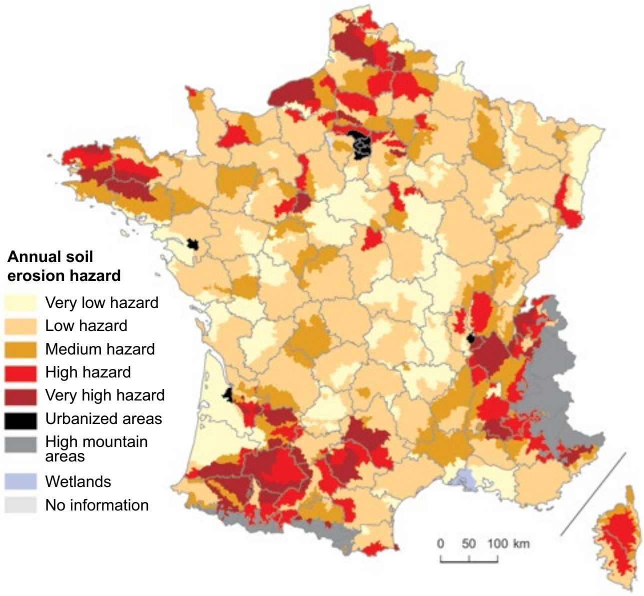
The development of soil sealing in the region of Chalon-sur-Saône between 1990 and 2006



Source: Gis Sol – IGCS, UE SOeS, CORINE Land Cover 1990, 2000, 2006.

Another major concern relates to soil erosion, which is often irreversible. Erosion mainly affects the loamy agricultural soils of the large Paris and Aquitaine basins, as well as certain regions in the Pyrenean foothills and Mediterranean areas.

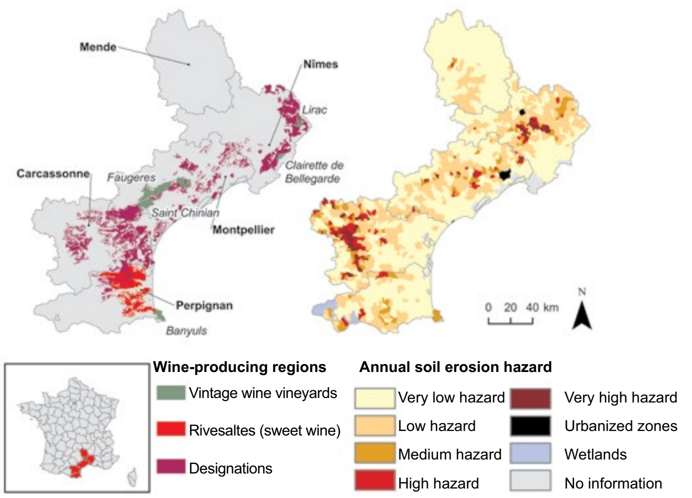
The annual soil erosion hazard in mainland France, integrated per small agricultural region



Source: Gis Sol-Inra-SOeS, 2011.

Note: The soil erosion risk integrated per small agricultural region is estimated using the Mesales model (Modèle d'évaluation spatiale de l'aléa d'érosion des sols – which translates to "spatial assessment model of soil erosion hazard"), developed by Inra. It combines several soil (e.g., sensitivity to surface crusting and erodibility), terrain (e.g., type of land use, slope) and climate characteristics (e.g., intensity and amount of precipitation). The risk is characterised by five classes representing the probability that an erosion event will occur.

Areas of PDO (protected designation of origin), wine-producing aptitude and the map of soil erosion hazard in the Languedoc-Roussillon region



Source: BRL – Languedoc-Roussillon Regional Chamber of Agriculture, Gis Sol, 2011.

Note: The regional geographical soil database on a scale of 1:250,000 covering the Languedoc-Roussillon region has enabled detailing of the regional soil erosion hazard. The hazard is high to the northwest of Nimes and Carcassonne because vineyards and cultivations only slightly cover the highly erodible soils, and the rain events in these regions are extreme.

In numerous cases, erosional soil losses are greater than the amounts of soil formed by natural weathering of the rocks. Beyond the sometimes spectacular damage that it causes downstream of eroded areas, soil erosion is likely to foster uncertainty in the long-term sustainability of certain agro-ecosystems. It could, furthermore, become amplified by an increase in extreme weather events.

Finally, large uncertainties remain on the state of **compaction** of agricultural and forest soils and on their long-term structural evolution.

The mudflow of 9th – 10th May 2009 in the Sundgau region (Southern Alsace).

Conclusion

This synthesis provides a first assessment of the state of the soils in France. It underlines the main concerns regarding the evolution of soil quality. *A contrario*, it presents evidence for a certain number of positive points. Finally, it highlights great uncertainties on some points, with different origins: a lack of historical data to evaluate on-going evolution; the modification and impact of future pressures; and the absence of data or relevant indicators.

The appraisal therefore remains quite balanced. However, certain threats currently appear to be particularly ominous or have, in some instances, already caused almost irreversible damage.

The development of soil sealing has accelerated in the last decade. The understanding of this threat, which is largely irreversible, comes within the scope of methods other than those enacted by the Gis Sol (e.g., CORINE Land Cover, Teruti-Lucas, Cadastre). Erosion could also accelerate as a result of climate change.

Other past damage is difficult to reverse, particularly for diffuse or local contaminations, the origin of which is historic (e.g., leaded fuel, chlordecone in the French West Indies, etc.). For some of these contaminants, their prohibition (e.g., lead arsenate, various persistent organic pollutants, etc.) or a better control of their sources (e.g., limitation of industrial emissions, reduction of certain additives in animal feed, control of the contaminant levels of sludges, etc.) leads to think that the pressures on the soils will be lessened in the future. For other contaminants (e.g., lindane), the dispersion pathways into the environment still pose numerous questions with regard to their future.

However, the majority of contaminants are present in the soils only in very small quantities. Although some might pose real health problems, most possess only a very low risk of transferring into the food chain.

With regard to chemical fertility, this assessment does not suggest a need for a general alert, even if some issues of concern remain and require a more in-depth analysis regarding their input and output pathways. The juxtaposition of potential excesses and insufficiencies, particularly regarding phosphorus, suggests the need for better management of livestock effluents to correct both of these situations.

The DNA analysis from soils in France, in terms of quantity and biodiversity, demonstrates that soil is not sterile and that micro-organisms represent a considerable potential for a more ecological approach to soil management and agricultural production.

If the understanding of the state of the soils in France has considerably progressed, numerous uncertainties and issues remain. For example, carbon storage and its future as a result of climate change, the evolution of soil biodiversity, or the evolution of the physical state of soils are all areas where a lack of understanding persists.

Some of these uncertainties are simply linked to the lack of data. We do not have, for example, a national inventory regarding the distribution of certain contaminants (e.g., arsenic, mercury, selenium, etc.) or of the meso- or macro-fauna of the soil.

For some of these parameters, the soil sample archive created during the Gis Sol programmes constitutes a veritable soil history and should enable certain evolutions to be reconstructed *a posteriori*.

The uncertainties also involve some potential emerging contaminants, such as medical substances or some endocrine disruptors. The national diagnosis of the impact of certain fundamental processes (e.g., those linked to N_2O emissions) still suffers from major scientific gaps.

Other uncertainties are linked to those involving the evolution of pressures. For example, the uncertainties around future climate evolution, and its impact on the dynamics of soil organic matter, do not allow a spatial prognosis of soil carbon stocks. Moreover, changes in soil cover, uses or practices, which represent major evolutionary factors regarding pressures on soils, will depend on economic or political circumstances, which remain mostly unpredictable.

The «pédothèque» or «soil library» in the soil sample archive at Inra, Orléans.

Beyond this national assessment, the improvement and maintenance of soil quality require a more localised management by local stakeholders. Regional operations producing a mapped inventory of the soils, which are near completion, should become precious tools in soil management and decision-making processes, guaranteeing the maintenance of their services to the ecosystems.

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Appendix

The Gis Sol Programmes

The Soil Inventory, Management and Conservation programme (IGCS) aims to create an inventory and produce a multi-scale geographical database of soils in France. This programme is implemented on three different scales: the Regional Pedological Referential at 1/250,000 (RRP), the Soil knowledge programme of France on medium scales (1/100,000 and 1/50,000) and the Reference areas on detailed scales (1/10,000). At the end of 2010, the mapping survey of the RRP was completed for 28 departments of mainland France, the coastline band of Guyana and a part of the French West Indies. The geographical databases of the IGCS programme are used as decision-making and planning tools on various scales and in the context of multiple purposes: agriculture, forestry, water quality, greenhouse gas emissions, housing, etc.

The Soil Test Data Base programme (BDAT) is collecting, for mainland France, the results of analyses performed for arable farmers by soil analysis laboratories certified by the ministry for agriculture. It is computerised and standardised. The results are accessible to the public *via* an interactive map on a web server. This programme currently stores more than 19 million analytical results. Their spatial distribution is relatively homogenous in the main French agricultural regions. **A specific programme dedicated to the collection of trace metal analyses (the BD ETM),** which was previously dedicated to the spreading of water treatment sludges, was also initiated. These programmes provide a spatial and temporal view of the distribution and evolution of certain parameters in the agricultural topsoil layers in France.

Finally, the Soil Quality Monitoring Network (RMQS) programme is based on the installation and observation, at regular time intervals (every 10-15 years), of nearly 2,200 monitoring sites. They are installed on geo-referenced plots at regular spatial intervals, in accordance with a 16 km-square reference frame. All of mainland France and the French West Indies have been covered in ten years. The first results have enabled the fertility of French soils to be qualified and the carbon stocks to be estimated in relation to mitigating climate change. The completed mapping also highlights areas that are naturally rich in trace elements or those where diffuse, man-made contamination is suspected. The programme also feeds into numerous other studies, such as those regarding soil contamination by persistent organic pollutants or human bacterial pathogens, and the role of soils in greenhouse gas fluxes. The national soil sample archive, created from the sampling activities of the RMQS, is needed for this task.

Legal deposit: March 2013
2-7380-1318-X Code
EAN: 978 273 801 3187

2013

The state of the soils in France in 2011

A synthesis

This synthesis makes available, to a broad audience, the first appraisal of soil quality in mainland France and its overseas territories. It is based upon an extensive project of acquiring and exploiting data generated by the French Soils Scientific Interest Group (Groupement d'Intérêt Scientifique Sol) over a 10-year period. It summarises the main conclusions of the complete document, The state of the soils in France, *L'état des sols de France*, published in 2011.

This synthesis presents the knowledge and understanding acquired regarding the chemical, biological and physical state of the soils. Although major uncertainties still remain, this appraisal highlights the main concerns relating to the evolution of soil quality, but also shows evidence for certain positive points.

Indeed, the soils are the support for agricultural and forestry activities, and are the guarantee of our food security. In interacting with other media, they ensure services essential for humankind and for the environment. However, they still remain, mostly, poorly understood, as their presence is most often hidden by the vegetation, dwellings or infrastructures, which cover them.

Furthermore, the soils constitute a natural resource, the destruction of which is difficult to reverse, and the rehabilitation, very costly. Their uses and their future represent a major collective issue for sustainable development. The understanding of their state and its evolution is therefore fundamental as much with regard to the maintenance of human activities as for the preservation of the quality of our environment.

Considering "the soil" as an insufficiently understood issue, the Soil Scientific Interest Group, Gis Sol, was created in 2001 by several public parties. Today, it is contributing, with this first national assessment, to the improvement of soil knowledge and awareness and to their wider use by citizens, decision-makers or land developers.

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