2

Understanding Soils for Their More Efficient Management: A National Soil Information System

2.1. Introduction

The multitude of soil functions, stressed in 2002 by the European Commission [COM 02], remain poorly understood by society, despite the fact they are key components of major global issues, such as food security (in terms of quantity and quality), the quality of underground water and surface water bodies, climate change mitigation or biodiversity protection.

Soils are a natural resource that are necessary to both protect and increase the value of, both efficiently and sustainably, for the well-being of humanity. Their formation is very slow, but their destruction is rapid and almost irreversible: this resource can thus be considered as non-renewable. Soils are subject to increased pressure, which generates threats to the sustainability of their functions [COM 02].

Soil properties have a very high spatial variability; to manage them better, it is necessary to produce a mapping inventory. Moreover, some soil properties being likely to evolve, in particular due to anthropic pressures or climate change, the implementation of monitoring tools is needed in order to detect degradations, which may become irreversible early on. Taking into account the abundance of soil

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functions necessitates a better definition of the concept of soil quality, which no longer rests on the single concepts of physical, chemical and biological fertility.

While replacing them in an international context, in this chapter, we explain and discuss the capacity of French observation mechanisms to collect relevant data on different scales for the inventory and monitoring of soils in France.

2.2. The inventory and monitoring of soils in Europe and in the world

On a global scale, the only geographical database for soils in vectorial format is that produced at the scale of 1:5,000,000 [FAO 90]. It is a synthesis map based on soil groups with a very high taxonomic level. Its scale, as well as its essentially qualitative attributes, do not enable using it on continental and national scales. It has been used to carry out quantitative assessments of soil properties, such as organic carbon supplies [BAT 96], but the latter remains highly uncertain. At the global level, Hartemink [HAR 08] considered that one-third of countries, or 69% of the global land area, do not yet have a soil map on a scale greater than 1:1,000,000. In Europe, the most precise harmonized vectorial database corresponds to a scale of 1:1,000,000 [KIN 95], and several countries do not yet have a soil map of a scale either greater than or equal to 1:250,000.

As for systematic monitoring soil schemes, they are characterized by a very large heterogeneity, as much in their sampling strategies as in the monitored parameters and the methods employed [MOR 08]. The only harmonized continental scale networks are the European networks, BioSoil and LUCAS-Soil [PAN 12]. However, these networks do not have yet a timescale large enough to enable the detection of significant changes.

Ahead of the global issues posed by soil management, in 2012, the international community implemented Global Soil Partnership under the auspices of the FAO (Food and Agriculture Organization of the United Nations). It rests upon five pillars, with the fourth pillar dedicated to the acquisition and sharing of soil data. One of the major issues of this pillar is to implement harmonized databases regarding soil characteristics and their changes. It will benefit from the structuring of the scientific community within the GlobalSoilMap consortium [ARR 14], which produces specifications for a harmonized mapping of soil properties on a global scale.

Despite the availability of highly inaccurate data, assessments of the state of soils globally and in Europe have been produced, with notably in 2015, “The International Year of Soils”, a publication by the FAO and the United Nations which is a Report on the Status of the World’s Soil Resources, published as part of the Global Soil Partnership [FAO 15]. About 22% of land has soils that are potentially favorable to agriculture and, among these, 60% are affected by one or several forms of degradation. On a global scale, soil loss by erosion is estimated between 20 and 30 billion tons per year. That is more than 3 tons per inhabitant per year. Each year, approximately 20 million hectares of agricultural land are turned over to urban and industrial expansion globally. This is more than the surface area of arable land in France, and corresponds to a rate of soil take of 6,350 m^2/s (that is to say about one football pitch). Contamination of soils by metallic trace elements or persistent organic pollutants is a major problem in certain emerging countries, such as India and China. Thus, the loss of cereal production linked to contamination represents around 12% of China’s total production, or a cost of the order of 2.6 billion euros per year.

2.3. National mechanisms for the acquisition of soil data

2.3.1. *Issues and demands*

The access to soil data is necessary to respond to a multitude of issues, ranging from the management of a farm to the protection of natural resources and the development of rural and forest areas. At the national level, demands are growing and the needs are expressed on highly diverse scales according to many issues and players [LEB 06, RIC 12]. Ministries and national agencies most often express needs for mapping, zoning and providing national indicators to orientate their policies or in response to European reporting obligations, for example: assessing the carbon storage potential in French soils, in support of international negotiations, micro-pollutant concentrations (both metallic and organic) within soils to assess the risk of population exposure or even soil erosion as part of reporting to the Organisation for Economic Co-operation and Development (OECD). Other bodies, such as local authorities, natural parks and associations, have requirements over limited areas, for issues among which are the protection of water resources on the catchment or watershed scale, the management of biodiversity or land use and urban planning. As for the agricultural sector, its needs come on a variety of scales from large areas of agricultural production to farm scales, in view of the management of soil fertility. Increasingly, the demand requires spatialized databases, which may be directly exploited through Geographic Information Systems (GIS) or serve as input data for models and decision support tools. This broad spectrum of demands requires access to numerous and diverse soil characteristics and properties, as well as a good understanding of the processes involved.

2.3.2. *Structuring of national data collection mechanisms*

At the national level, several initiatives have been launched from the 1960s onward to improve the knowledge of French soils. Nevertheless, the Bornand report [BOR 97] observed that these initiatives suffered from a lack of coordination, as much in the data acquisition process as in the backing up of data, and that the majority would not lead to lasting capitalization and harmonization of soil information. Data acquired were of limited availability and difficult to process, although they could have had great potential. Moreover, no national soil monitoring strategy was implemented at the end of the 1990s. A review of the main European soil data acquisition [ARR 98] showed that at the end of the 1990s, France suffered a significant deficit in knowledge regarding its soils and monitoring changes of their quality, compared to its European neighbors.

Conscious of their converging national interests to collect information about the characterization of soils and the evolution of their quality, the ministries for Agriculture and Environment, the Institut National de la Recherche Agronomique (National Institute for Agronomic Research – INRA), the Institut Français de l'Environnement (French Institute for the Environment – IFEN) and the Agence de l'Environnement et de la Maîtrise de l'Énergie (French Environment and Energy Management Agency – ADEME) decided to strengthen and join their efforts to implement a national soil inventory and monitoring mechanisms for soils. Thus, in 2001, the Groupement d'Intérêt Scientifique Sol (Soil Scientific Interest Group – Gis Sol) was created, grouping together these organizations, which were joined by the Institut de Recherche pour le Développement (Institute of Research for Development – IRD) and the Institut National de l'Information Géographique et Forestière (National Institute for Geographical and Forestry Information – IGN). The Gis Sol set up national programs for data acquisition, and the INRA Unit InfoSol was created to coordinate these programs at the national level, in order to ensure harmonization and permanent management of the collected data, as well as to make them available to local authorities and society as a whole. Gis Sol was completely original at the European level. It was renewed in 2006 and then in 2012. This is detailed in Box 2.1.

The Groupement d'Intérêt Scientifique Sol (Gis Sol) was created in 2001. It groups together the ministries responsible for Agriculture and the Environment, the French Environment and Energy Management Agency (ADEME), the National Institute for Agronomic Research (INRA), the Institute of Research for Development (IRD) and the National Institute for Geographical and Forestry Information (IGN).

The aim of Gis Sol is to constitute and manage an information system for French soils, responding to regional and national needs in the European and global context. The Gis Sol organizes the coordination and cooperation between its members with the aim of designing, orientating, coordinating and ensuring that the actions of the geographical soil inventory, soil quality monitoring and the creation and management of an information system respond to the demands of local authorities and society.

Gis Sol thus manages the principal environmental soil monitoring tool in France. Its work is conducted around three major complementary programs. They are the Inventory, Management and Conservation of Soils (IGCS), the French Soil Monitoring Network (RMQS), and the Database of Soil Tests (DBAT). Their coordination at the national level is entrusted to the service unit InfoSol within INRA, which mobilizes regional partner networks. The initial inventory on the soil quality in mainland France and the overseas departments was published in 2011, in the Report on the condition of soils in France.

Box 2.1. *The Groupement d'Intérêt Scientifique Sol (Soil Scientific Interest Grouping, available at www.gissol.fr)*

Two complementary strategies for data acquisition are being implemented as part of the Gis Sol framework so as to, on the one hand, understand and manage the diversity of soil cover, and, on the other hand, to provide a soil monitoring mechanism which is likely to detect early changes in soil quality. Both soil inventory and monitoring data are collected through dedicated Gis Sol programs and are described in detail in the rest of this chapter. The two strategies implemented according to the various means aim to optimize collection, by combining the capitalization of preexisting data and new data acquisition through dedicated mechanisms (Table 2.1). The common factor for all of these programs rests upon the mobilization and leadership by the INRA InfoSol unit of the network of partners on a national scale and ending with a capitalization of:

– data within a unique and harmonized system, aiming to facilitate the exploitation (DoneSol national database); and

– samples within the Conservatoire Européen des Échantillons de Sols (European Archive of Soil Samples – CEES), of which the unit INRA InfoSol also ensures management.

	Inventory	**Monitoring**
Capitalization of preexisting data	Inventory, Management and Conservation of Soils (IGCS)	Soil Test Database (BDAT) and Database of Metallic Trace Elements (BDETM))
Acquisition of new data		French Soil Monitoring Network (RMQS)

Table 2.1. *Strategies of various national programs for soil data acquisition (source: M. Bardy)*

In parallel, as part of the policy for the management of sites and polluted soils, the French Ministry for Ecology is piloting, independently of Gis Sol, the inventory of:

– potentially polluting activities; and

– polluted sites and soils or potentially polluted soils, calling for local authority policies as preventive or curative measures. These data feed into two databases: Basias and Basol.

2.3.2.1. *Soil inventories on various scales*

At the national level, soil inventory programs have been initiated since the 1960s. They have continued on various scales and were structured in a unique national program in 1990, the "*Inventaire Gestion et Conservation des Sols*" (IGCS, French Inventory, Management and Conservation of Soils), taken up by the Gis Sol in 2001. The aim of this program is to capitalize on legacy soil data using a unique format and to gain new data on diverse scales, with the aim of achieving short-term national coverage on a scale of 1:250,000. Since 2011, finalizing this coverage has been all the more necessary, since this database currently serves to support the review of zonings of the Common Agricultural Policy (CAP).

The information collected as part of this program enables the constitution of the map representation of spatial soil distribution, taking the form of Soil Mapping Units (SMUs), associated with a database using a national format, DoneSol [INR 14], describing the Soil Typological Units (STUs) that compose them. Data acquisition is carried out in accordance with the French General Technical Specifications (known as "CCTG") IGCS [INR 05], itself consistent with the NF X31-560 standard [AFN 07], which describes methods of data acquisition, organization and validation of soil inventory data. The IGCS program is multi-scale and is organized in the various components:

– the Regional Pedological Referential (RRP) section, operating on a scale of 1:250,000, aims to produce regional soil maps [LAR 14], mobilized as support assistance for decision-making at the national, regional or district level;

– the Knowledge of French Soils section (known as “CPF”) on medium scales (1:100,000 to 1:50,000) aims to improve knowledge of the diversity of soils and their laws of spatial distribution on the basis of factors leading to their formation [RIC 14], with privileged use over watersheds or landscapes of interest; and

– the large-scale Reference Sectors (RS) section (scales of the order of 1:10,000) aims to produce more detailed soil studies enabling agricultural or environmental issues to be dealt with on local scales, with the possibility of extrapolation over a small natural region.

At the end of 2016, 92% of the mainland territory had a finalized mapping of 1:250,000, acquired at the departmental or regional level [LAR 14]. National harmonization of these maps is in progress to produce a national map on a scale of 1:250,000. Moreover, maps on scales of 1:100,000 and 1:50,000, respectively, cover 24% and 18% of the mainland territory [RIC 14]. Overseas, an inventory of 14% of the territory of Guyana has been made, with the overseas territories having soil maps on different scales, which were updated as part of the IGCS program [DUP 15].

2.3.2.2. *Data collection on soil characteristics*

2.3.2.2.1. Databases of soil tests

From 1980 onward, the École Nationale Supérieure d’Agronomie de Rennes (ENSAR – Agronomical Engineering School) implemented a program for the collection of soil tests in Brittany. This was generalized across the whole of France by means of an agreement with the Association Française pour l’Étude des sols (French Association for Soil Studies) and then sustained as part of the Gis Sol program. This monitoring program capitalizes within the Soil Test Database (BDAT) the results of soil analyses [SAB 14], which are produced at the request of farmers at laboratories certified by the Ministry for Agriculture. Unique in Europe, this national database includes, and thus makes usable, analyses of more than 2.5 million samples of agricultural surface soil horizons, including samples that have been measured for more than 25 years. Mainly agronomic parameters are informed in this database. Data are geographically referenced on the municipality scale. The quantity of data, as well as the time elapsed, enable the interpretation of evolutive trends for some of these parameters. It therefore constitutes a monitoring and warning tool regarding the evolution of agricultural agronomic soil characteristics.

Concerning forest and urban areas, data are currently less organized within easily accessible databases or even in a totally incomplete form (Box 2.2).

Regarding forest soils, there is a significant and under-exploited resource for data [EGL 14] available within a diversity of organisms for research and development (e.g. INRA, ONF (National Forests Office), IGN and FCBA (French Institute of Technology for Forest-based and Furniture Sectors)). Although some sources are accessible (e.g. the RMQS data of forest soils), much data are still difficult to process and rarely exploited, outside of the organizations that collected it. Faced with dispersion and low data harmonization, significant work has to be implemented to favor their dissemination and use (e.g. placing data within databases, production of metadata and common semantic frames of reference and the clarification of property rights).

Concerning urban soils, there is still a shortage of data, which are less organized and therefore poorly accessible. In general, they are produced by local communities during spatial planning activities, by research programs for specific uses (e.g. garden soils and urban planning [KEL 12] or through national surveys [JOI 16]). At present, various initiatives are trying to collect data upon agronomic (such as texture and fertility) and environmental characteristics (e.g. concentration of metallic and organic micro-pollutants) of urban and peri-urban soils, so as to constitute an initial national database.

Simultaneously, regardless of forest or urban soils, we should question the possibilities in the medium term to improve the coordination between the production and management of data, so as to centralize them using the same system.

Box 2.2. *What data are available on forest and urban soils?*

2.3.2.2.2. “Metallic Trace Elements” Database

Since 1997, a preliminary study on the spreading of sludge from treatment plants has been necessary to characterize the ability of soils to receive it. Metallic trace elements and pH should thus be analyzed on the soils of the fields involved in such spreading programs. These analyses are centralized by various organizations (e.g. chambers of agriculture, engineering consulting firms and local government) distributed throughout the country. During the course of two campaigns, conducted in 1998 and 2008, the Gis Sol gathered, centralized and structured this information. At present, there are approximately 500,000 metallic trace element results which have been collected and are available to produce statistics for distribution and evolution.

2.3.2.3. *Monitoring system for French soils*

With the creation of the Gis Sol, France was equipped with a mechanism enabling it to assess and monitor soil quality, with the implementation, in 2000, of the Réseau de Mesures de la Qualité des Sols (French Soil Monitoring Network – RMQS). This rests upon the systematic monitoring of 2,240 sites distributed uniformly across all of mainland France in a square grid of 16 km × 16 km (Figure 2.1) based on the European Network for Forest Damage Monitoring (Forest Health, ICP-Forest Level 1) and representative of the main combinations of various soil types for given land uses, encountered at the national level. This grid system is gradually being extended to French overseas departments. This monitoring network rests upon the production of measurements and observations at the centre of each cell with a time interval of the order of 15 years. The first campaign, in mainland France, took place from 2000 to 2009. During this period, sites have also been described and analyzed within the French West Indies (in Martinique and Guadeloupe) and supplemented since then by the installation of sites in La Réunion, Mayotte and in the coastal fringe of Guyana, in partnership with IRD (Institute of Research for Development) and CIRAD (the International Centre for the Cooperation in Agronomic Research for Development).

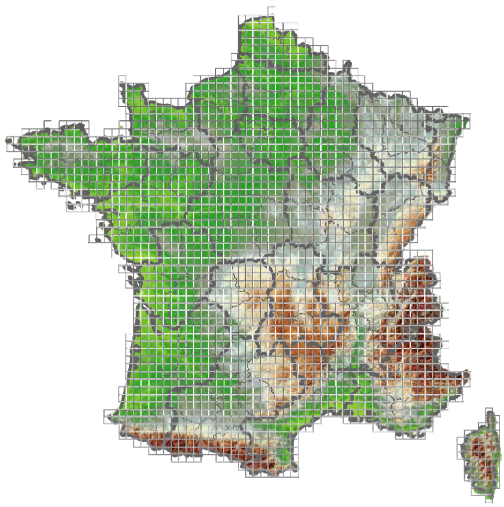

Figure 2.1. *Network grid for Soil Monitoring in Mainland France (source: French Soil Monitoring Network – RMQS)*

Analyses of physical, chemical and biological properties are carried out on samples collected and capitalized within the national database DoneSol. The samples are archived in a systematic way within the European Archive for Soil

Samples on the site of INRA in Orléans [RAT 10]. Initial soil samples can be remobilized and analyzed in a retrospective manner, in response to emerging problems or following the development of new analytical methods. This has, for example, been the case recently with the determination of the biological parameters of soils [RAN 13] or the analysis of persistent organic pollutants [VIL 13] across all of the mainland territory.

The second collection campaign by the French Soil Monitoring Network began in 2016. The sampling strategy was completely revised. The initial campaign had advanced on a regional basis, depending on when new partners were mobilized. The second campaign rests upon an annualized sampling strategy, with distributed samples taken every year throughout the country. Its main aim is to respond to issues linked to climate change: for example, it will implement measurements to enable the detection of changes in organic carbon contents and stocks and the acquisition of physical soil parameters, relating to the management of water resources. Moreover, this campaign is enriched in terms of collection, with samples taken from greater depths (1 m instead of 50 cm as for the initial campaign). The various determinations will be enriched progressively, as sampling is implemented, as part of research programs or requests from national agencies.

2.4. Data exploitation for the production of maps and indicators

All of the national programs previously presented have their own advantages and disadvantages. Their complementarities, as well as hyperlink data collected with external data and modeling, enable multiple exploitation in response to the concerns of local authorities and society.

The French Soil Monitoring Network presents an unbiased and systematic approach, with numerous measurements and connected information registered for all of its 2,240 mainland sites. It thus enables a characterization of the soil quality in France without bias. It has permitted, for example, the mapping of the global distribution of metallic trace elements in French soils and identification of their sources [SAB 11], according to their origin. These can be natural (geological and pedological) and anthropogenic (diffuse or specific contamination linked to industrialization, transport, amendments, phytosanitary treatments and others). “Natural” trace element contents were quantified on a regional basis. Their comparison with soil analysis results enables the detection of anomalies, which constitutes a valuable tool for the identification of contaminated sites. Moreover, large contamination diffuse gradients have also been able to be revealed, for example, in the periphery of highly urbanized or industrialized zones [SAB 06] or even on far more significant surfaces; deposits transported for long distances through the atmosphere [VIL 13].

The French Soil Monitoring Network is also a remarkable support program for the production of national assessments or simulations. The most recent examples concern the assessment of soil carbon stocks (Figure 2.2) [MAR 11, MEE 12], and the prediction of their evolution due to climate change or soil use change [TOS 14]. The French Soil Monitoring Network thus constitutes a significant support for public policies within the sphere of negotiations concerning the climate. It will become even more relevant in the future as the second campaign for sample collection progresses, with the added time dimension.

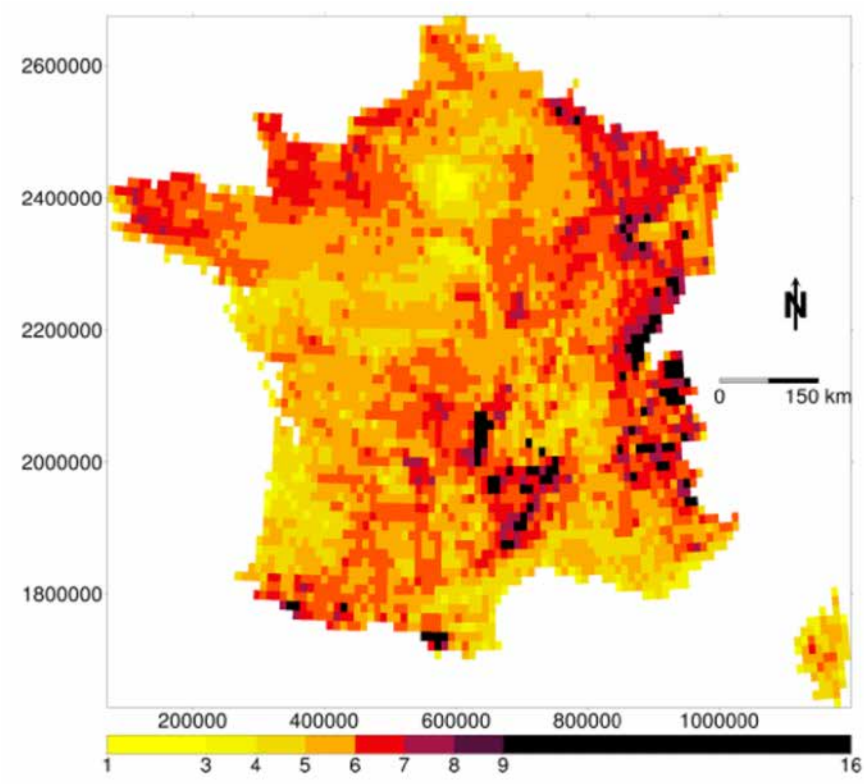

Figure 2.2. *Map of organic carbon within the first 30 cm of soil (in g km^{-2}) (source: M. Martin and contributors). For a color version of this figure, see www.iste.co.uk/berthelin/soils1.zip*

The BDAT and BDETM (Database of Metallic Trace Elements) have had a larger time lapse, from around 1990 to the present day. These databases are however heterogeneous as regards sampling, from both a spatial and a temporal viewpoint. Only agronomic parameters are collected within the BDAT, whereas the analyses of metallic trace regulatory elements are carried out within the BDETM. Both databases only address topsoil. However, they have (especially the BDAT) data acquired "en masse" (Big Data), which confers upon them a relative statistical robustness. Thanks to data from BDAT, and by aggregating them over several years and at the county level, it was possible to identify and quantify some major trends of soil changes (Figure 2.3, [LEM 08, SAB 08]) and to characterize regional or national gradients [FOL 09] and to reveal statistical relationships between certain soil parameters [ARR 06].

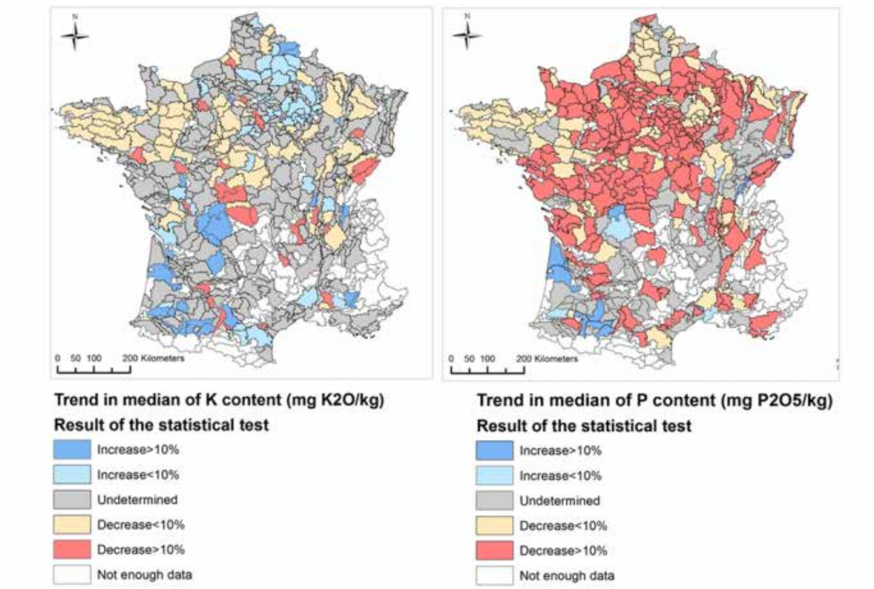

Figure 2.3. *Evolution of median content in exchangeable potassium (K_2O) and exchangeable phosphorous (P_2O_5) by small agricultural regions, between the periods 1990–2004 and 2005–2014 (source: Gis Sol, BDAT, 2016; IGN, Geofla®, 2008). For a color version of this figure, see www.iste.co.uk/berthelin/soils1.zip*

The IGCS program has the advantage of providing a more refined description of soil distribution than the two programs mentioned above. It therefore permits more local applications thanks to its finer spatial resolution. Recent examples concern the use of IGCS data for a pre-delimitation of wetlands or less favored areas, both zones supporting public policies [LAR 14]. The resolution of data collected, as well as the depth of soil investigation, offer the possibility of more local applications (e.g. protection of surface or sub-surface water, zoning of erosion risks, helping the decision for land-use planning and geotechnical applications). The Mixed Technological Network for Soils and Territories (Box 2.3) favors the use of soil invetory databases. Given the harmonized national format, DoneSol, for data capitalization, methodologies for using data can be jointly developed and then adapted to local contexts. However, the parameters measured by this program (which mainly have perennial characteristics) and its spatiotemporal uncontrolled sampling scheme (from a statistical viewpoint) make it poorly adapted for detecting short-term and medium-term evolutions.

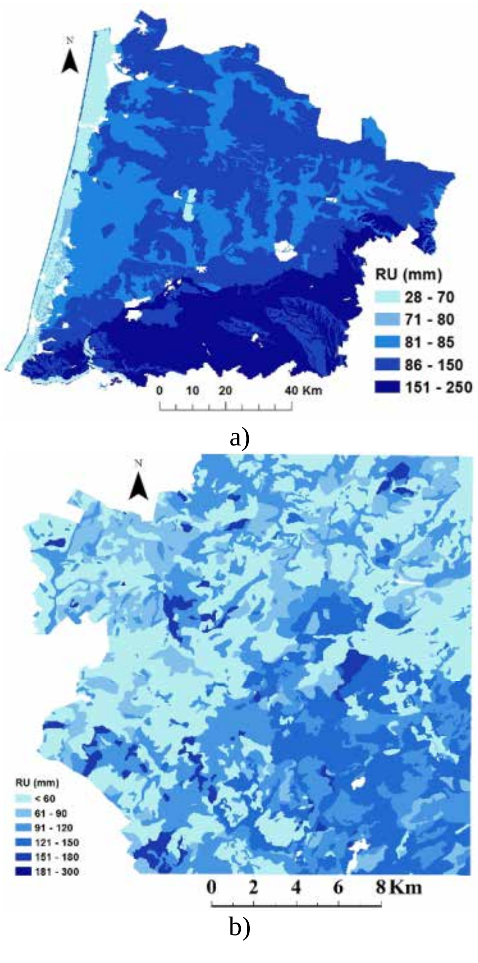

Figure 2.4. *Example maps of available water capacity of soils: a) from 1:250,000 of the Landes département and b) from 1:50,000 of the commune, Patay (source: provided by Richer-de-Forges [RIC 03]). For a color version of this figure, see www.iste.co.uk/berthelin/soils1.zip*

Increasingly, works develop the mutual enrichment of data acquired at the level of various programs and their joint exploitation. All of the data are, for example, mobilized to produce the French contribution to the program, “GlobalSoilMap” [ARR 14], which aims to create a global database for a number of soil properties considered as significant to assess their functions and services. On the scale of mainland France, trials have produced maps, from spatial models, concerning soil depth [LAC 16], organic carbon content [MUL 16a], soil texture and pH [MUL 16b]. These works are continuing to refine these predictions, mainly within the Centre region [CIA 14], in Brittany [LEM 12] and in Languedoc-Roussillon [VAY 15] and to extend them to other parameters.

In 2011, after 10 years of works, Gis Sol published the Report on the Status of French Soils, i.e. the first assessment of soil conditions for mainland France and French overseas territories. This is shown in detail in Box 2.3. Its publication was largely relayed in the press. This report is an excellent support for raising awareness of the need to consider soils in public decision-making.

The first synthesis on the state of soils in France

After 10 years of work, the Soil Scientific Interest Grouping, Gis Sol, wished to draw up the first scientifically quantified assessment of soil conditions in mainland France and French overseas territories. This 188-page report [GIS 11], based on the exploitation of all available data, supplies all citizens and environmental actors with the solutions to understanding soil functions, the services they render and the pressures which they are subjected to. It establishes a diagnosis of their chemical, biological and physical conditions. It stresses the positive aspects and reveals the main threats.

A generally positive assessment

The report advances numerous positive points, such as low contents for the majority of metallic and organic contaminants, good management, on a national scale, of the acidity of agricultural soils and their potassium contents and the presence of microbial DNA in all of the soils. The report thus demonstrates that the soils are indeed “alive”.

However, the report reveals some points of concern. Some pesticides, nowadays prohibited, but highly residual (e.g. DDT and lindane), have been found within all measuring points, including those where the pesticides were never used. In the West Indies, contamination by chlordecone is severe. The report also shows imbalances in phosphorous content, with some regions having a deficit and others a heavy surplus, able to contribute to the eutrophication phenomenon. Finally, a major concern is the progress of land take and soil sealing.

Knowledge yet to be acquired

Moreover, the report highlights numerous uncertainties linked to our lack of knowledge. This includes, for instance, soil carbon storage as impacted by climate change, the evolution and functions of soil biodiversity and the physical condition of soils (compaction and erosion) as well as related issues.

Box 2.3. *Report on soil conditions in France, available at: www.gissol.fr/publications*

Since then, collaborative publications by Gis Sol's partners have underlined the recent results stemming from the Gis Sol programs. The first [ADE 14] is a synthesis regarding carbon in soils, detailing the issues for the climate and agronomy. The second [SOE 15], published in 2015 during the International Year of Soils, is a panorama of indicators and key figures around soils and the environment, highlighting the issues relating to soils. These two publications were widely disseminated to a variety of audiences: public with various degrees of awareness on soils and agricultural education systems, among others.

2.5. Dissemination and availability of data

After about 10 years devoted to the implementation of programs and data collection, Gis Sol has, since 2012, devoted means to the dissemination of collected data, in raw or more elaborated forms.

2.5.1. *A national soil information system focused on data dissemination*

In recent years, the national soil information system structure has been entirely reviewed, in order to favor data availability. The core of the information system remains the "operational" databases within which raw data are stored. The national database, DoneSol, in particular, is the relational database within which data capitalization, from inventories and the systematic soil monitoring, occurs. Its structure is relatively complex, due to its wealth of data. As a result, its handling is not easy for the uninitiated public. Built on to this operational information system, the following were developed:

– a decisional information system within which data relating to soils, as well as external data, are stored in both simplified and harmonized formats. This facilitates on the one hand, their availability in simple formats to various stakeholders, and on the other hand, their subsequent processing for the unique needs of Gis Sol; and

– a statistical information system within which data processing scripts are capitalized. They are able to be automatically executed, in order to facilitate the updating of data processed and then their dissemination.

These elements are supplemented by tools for verifying data consistency, the traceability of data transformations and data documentation in the form of metadata. Finally, the link with a geographical data infrastructure enables the creation of Web services and the feeding of the various mapping interfaces, enabling the consultation and access to data.

2.5.2. *A progressive enrichment of data and metadata supply*

The growing interest in soil data and the current context of Open Data have strengthened the need to facilitate access to data produced within the Gis Sol framework. The Gis Sol website (www.gissol.fr) was entirely overhauled in 2015, and has enabled the enrichment of the online supply of information upon soils in France, with:

– the possibility of uploading certain data sets;

– a supply of Web services enabling data integration within geographical information systems (GIS) or spatialized data infrastructures;

– an enrichment of metadata, which feeds the tool, Refersols (available at: www.gissol.fr/outils/refersols-340). This tool enables the identification of existing soil studies at the national level; and

– the revision of the tool, Geosol (available at: www.gissol.fr/outils/bdat-346), which enables the production and export, in various formats, of specially prepared maps of soil properties, obtained from the BDAT.

Moreover, the RMT (Réseau Mixte Technologique) Sols et Territoires – MTN (Mixed Technological Network for) Soils and Territories – (Box 2.4) developed in recent years:

– the database, Applicasol [GIR 17] (available at: www.gissol.fr/outils/applicasol-342), which favors the readability and sharing of specialized mapping produced from soil data, as well as the associated methods; and

– the application, Websol [VIN 13], which enables both the online consultation and examination of databases of soil inventories.

Mixed Technological Networks (MTNs)

MTNs are mechanisms implemented in 2006 by the French Ministry of Agriculture with the objective of creating a new innovation dynamic within the domains of agriculture, food and forestry. It is a question of favoring, with financial support, network creation and specialized collaborations between actors in research, training and agricultural development.

The emergence of MTN Soils and Territories

Created in 2010, the Mixed Technological Network for Soils and Territories (MTN S&T) now has 11 founding partners and 24 associated partners. It is structuring its programs to complement those of the Gis Sol around the following two issues:

– understanding soils and providing access to knowledge of soils within the territories; and

– taking better account of soils within various policies, projects and agricultural, environmental and rural action programs.

Their implementation rests upon the five areas of work depicted in Figure 2.5.

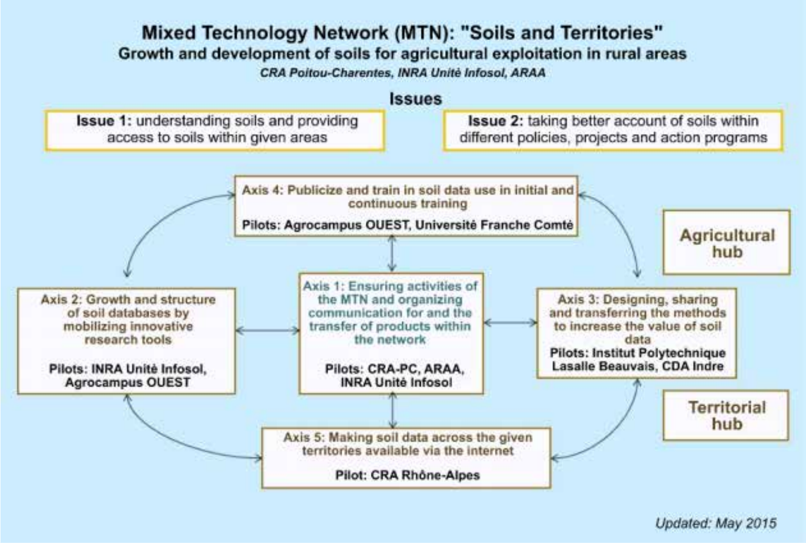

Figure 2.5. *Issues and areas of work of the MTN Soils and Territories*

After an initial phase (2010–2013) of internally structuring the network around a "nucleus" essentially of partners with soil competences, the MTN S&T has been opened more broadly, since 2014, to the essential competences of specialized data development within the given territories (planning, law, urbanism, agronomy and others). The organization's work complements the work of Gis Sol. By mobilizing and consolidating regional soil expertise, MTN S&T favors dissemination and development within the territories of data acquired as part of Gis Sol [GUE 14].

Box 2.4. *Mixed Technological Network Soils and Territories (source: M. Bardy). More information available at: www.sols-et-territoires.org*

2.5.3. *Assisting the use, improvement and control of data*

Gis Sol and MTN S&T are leading complementary initiatives favoring soil data appropriation for a broad public. Awareness-raising, from the initial training pathway, continues, and user support is a key element for a sound appropriation of data and for the quality of uses that are made of it.

Besides the digitalization of data and its dissemination in formats adapted to their production, Gis Sol offers training sessions for using the DoneSol national database for its general use on the one hand and the production of thematic mapping on the other (e.g. available water capacity of soils). This is supplemented by MTN S&T, which made available a database user guide for the production of thematic maps [LEM 17].

Finally, in 2017, the MTN S&T accompanied the publication of a soil manual entitled "Maps and soil data, tools serving territories" [DUC 17] aiming to supply teachers with training materials to familiarize students with soil databases and to deal with a large number of issues.

2.6. Conclusion

Despite the delay at the end of the 1990s, France is now equipped with a mechanism for the inventory and monitoring of soils, which is both acknowledged and envied at an international level. Thanks to the implementation of Gis Sol and the mobilization of its partners within its various national programs, an initial inventory on soil quality in mainland France and the overseas territories has been produced. Data available at the international level are progressively being added to, consistent with international dynamics.

Beyond this national diagnosis, the improvement and maintenance of soil quality rests upon local management by interested actors. For this reason, regional mapping inventory operations of soils nearing completion, as well as the initiatives of the MTN S&T, may constitute precious tools to assist decision-making for soil management guaranteeing the maintenance of their ecosystem services.

A perspective for developing the mechanism will depend on soil inventory programs, which will increasingly use methods of digital mapping. On the basis of predictive spatial models, including information of a diverse nature (this comprises the landscape, agriculture, relief and other factors), these methods enable the association of predicted values with an assessment of uncertainty, which will diminish as the databases themselves are enriched. The actual process of soil data acquisition will certainly be modified in the near future by another one based on the issues and prospects of the uses of the considered or studied territories.

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