Soil Mapping and Soil Monitoring: State of Progress and Use in France

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Introduction

The Service for the Study of Soils and the Pedological Map of France (French acronym: SESC PF) was founded in 1968. Within the INRA (National Institute of Agronomic Research), it ensures the coordination of most soil mapping and monitoring programmes in France. This is made possible by data received from a number of other public or private organisations that are partners in these programmes: research institutes (CNRS: National Centre for Scientific Research, Universities), professional development organisations (Chambers of Agriculture, National Forest Bureau), land development companies and design offices, etc. Work is carried out at the request and with the support of the Agriculture and Environment Ministries, as well as local governments (Regional Councils).

France is composed of 56% arable land, 28% wooded surfaces, 8% of surfaces that are unused or are destined to protect natural environments and finally 8% surfaces that have been built upon (IFEN, 1999). Current trends indicate a loss of land to building and infrastructure of close to 40,000 hectares (ha) (100,000 acres) per year, the equivalent of one French Department every 10 years. This trend is undoubtedly one of the prime menaces for the “soil” heritage. It is also an indicator of a large number of other pressures on soils and may cause their irreversible degradation.

Soil mapping programmes are a valuable tool for land management. In spite of this, there are currently significant reductions in the resources allocated to these programmes.
At the same time, increasing demands are being made that are more diversified and more specialised in terms of agricultural and environmental functions of soils. A systematic inventory of the country is no longer sufficient to respond to these demands. In addition there are a multiplicity of actions that must be coordinated at the national scale in conjunction with European programmes.

The aim of this paper is to describe several of these actions and briefly demonstrate their use in long-term natural resource management programmes. More detailed information can be found in the soil chapter of the last French environmental report (IFEN, 1999) and in an in-depth review of research over the past 30 years (Bornand, 1997).

**Soil Mapping**

The “Pedological Map of France” (CPF) programme has been in existence for more than 25 years. It has led to the acquisition of a large quantity of data on the soil resources of the country and to a basic understanding of the typology and spatial variability of the principal soil systems (Jamagne et al., 1995).

This programme was the reason for the creation of SESCPF, leading to the development of a national platform for coordination and cooperation in the field of spatial analysis of soil. By the end of 1998, 27 maps at a scale of 1:100,000 had been published and 13 additional maps were being prepared, accounting for about 15% of the territory (Figure 1).
The resources allocated to this programme, however, are not sufficient to achieve the total coverage of French territory in the medium term. It was thus decided to reorient the CPF programme to give preference to the detailed formalisation of soil distribution laws within zones representative of the main French pedological systems. In essence, this means that old data will be computerized and new acquisitions will be made in little prospected regions. This programme is intended as a scientific support for inventory programmes carried out at broader scales including that described below.

The “Soil Inventory, Management and Preservation” (IGCS) programme conducted by the Agriculture Ministry and INRA since 1990 aims to prepare a map with an associated database at a scale of 1:250,000 for each of the French Regions (Bornand et al., 1989, Jamagne et al., 1995). Up-to-now, 3 regions have been completed, as well as 12 Departments, accounting for about 40% of the country (Figure 1).
A test of data transfer to the European system is under way in the Côte d’Or Department in Burgundy (Finke et al., 1998). A second aim of the programme is to carry out detailed studies, at a scale of 1:10,000, of small size sample landscapes. Monitoring the agricultural and environmental functioning of these zones provides a reference base that can be generalized and applied to similar soil systems identified at a scale of 1:250,000 (Favrot, 1987; Favrot and Lagacherie, 1993).

These two programmes do not cover all mapping activities. Several regional or national organizations have started mapping programmes at smaller scales, e.g. 1:50,000 in the Centre Region, 1:25,000 in the Aisne Department, typology of forest stations, regional typologies, etc. In addition, there are many local studies, but it is difficult to estimate the extent of this information (Bornand, 1997).

Figure 2: Location of monitoring sites of the OQS and RENECOFOR programmes.
Finally, there is the synthesis map at a scale 1:1,000,000 that has been revised in the framework of European projects (Jones et al., 1998, Le Bas et al., 1998). Even so, this work is insufficient to meet current needs and the expected coverage at the 1:250,000 scale will lead to a thorough revision of the 1:1,000,000 geographic database.

Soil Monitoring

There are two main French soil-monitoring networks. The first deals with long-term changes in cultivated land and natural non-wooded spaces. The second involves forests.

The main purpose of the “Soil Quality Observatory” (OQS) is to assess the present situation of soils and monitor their changes in order to improve on and implement a soil preservation policy (Martin, 1993). Eleven sites each of about 1 ha were chosen on the basis of their representative nature for soil and land use. There is a minimum set of parameters that are systematically measured at all sites of the network. For some specific degradation problems, additional measurements may be conducted at some sites, e.g. light fraction C and N, mineralisable C and N, microbial biomass, soil enzymes, earthworms. The recommended time step is five years.

On one agricultural site, continuous pig slurry application has been shown to increase significantly the organic carbon content and that of some metals (Cu, Zn). In an acid brown soil under a mature spruce stand, a decrease of total elements in the organic layers, and of the exchangeable elements in organo-mineral horizons has been observed, which could have severe consequences for future forest nutrition.

A decrease of the lead concentration in forest litter may be considered as an encouraging sign in the campaign to render gasoline greener. Other ongoing work involves the definition of biological indicators and development of a sampling strategy for soil microbial biomass and determination of soil fauna.

The RENECOFOR programme is a long-term monitoring system for forest ecosystems (Figure 2). It was created by the National Forest Bureau in 1992 in order to extend the system for monitoring the health status of forests (Ulrich, 1995). It is the French part of a set of permanent parcels installed in 34 European countries. It covers highly varied areas of forests.

Two soil profiles are systematically studied and fertility is monitored. With respect to the "Cataenat" sub-system (total acid load of atmospheric origin), atmospheric deposits have been measured in 27 parcels since 1993, and measurements are conducted on soil solutions taken from 20 and 70 cm depth from 17 parcels.

Other monitoring systems including soils have been implemented, but they are concerned with other components of the environment, especially water resources. In addition, databases have been created from results of old analyses of soils sampled separately from, or in the context of, local programmes (for example, see next section on the National Base of Land Analyses, French acronym: BNAT). These data are localised in space and in time and provide information on medium- and long-term changes. It has not yet been decided, however, whether to continue the systematic collection of the data from the laboratories concerned.

Soil Databases

In 1990, a unique database structure was adopted for all nationally integrated programmes. The system is called DONESOL and includes three parts (Gautier et al., 1993):

1. Point data obtained from observations and measurements made on soil profiles.
2. Descriptive data of soil mapping units, soil typology units of soils and horizons. Additional data, provided by expert advice, take into account the spatial variability within these entities. Digitized contours are included in a GIS linked with DONESOL.
3. Metadata that indicate bibliographic references of the studies as well as their location and precision (Favrot, 1994). Over the past several years, considerable effort has been devoted to cataloguing all detailed scale pedological studies. This work is currently being extended by studies at medium and large scales. A directory of soil mapping professionals has also been published (Favrot, 1997).

Information about mapping and monitoring programmes can be found on the INRA Orleans World Wide Web site (http://www-sescp.orleans.inra.fr/public/). One objective is to develop this site particularly to include the metadata described above.

Other databases have been prepared in conjunction with, or in parallel to, the DONESOL database. In contrast to the above-mentioned programmes, these databases have been compiled in the context...
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of targeted research projects, including ASPITET, SOLHYDRO and BNAT.

ASPITET: In 1994, INRA a research programme began entitled “Implications of Pedological Stratification on the Interpretation of Trace Elements Contents” (French acronym: ASPITET). The aim of this programme was to acquire reference data on the natural contents of trace elements in soils. The work entailed taking into account soil types and geological parent materials.

The population of samples studied up to the end of 1998 was 1310 pedological horizons, corresponding to 706 distinct sites. Total trace element concentrations were determined for each sample (systematically Cd, Cr, Cu, Mn, Ni, Pb, Zn, often As, Co, Hg, Se, Ti).

The results show that the general degree of contamination by human activities is very low in comparison to the stocks of natural trace elements in soils.

Nevertheless, there are three types of exceptions in cultivated lands:

(i) regions in which grapevines have been planted and those devoted to arboriculture, that are almost always contaminated with copper;
(ii) parcels fertilised with sewage sludge having a large heavy metal load;
(iii) parcels located in proximity to ore processing factories (affected by atmospheric pollution).

Figure 3: Organic matter content of the surface horizon in cultivated lands, extracted from the BNAT.
SOLHYDRO: A project was started in 1998 to compile an analytical database of the hydraulic properties of French soils. The purposes of this database are to:

(i) assemble all data on these properties determined by different research laboratories, as well as any additional analytical or descriptive data;
(ii) make these data available to researchers for comparison of methods of measurement and for preparation of pedotransfer functions using the range of French soils;
(iii) prepare nationally recognised references for users.

There are links between this database, DONESOL, and the European HYPRES system (Wösten et al., 1998).

BNAT: More than 200,000 soil analyses are carried out by private companies each year. A feasibility study was conducted from 1990 to 1994 to assess recovery of these data and determine whether to include them in a database termed 'Base Nationale des Analyses de Terre' (National Base of Land Analyses) (Walter et al., 1997, Schwartz et al., 1998).

The data have been collated by township and by districts to protect the rights of the owners of the analyses. Each variable can be expressed in the form of maps or statistical tables and these documents have led to the confirmation of spatial structures that are often known but never quantified, especially for variables that are difficult to determine in conventional mapping work (Figure 3). The value of this database is that it facilitates the analysis of possible changes in soil properties over time. The detection of these changes will require a longer time span.

The collection and structuring of analytical data obtained by private parties is a valuable source for regional or national reviews. In addition to the BNAT, the AGREDE programme conducted by ADEME and INRA recovered close to 12,000 analyses of heavy metals obtained between 1992 and 1997 relating to studies before fertilisation with sewage sludge from water treatment stations. Maps currently being edited display the general quality of agricultural soils and reveal zones of anomalies, either natural or induced by local pollution.

Use of Existing Soil Data

Examples of the use of the soil databases described above were selected on the basis of themes directly involving the soil (erosion), agricultural production (quality of products), or the management of natural resources (aquifers, rivers). The examples were also selected to demonstrate national or regional applications that show the value of the different databases in different ways.

Among the various threats to soil, erosion is clearly one of the most visible, in terms of both agriculture (loss of land) and the environment (water pollution, damage to and by urban and road infrastructures). At the request of the Environment Ministry, two national mapping programs were started.

The first was an inventory of mudflows based on insurance claims filed for natural catastrophes between 1985 and 1995 (Figure 4). The second was a map of the “soil erosion” probability, produced by combining the various factors responsible for this erosion in a GIS (Le Bissonnais et al., 1998): crusting and soil erodability determined from the 1:1,000,000 database, plant cover taken from CORINE land cover, slopes and precipitation (quantity and intensity).

The combination of these inputs was carried out with a simple empirical model using grids with a step of 250 m. The results were then collected according to catchment or to small agricultural regions and presented for each season (Figure 5).

The two documents facilitate inter-regional comparisons that define the nature and intensity of the erosion. These documents are compared to regional studies (King et al., 1998) or sent to regional authorities so that they can promote sensitivity campaigns and proposals for combating the problem.

Trace element contents in soils result from the combination of natural processes (heritage from parent rock) and direct or indirect inputs resulting from human activities. Results of the ASPITET programme together with work done in cooperation with the AGREDE programme have identified areas containing high natural levels of metals that are often higher than regulatory thresholds for sewage sludge fertilisation (Baize, 1997).

For example, Figure 6 shows four zones in the Seine-et-Marne Department having abnormal concentrations of Zn (higher than 80 mg/kg), corresponding to fertilisation sites close to four railway stations at which the composts were unloaded (Baize and Paquereau, 1997). This type of study clearly pinpoints zones in which fertilising with sewage sludge should be controlled or prohibited.
The database resulting from the IGCS programme is rarely used alone to express a soil property. In most cases soil information is combined with other databases, in particular those of climate, topography and agriculture. Combinations are created using dynamic models that reproduce past events by simulation (agrometeorological models, hydrological models). The maps show risks related to a change in agricultural practices or to climatic change, in the form of frequency analyses.

This is a topical area of research and the number of studies is high (MAPA, 1998): for example, risk of nitrate leaching in Brittany (Saby et al., 1999), irrigation management in the Beauce (Cousin et al., 1998), vulnerability to fertilising, fertilising with urban composts (Legros et al., 1991), quality of agriculture production (Monnet and Gaiffe, 1998), diversification of cultivation after removal of grapevines (Bornand et al., 1994).

In most of these studies, the soil has a pivotal role in the results, but it is difficult to determine the weight given to it in the final decision. This results from the modelling methods that use other environment variables and from sociological and political factors that are necessarily present in decision-making processes. This observation has also been verified in relation to the use of monitoring networks. For example, the objectives concerning air pollution are to reduce the emissions of pollutants that affect ecosystems at long distance. The concept of critical loads enables the effects of atmospheric fallout to be quantified in terms of forest decline and pH of streams.

In France, the ADEME has implemented and led regional and national research to respond to the particular needs of the Environment Ministry at the time of revision of international protocols (e.g. Dambrine et al., 1998, Thomas et al., 1998). The network data used in this case are an essential support for international comparisons.
Perspectives

Perspectives are discussed in terms of three aspects: soil mapping, soil monitoring and the distribution of information.

In the field of mapping, surveying at the scale of 1:250,000 is continuing in order to obtain exhaustive and integrated information for the whole of France. This scale, however, is insufficient to respond to all kinds of social demands that are highly varied and require precision. There are no national plans to allocate considerable resources to respond to this demand for precise information.

On the other hand, it has been proposed to reinforce 1:100,000 existing studies by organising the results obtained in knowledge bases.

In this way, local governments and institutions, rural land managers or design offices can consult the data and apply this knowledge to the areas with which they are concerned. In addition, there is an increase in the needs for mapping at highly detailed scales, i.e. down to the level of agricultural plots.

This has resulted from progress in techniques of spatial positioning and their potential to use alongside associated agricultural techniques (precision farming).
It is thus planned to reinforce research on these new techniques, in particular, the use of geophysics and digital elevation models. Finally, this multi-scale approach, from the plot to the region, requires continuation of research into scale transfer methods (e.g. Lagacherie et al., 1997). Concerning soil monitoring, French systems are judged satisfactory for forestry but insufficient for agriculture. There is thus a need to develop a new system that includes two levels.

The first would be composed of a large number of sites monitored with a time step of about 5 years. The aim of this would be to have an alert system that makes no prior judgments on pressures that may be exerted on soils within the coming years. The second would be applied to a limited number of sites to follow fluxes at shorter time steps (day, month) and thereby be able to analyse and explain recorded long-term changes.
In this context, the Environment Ministry has started a research programme (GESSOL) whose aim is to establish the scientific tools and bases to assess, monitor and even restore soil quality.

Finally, it is recognized that all current or future programmes will be of interest only if the data gathered are distributed as widely as possible and in the most instructive manner possible. This implies the continuation of research in the field of combining spatial data and in that of error propagation when different data sets are combined. In addition, there is need to develop methods for structuring and distributing information, in particular using modern computer technologies (Web, CD-ROM). It is also necessary to obtain more information on user needs in order to develop the tools that can most efficiently respond to these needs.

Acknowledgments

The authors thank all the people, partners in the programs or members of their scientific committees for sending the information for this publication, especially D. Arrouays, D. Baize, M. Bornand, J.C. Favrot, R. Hardy, P. Lagacherie, C. Le Bas, C. Schwartz and C. Walter.

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