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# Mapping of Soils and Land-Related Environmental Attributes in France: Analysis of End-Users' Needs

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**Abstract:** The 1:250,000 soil mapping program of France is nearly complete. Although mapping has been conducted using conventional methods, there is a discernible need to obtain more precise soil data using other methods, and this is attracting considerable attention. However, it is currently not possible to implement a conventional and systematic program throughout the French territory, as the cost of acquiring new data on a finer scale is too high. In light of this, the Ministry of Agriculture commissioned a national survey to determine the needs of soil mapping in France, which asked questions to soil data producers and end-users. The results presented here summarize the main needs expressed by end-users. The main topics covered by soil mapping applications are identified in addition to the main mismatches between topics currently covered using available soil maps and the needs of end-users. Certain priorities for producing new soil information are identified in relation to geographical environments and settings, soil attributes, the spatial resolution of maps and the use of uncertainty estimates. Digital Soil Mapping is identified as a method that can bridge economic, scientific and practical considerations, but it requires dedicated efforts in order to build capacity. Finally, there is discussion of how the consideration of user needs can be employed to enhance the contribution of a new Digital Soil Mapping era, and to launch an operational soil security paradigm in France.

**Keywords:** soil mapping; end-users' needs; digital soil mapping; France

## 1. Introduction

The concept of Global Soil Security was initially defined in two seminal papers [1,2], and aims to solve the global soil crisis by maintaining and improving global soil resources. This concept includes five dimensions (soil capability, soil condition, soil capital, soil connectivity and soil codification) that are fully described in the two papers and were discussed in depth during a conference at College Station (Texas, USA) and another in Paris (France) [3,4]. Although soil security is a global issue, its implementation needs action at a more local scale (e.g., a national scale). This is why we report here the needs of soil map end-users that were expressed through a vast survey recently conducted in France. This paper summarizes a communication given during the third Global Soil Security conference held in Sydney, Australia, in December 2017.

The French national soil mapping strategy was driven by the Ministry of Agriculture and INRA (French National Institute of Agronomic Research), and then taken over by GIS Sol (group of scientific interest for soil). Since the beginning of the 1990s, it has favored the completion of an exhaustive coverage of the territory by compiling a Soil Geographical Database on a scale of 1:250,000. The compilation of this database has mainly been based on conventional 1:250,000 soil mapping conducted on a regional level ('Référentiels Régionaux Pédologiques', RRPs) and coordinated by INRA on a national level. The data from these RRPs have been progressively made available to users through a national standardized soil information storage system (DoneSol) and user interfaces that are accessible on the web.

This French RRPs program is nearly complete. However, although its results have already been largely available and employed since the early 2000s [5], there is a growing need for more precise soil data. This need is attracting considerable interest [5,6], and the Ministry of Agriculture has commissioned a committee of experts to identify a new agenda for conducting the next step of the national soil mapping strategy in France, and has requested one that considers the soil mapping needs of end-users, remains realistic in terms of cost and considers new developments in digital soil mapping approaches [7]. Within this framework, the specific challenges for soil mapping in France are thus to better assess the users' data needs for a new implementation program. As a first step in expediting this, the committee conducted a national survey to compile a factual statement relating to demand–production correspondence on a technical level. Considering the above, the objectives of this current paper are as follows:

(i) to identify the main mismatches between the topics currently covered by available soil maps and the needs of end-users;
(ii) to highlight some of the priorities inherent in the production of new soil information in relation to geographical environments and settings, soil attributes, the spatial resolution of maps and the use of uncertainty estimates;
(iii) to identify technological barriers and the need for capacity building and
(iv) to discuss to what extent the needs of end-users can be fulfilled in the near future, and how a suitable improved soil mapping strategy could help provide useful inputs to the five dimensions of soil security in France.

## 2. Materials and Methods

The committee in charge of compiling the survey questionnaire included experts from research, higher education and agricultural development, in addition to people with extensive experience in soil mapping (either in a conventional or digital way, or both) and in using soil data in various applications. To create an inventory of soil knowledge using the soil maps currently produced and used in France, the committee created two surveys: one for map producers and one for end-users. These questionnaires were firstly tested by conducting oral interviews on a panel of 15 people from various origins. After refinement, one questionnaire was sent to map producers (using either conventional or digital soil mapping techniques) and the other to current or potential end-users.

The questionnaires included a broad range of questions (up to 92 for map producers and 67 for end-users) that covered practical, technical, scientific, economic and governance issues. This paper reports only on the practical, technical and scientific issues relating to the development or use of the maps. The types of questions used in the present paper are summarized in Table 1.

Certain generic questions were asked to both end-users and producers, whereas the wording of technical questions differed substantially between the two groups. The reason for this was to analyze to what extent the maps meet current needs, and to identify the main gaps between the demands of users and the current maps provided. The surveys included a number of open- and closed-ended questions; most of the closed-ended questions were formulated to enable results to be quantified, whereas the aims of open-ended questions were to allow participants to express themselves freely in their own words, and to allow each individual to explore his/her ideas without being constrained by a fixed and limited choice of responses. The complete list of questions and associated type (closed- vs. ended-question) is available (in French) online [8].

**Table 1.** Types of questions in surveys for map producers and end-users.

| Soil Map Producers | Soil Map End-Users |
|---|---|
| Type of organization | |
| Nature/origin of the demand | |
| Topics/issues for which soil data is used | Topics/issues for which soil data is needed |
| Variables collected | Variables of interest |
| Use of Digital Soil Mapping (DSM) methods? | Knowledge about DSM products |
| Production of uncertainty estimates? | Use of uncertainty estimates? |
| Scales/resolutions of maps produced | Scales/resolutions needed |
| Capacity building needs | |

A total of 875 surveys were sent to people from 676 different organizations (Figure 1), and 271 people responded, which is a very satisfactory response rate given the time required to answer the questionnaire (nearly 45 min for producers and 1.5 h for end-users).

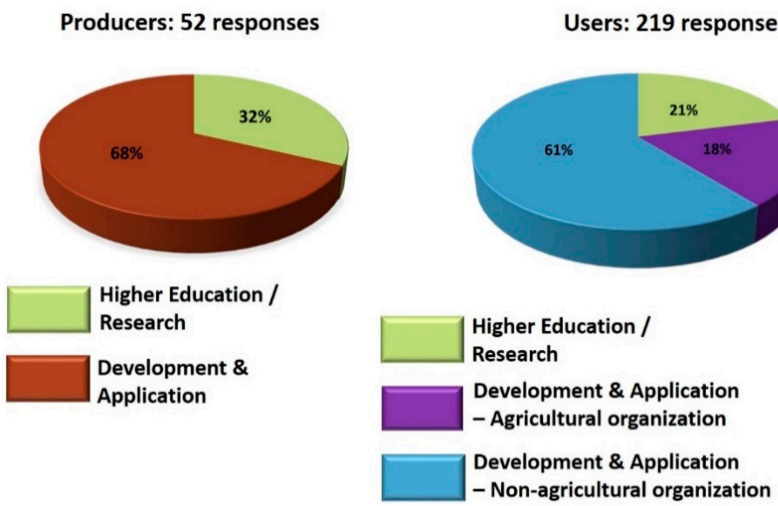


**Figure 1.** Classification of respondents.

The end-users provided more extensive feedback with the open-ended questions than the producers did.

## 3. Results

This section presents a summary of questionnaire responses.

### 3.1. Applications of Soil Maps

Figure 2 shows a summary of the results obtained from closed-ended questions relating to a fixed list of soil map applications. Map producers were asked to rank these applications according to their relative frequency of production, whereas end-users were asked to rank them according to their needs. These rankings were then combined to obtain a final score ranging from 1 to 6. The colors are used to classify these applications into large groups.

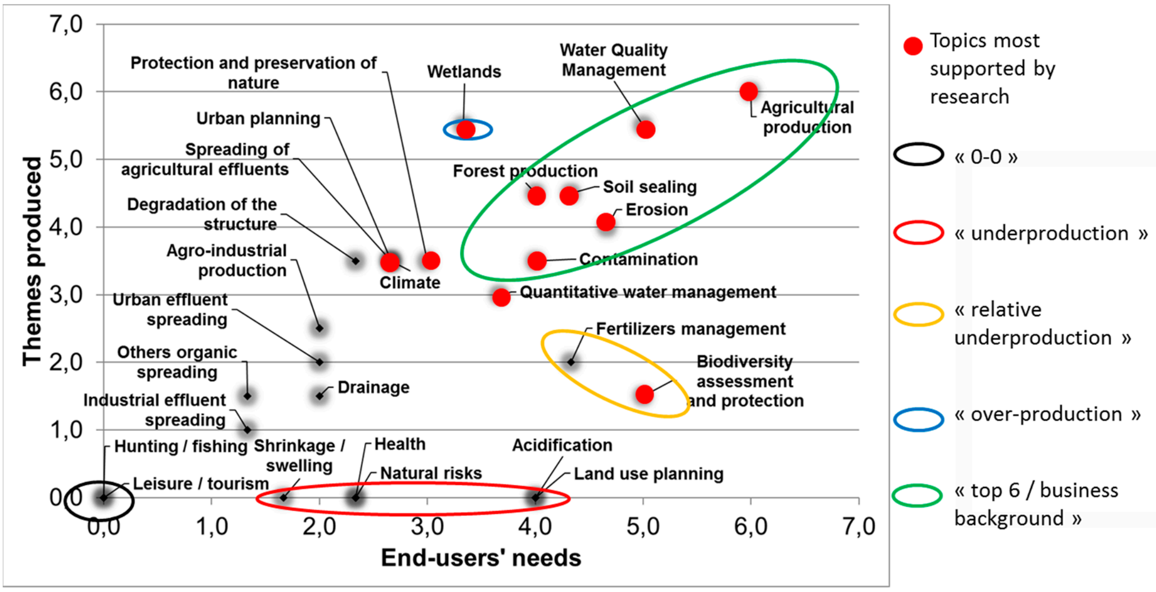


**Figure 2.** Main applications of soil maps described by end-users ($x$-axis) vs. main applications of soil maps reported by producers ($y$-axis).

The answers from end-users showed that, in addition to agriculture, they were also interested in other topics. According to this graph, the topics aligned along the diagonal indicate quite a good correspondence between the needs of producers and end-users. At the extremes of the diagonal, it is possible to distinguish some topics that were almost never cited (such as hunting/fishing and leisure/tourism) on the bottom-left, whereas those on the top-right indicate both highly requested and developed topics (agricultural production, water quality management, soil sealing, erosion, forest production and contamination). These six topics can thus be considered to be the customer base of soil mapping applications, as the frequency and importance of dealing with these topics are ranked equally by both users and producers.

The results show that some user needs are not covered by map producers. Along the $x$-axis and circled in red, some topics appear to be clearly underproduced compared to the extent that they could be generated in accordance with demand. Other topics (circled in yellow on the right side, a little below the diagonal) that are deemed important by users are also relatively underproduced. This is particularly the case for biodiversity assessment and protection, which are considered by end-users to be very important but remain poorly covered by production.

One apparent area of 'over-production' (wetlands) corresponds to a demand from policy makers. This case is undoubtedly linked to the legislative effect of a decree concerning the zoning of wetlands, and to the fact that most of the requests for this zoning were directly sent to data producers. Indeed, the decree concerning the zoning of wetlands was related to a very large number of local authorities who then commissioned these maps. In doing so, these local authorities exerted an influence on mapping activities that is larger than their degree of representativeness among the end-users.

The red dots represent themes identified as being the most important by the research community, whether producers or users. Their position towards the positive extremes of the diagonal suggests a rather good match between research priorities and the overall ranking, although the research partly bears this ranking. Note the particular positioning of biodiversity issues, which are identified as a priority by users but have not yet been fully integrated into the mapping activities of producers.

*3.2. Land Cover and Related Issues That Are Not Sufficiently Addressed*

Figure 3 represents an attempt to identify the main thematic gaps and to classify them according to land cover. This is conducted using information provided in answers to several open-ended questions.

The corners of the triangle in Figure 3 represent the main land cover types, which are grouped into three broad categories (i.e., urban and industrial, agricultural, forest/undisturbed areas). Colors are used over this triangle to represent the following: main global issues identified as being insufficiently covered by maps (blue), missing information about soil states (black), actions for which more precise soil data are needed (red), and certain non-strictly soil information (yellow) identified by end-users as missing but required for decision making and in order to deal with certain issues. The relative positions of these blocks indicate a preferential link to a given land cover.

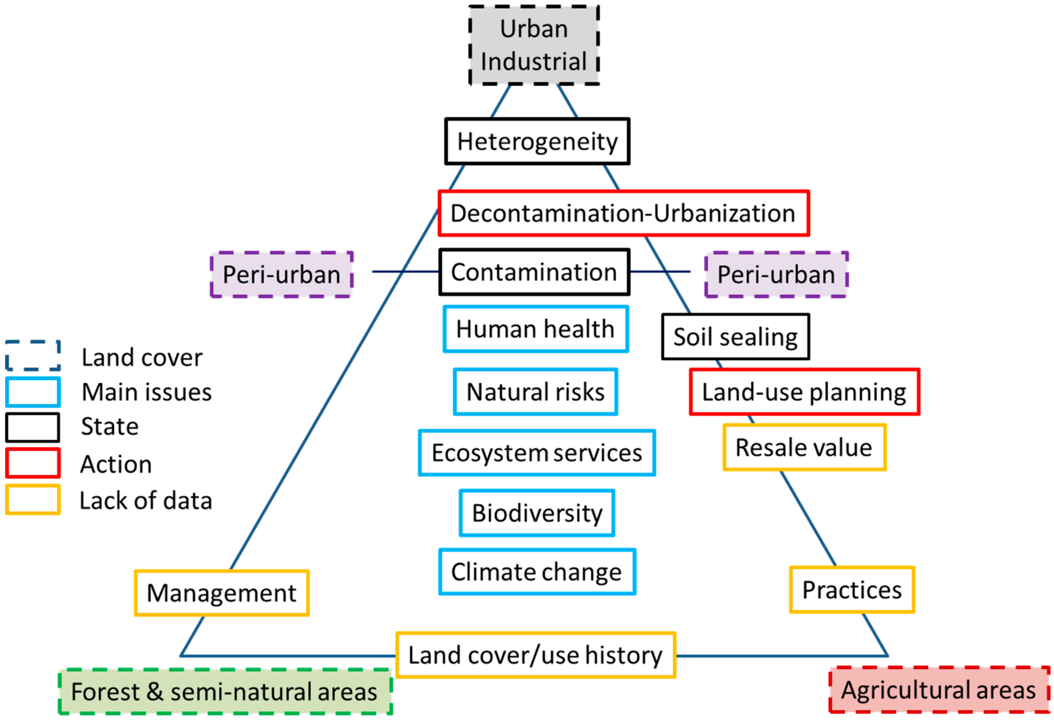


**Figure 3.** Main issues and gaps identified relating to land cover, soil capability and condition (state), and human actions.

At the top of the triangle, and at the borders of urban/industrial and peri-urban areas, the themes of decontamination and urbanization emerge. It is considered that soil in these environments has a very high heterogeneity and that there is a subsequent lack of precise soil data. Human health is a major issue in such environments, and although important everywhere, it is a higher priority in areas that are most populated, as these are also often the most contaminated. This explains its position close to the upper part of the triangle.

Soil sealing and land use planning are located along the side of the triangle, joining the urban and agricultural corners. When dealing with these topics, the 'market value' of the land is a major decision criterion. This criterion is not only due to intrinsic soil properties, but also to their location (e.g., closer to or further from urban areas, or to main roads and transportation lines) and to whether there is a human-related origin, such as the existence of protected areas or the influence of markets and trade regulation.

Along the side that joins the agricultural and forest or semi-natural corners are mainly data relating to past or current human actions that have been identified as lacking. End-users strongly expressed the need for information on land management and agricultural practices, both for current practices and also for information about the past history of land cover, land use and land management. This kind of information is of particular importance when dealing with issues relating to climate change, such as $CO_2$ or $N_2O$ fluxes between the soil and atmosphere, or the potential of soils for adaptation, which partly explains the position of this issue in the triangle.

The side joining the urban and forest/semi-natural corners appears quite empty, which suggests that no specific soil-related issue has been identified at this interface.

Moving upwards in the triangle, biodiversity remains mainly the stake of non-strictly urban environments. For this issue, the difficulty lies in the acquisition of relevant data and their translation into operational indicators.

The center of the triangle represents the generic issue of valuating ecosystem services, which is considered equally as important for all environments.

Gradually moving closer to more anthropic environments, the theme of natural risks owes its position to impacts on buildings and infrastructure and on risks incurred by populations. Finally, the lack of soil data relating to health issues appears to be associated with urban and peri-urban environments.

### 3.3. Correspondence between Produced and Requested Variables

Figure 4 indicates the correspondence between selected variables recorded and used by producers and those requested by end-users. Map producers were asked to rank these variables according to their relative frequency of production, whereas end-users were asked to rank them according to their needs. The rankings were then combined to obtain a final score ranging from 1 to 10, and colors were employed to classify these applications into large groups. Some of the variables are both requested and produced, but others need the use of pedo-transfer functions (PTFs) or are rather difficult to access and process to derive a map. Furthermore, some remain essentially qualitative or less present in databases, and/or may exhibit quite fast changes with time. Finally, some of the variables are rarely produced.

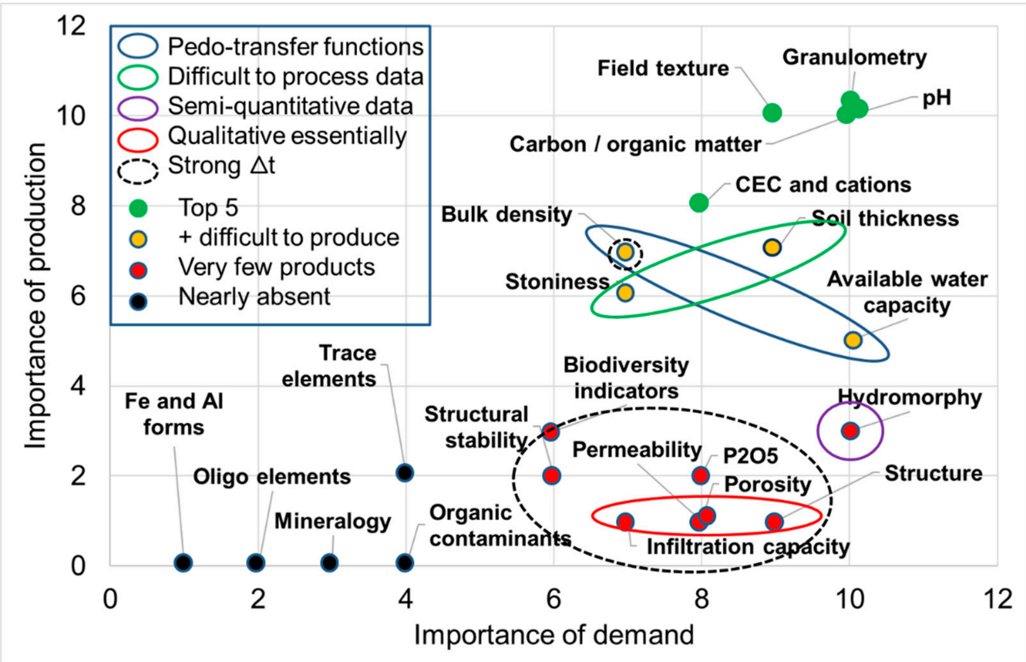


**Figure 4.** Correspondence between the demand and production of selected soil attribute sets.

According to this graph, different groups of variables can be identified according to whether they are relatively simple or costly to measure and map and whether they are stable over time. Interestingly, quite a large number of attributes relating to soil structure and soil water behavior are often considered important by end-users but are difficult for producers to map. The same occurs for biodiversity indicators.

A more complex situation is illustrated in the following with respect to the responses of end-users concerning the statement that they would like the thickness of soil to be described and quantified for different types of soil attributes.

If we refer to internationally agreed specifications (i.e., *GlobalSoilMap* specifications [9]), the soil thickness, also called the 'soil depth', corresponds to the definition provided in [9,10], which is 'the depth of a lithic or para-lithic material'. However, the soil thickness information required by end-users covers a wide range of values from 0.2 to more than 2 m. Approximately 17% of end-users only require information about topsoil properties (i.e., depths of 0–10 to 0–30 cm), and their needs are mainly focused on indicators of soil chemical fertility (such as major nutrients (N, P, K), some oligo-elements, pH and cation exchange capacity) for plant growth, or on soil contaminants (such as certain trace elements and pesticides). Nearly 35% and 31% of end-users require information about soil thickness to a depth of 1 m and 2 m, respectively. Overall, therefore, the range of thicknesses for which end-users required information is consistent with *GlobalSoilMap* specifications [10] for 82% of responses. In addition, the remaining requirements of 18% of respondents for information at deeper levels (i.e., deeper than 2 m) mostly related to applications involving deep-rooted crops such as vines and trees.

This result raises questions about both the definition of 'soil depth' and the information about soil thickness collected and stored in databases. One question could be formulated as, 'should a rock that has fractures enabling roots to go deeper than 2 m still be considered part of the soil?' and/or, 'should a friable regolith or C horizon be considered part of the soil?' The latter question relates to the lack of information about very deep layers contained in soil databases and the need to develop methods for dealing with right-censored values that have been generated by the use of augering at limited digging depths to collect information [11–13]. In fact, the responses from end-users about soil thickness information requirements appear to relate to their need to know both the thickness of the soil for which they require soil property values and the value of the soil thickness itself. This allows a better interpretation of the somewhat surprising position of soil thickness in Figure 4.

The types of soil attributes that are most frequently employed by end-users to derive thematic maps are shown in Figure 5, and these attributes are grouped into five broad categories as follows,

1. Soil type or soil class, according to national or international classifications;
2. Physical properties (including particle-size, texture, bulk density, stoniness and thickness);
3. Hydric properties (including available water capacity, porosity and infiltration capacity);
4. Chemical properties (including pH, cation exchange capacity (CEC), exchangeable cations ($Ca^{++}$, $Mg^{++}$, $K^{+}$, $Na^{+}$), major nutrients and oligo-elements);
5. Biological properties (including carbon, biodiversity measurements and populations of nematodes and earthworms).

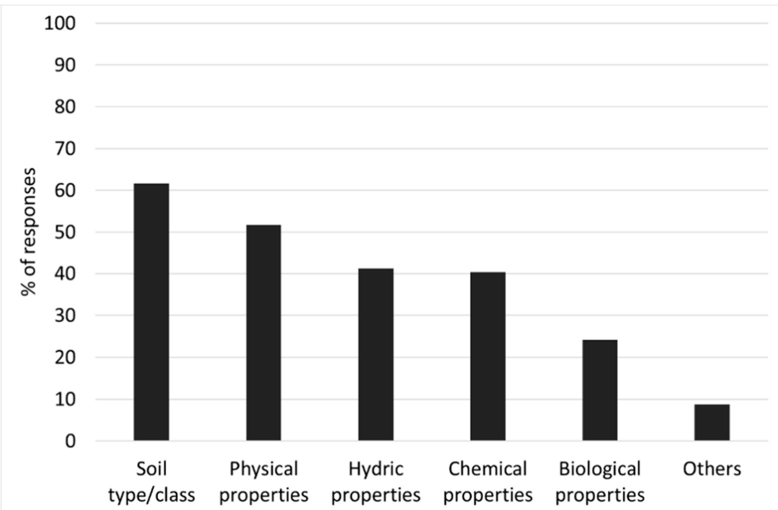


**Figure 5.** Frequency of five major groups of soil attributes employed by end-users (the sum of bars does not equal 100% because several responses were allowed).

Interestingly, soil type is the most commonly used attribute, and this is partly attributed to the fact that many legacy soil maps are still only scanned and thus provide only a soil type/class in their legend. Therefore, if there is no further semantic information extracted from soil profiles or from soil databases (DBs) relating to maps, the only information available to end-users is the soil type/class. Another possible reason is that information about the soil type and class (for instance, in the World Soil Reference Base [14]) is often used as a 'proxy' for a large number of thematic maps (e.g., Arenosols indicate a sandy soil texture, Chernozems imply a high soil organic content in the upper and deep layers, Rendzic Leptosols provide information about the $CaCO_3$ content, ranges of pH and soil depth and Gleysols provide useful information about water-logging). However, some high-level groups, such as Cambisols, cannot be used to derive soil properties if they are not described using enough qualifiers.

The second group of soil properties is 'physical properties', particularly with respect to particle-size distribution and soil texture. This is consistent with their position in Figure 4 and the fact that soil texture may be used to derive certain important soil properties by using PTFs (e.g., [15–18]).

The third group is that of 'hydric and chemical properties', which received similar scores. The position of hydric properties may be attributed to the fact that they do not have a large enough presence in soil DBs (see Figure 4). However, the position of chemical properties is a little more surprising and is in contradiction with the positions of pH, CEC and cations in Figure 4. However, it must be remembered that very few oligo-elements are included in soil DBs. Another possible explanation is that most of these properties (N, P, K, pH, CEC and cations) have been published in a report on the status of French soil resources [19], and that all these national maps are available online [20,21].

The final group is that of 'biological properties', which re-enforces the need to include biodiversity measurements and indicators in soil DBs [22]. Indeed, although very significant progress has been made on mapping microbial abundance and biodiversity on a national scale [23–27], measurements are still very sparse on more local scales and are not usually integrated into soil DBs. In addition, there are still only sparse measurements of other organisms that are very important for soil biodiversity and functions, although on-going programs aim to fill these gaps, e.g., in [28,29]. Finally, many biological soil properties vary highly with time, and it is thus more difficult to map them than it is to map stable variables.

### 3.4. Certain Methodological Considerations about Mapping

Although quite clear to map producers, end-users still tend to confuse scale, spatial resolution and precision. In particular, end-users' responses reflected that they are confused (or unaware) about the effects of the type and size of mapping supports employed (e.g., points or blocks, polygons or grid-cells). Figure 6 shows the responses from producers and end-users to the question, 'At which scale are polygon soil maps useful depending on the area they cover?'

| PRODUCERS scale | World | Europe | Country | Region | County | Sub-county | Watershed | Small natural area | Municipality | Farm | Field |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 1/1 000 000 | 2 | 5 | 6 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 1/250 000 | 0 | 0 | 1 | 14 | 9 | 2 | 2 | 2 | 0 | 0 | 0 |
| 1/100 000 | 0 | 1 | 0 | 1 | 5 | 6 | 2 | 2 | 2 | 1 | 0 |
| 1/50 000 | 0 | 0 | 1 | 0 | 0 | 6 | 5 | 4 | 3 | 0 | 1 |
| 1/25 000 | 0 | 0 | 0 | 1 | 1 | 0 | 3 | 1 | 3 | 3 | 1 |
| 1/10 000 | 0 | 0 | 0 | 0 | 0 | 1 | 2 | 2 | 5 | 5 | 1 |
| 1/5 000 | 0 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 3 | 3 |

| END-USERS scale | World | Europe | Country | Region | County | Sub-county | Watershed | Small natural area | Municipality | Farm | Field |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 1/1 000 000 | 3 | 3 | 3 | 2 | 2 | 2 | 1 | 1 | 0 | 0 | 1 |
| 1/250 000 | 1 | 2 | 3 | 7 | 4 | 1 | 1 | 0 | 0 | 0 | 0 |
| 1/100 000 | 0 | 0 | 0 | 4 | 3 | 4 | 1 | 1 | 0 | 0 | 1 |
| 1/50 000 | 0 | 0 | 1 | 2 | 2 | 5 | 3 | 2 | 2 | 0 | 0 |
| 1/25 000 | 0 | 0 | 1 | 3 | 7 | 5 | 6 | 1 | 4 | 0 | 0 |
| 1/10 000 | 0 | 0 | 0 | 0 | 0 | 1 | 3 | 3 | 4 | 2 | 1 |
| 1/5 000 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 4 | 3 | 4 |

number of responses: 1 to 2 (yellow); 3 to 4 (light orange); 5 to 6 (orange); 7 to 14 (red)

**Figure 6.** Responses to the question 'At which scale are polygon soil maps useful depending on the area they cover?'.

The responses from both categories (producers and end-users) roughly follow a diagonal (from small-scale maps for very large areas to large-scale maps for small ones), which appears quite logical. However, it is of note that the responses from end-users show a larger spread around this diagonal, which indicates that end-users are more confused about the notion of scale. In particular, it is astounding that some end-users still believe they can employ a 1:1,000,000 scale map for field-scale decision making.

However, when asked about their need for resolution, most end-users said they require rather fine resolution products (i.e., from 25 to 250 m), which may suggest that most applications require a fine resolution and/or that end-users are aware that it is easier to aggregate fine grids into coarser ones than the reverse.

End-users express a strong interest in obtaining uncertainty indicators. However, a large proportion of them do not know which indicators are best suited for their purpose or how to consider them and communicate about them. In addition, there are strong differences between the answers of different categories of end-users (Figure 7).

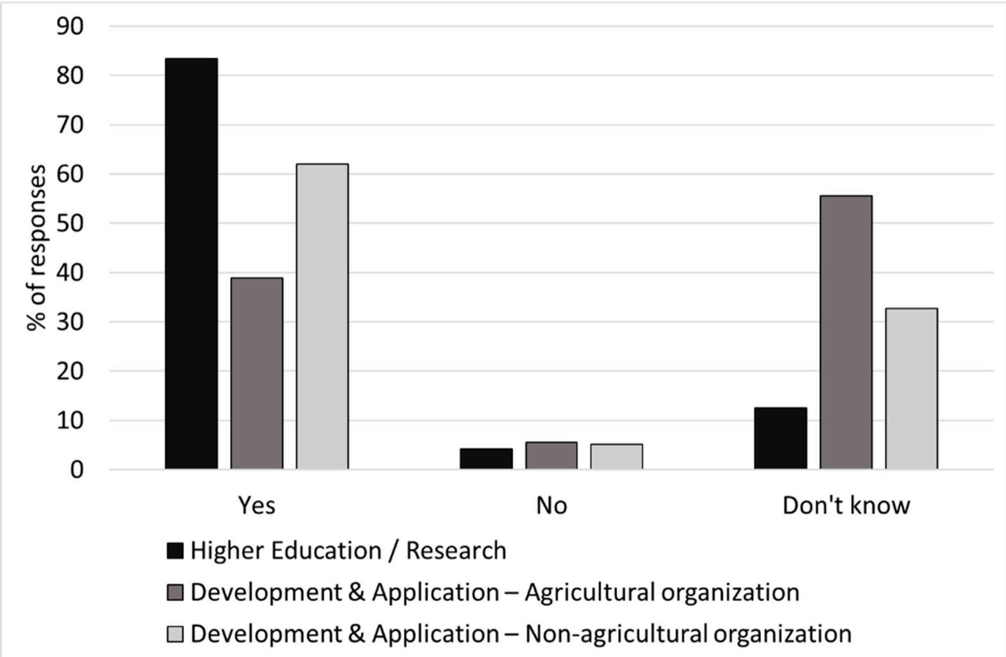


**Figure 7.** Responses to the question 'Do you think you can consider uncertainty in the uses you make of a soil map and that this uncertainty will be considered by decision makers?'.

Respondents from research and higher education fields (mainly research institutes, universities and agronomy high schools) were mostly very confident that the uncertainty indicators (or indicators of the prediction performance of the maps) would be easy to use and that it would be easy to communicate this to decision makers. Respondents from the development and application domains were much less confident in their ability to consider uncertainty indicators, and were not very confident that these uncertainties would be considered by decision makers. This general tendency shows that a large number of end-users still feel uncomfortable about producing and using uncertainty indicators, and this tendency was much more apparent with people from agricultural organizations.

Both producers and end-users expressed a strong interest in moving from conventional to digital soil mapping (DSM). However, most indicated that they would need strong technical support to acquire new concepts and methods, and a significant proportion of end-users felt uncomfortable with uncertainty. The responses to many open questions showed that end-users would like to not only have digital maps of soil properties but would be more interested in maps that represented changes in these properties over time, or even maps forecasting possible future changes.

## 4. Discussion

This section discusses certain elements relating to this survey and its principal findings, and observations are linked to the five dimensions of the Soil Security concept [1,2]. Indeed, linking soil attributes to soil security offers a unique opportunity to enhance the link between soil scientists, stake-holders, policy makers and other disciplines. The communication of soil security may be more effective than focusing on soil itself [1–4,29].

### 4.1. Limitations of This Survey and Points of Interest

A large number of responses from both map producers and end-users were gathered via the survey. Although the results may be somewhat biased, as it required the willingness and time to complete the long questionnaires, and therefore only a certain number of end-users and producers completed it, this was the largest survey conducted on soil mapping needs in France since a report published more than 20 years ago [30]. In this survey, we investigated whether the data produced matches the data required by end-users, and results show a correspondence in this respect for many variables but not for all. It is essential that users know what information exists and where to find it, and an effort to disseminate information (metadata and data) needs to be made to strengthen the 'Connectivity' between producers and users. 'Soil Connectivity' describes the social dimension, i.e., how people view and value the vital soil resource [2].

### 4.2. Filling the Gaps for Certain Land Cover/Environments

There is still a severe lack of soil information for some environments (such as urban and peri-urban areas and industrial areas), which is concerning given the importance of associated threats such as urbanization, contamination and natural risks, and considering that a vast proportion of the French population lives in or close to a city. This oversight may be partly attributed to the fact that the first soil surveys were historically developed for agricultural production. In fact, with some rare exceptions, urban soils have simply been cut out on most of the previous conventional medium-scale legacy soils maps, and are considered to be areas of 'no soil'. Moreover, in these environments, the lack of contamination mapping is a concern for human health, as the areas with higher populations are also often the most contaminated. Specific point data on the contamination of urban and industrial soils do exist, nevertheless [31], but they are not often mapped, and they require a strong investment into the development of methods that are adapted to the particularities of these environments, which exhibit considerable heterogeneity over a short distance. More efforts are required to enable the mapping and characterization of urban and industrial soils, and certain initiatives are currently ongoing in this respect [32,33]. On a national level, a spatial analysis of a regular 16 km to 16 km grid covering the French territory has enabled the mapping of large trends according to geochemical background and diffuse contamination (e.g., [34–36]). However, there is an urgent need to fill the gap between mapping large trends and more local 'hot-spots', both in urban and industrial areas and in local environments and settings.

### 4.3. Requirements for Other Data Relating to Factors Controlling Soil and Associated Changes

The results of this survey indicate that many attributes relating to soil structure and soil water behavior are often lacking in soil DBs. Indeed, some soil structure descriptions and related properties are often stored in DBs as qualitative variables (for example in relation to structure as being crumby, granular, polyhedral, blocky, prismatic and columnar; or to porosity and permeability as ordinal classes). However, they are still rarely used to derive functional soil properties, which suggests that research should be conducted to assess if and how they could be included in some PTFs. Similarly, biological activity descriptors and measurements are often missing, although some ongoing attempts to include them are being made [22,28]. Available water capacity is also rarely measured, which stresses the need for complementary measurements such as those currently being conducted in the framework of the second round of the French soil monitoring network, and/or the need for assessment of the potential of some co-variates for mapping this property (e.g., the response of vegetation under drought, which could be captured by remote sensing though a spectral index such as Normalized Difference Vegetation Index (NDVI), or by yield measurements). In general, however, some end-users express the need for maps of functional soil properties rather than maps of soil state variables, which emphasizes the need to move from a DSM to a digital soil assessment, and thus implies an increased need for process knowledge in mapping [37,38] and for mapping soil ecosystem services. This last point could bring new insights about ways to assess soil 'Capability' and 'Capital' and to increase soil 'Connectivity', by highlighting the role of soil in providing services that are essential to human well-being.

The need to know soil characteristics is often related to the need for information about agricultural and management practices with respect to soils. The same is true for past land management, where there is a lack of essential information, such as that relating to the history of land use. In general, these practices or management methods are essential for making measurements and predictions, and for monitoring future changes. Many issues relating to soils require both soil maps and maps of cropping systems and agricultural practices. However, the production of the latter map types does not depend on a soil mapping strategy in the strictest sense, but rather on using complementary approaches such as surveys, aerial photographs, old maps of land cover, integration of remote sensing data and conducting research into markers or specific tracers of land cover and land use changes. This is of crucial relevance for understanding and modeling processes controlling dynamic soil properties, such as those related to global cycles of water, carbon and nitrogen. Moreover, the capacity to monitor land use changes and practices in the future via remote sensing provides the opportunity to move from DSM to Digital Soil Monitoring. Additionally, the integration of the effects of changes in land use and practices by modeling could enhance the possibility of simulating scenarios to foresee or predict their effects on soil 'Condition' and on fluxes between other environmental systems such as air, water and vegetation.

It is interesting that some end-users say they would also like economic data, particularly for the interface between peri-urban and agricultural areas. Information about the resale value of land (especially if it is converted to land for expanding cities and surrounding commercial activities) is one of their high priorities. Conversely, helping decision makers to plan land use also requires information about the value of ecosystem services rendered by soils [39–41], and this relates to the dimension of 'Capital' in the concept of Global Soil Security [1–4].

### *4.4. Considerations about Digital Soil Mapping and Uncertainty*

Although producers and end-users express a strong interest in moving from conventional mapping to DSM, they also express the need for strong scientific and technical support. End-users (and even some map producers) appear to be confused about the implicit link between spatial resolution and uncertainty that is frequently wrongly made. Many still feel that if the size of the support is finer then it will include more reliable and accurate semantic information. Furthermore, many end-users simply do not know how to use uncertainty or how to communicate it. Decision-makers frequently feel uneasy about uncertainty, and they often prefer delineating areas that have sharp boundaries, mainly for legal reasons (such as land planning or zoning decisions), because communicating uncertainty opens the possibility of decisions being questioned and can lead to endless discussions. This may explain why respondents from agricultural organizations do not entirely believe that decision makers will consider uncertainty. Indeed, maps are often used as tools to help decision making about policies linked to agricultural practices (e.g., the spreading of effluents, irrigation quotas, the delineation of protected areas, subventions to maintain agricultural activities and the use of fertilizers and pesticides) or for land use planning (see Section 4.3).

### *4.5. From Digital Soil Mapping to Digital Soil Monitoring and Modeling Future Changes*

The end-users express interest in obtaining maps that show changes in soil properties over time, or even maps that forecast possible future changes. In other words, they are not only interested in obtaining information about soil properties that may be considered rather stable and related to their intrinsic biophysical characteristics (which refer to the dimension 'Capability'), but they also want information about changes in soil 'Condition' [1–4]. An underlying question that was not addressed in the questionnaire, is whether soil scientists are able to establish better links between the 'Condition' and 'Capability' of soil and/or to define thresholds for which changes in 'Condition' will modify 'Capability' in a more or less irreversible way. The responses from end-users also suggest a need to build interfaces between existing soil information (either 'Capability' or 'Condition') and the need for process-based modeling tools to predict future changes under different scenarios such as climate change, changes in land use, human demands for food, and markets and regulations (the latter refers to the dimension 'Codification').

## 5. Conclusions

Although several topics were considered important by both soil map producers and end-users, there is an evident lack of information pertaining to certain environments, both in terms of associated soil data and their mapping. This is particularly true for urban and peri-urban settings and their interface with the rural environment. It is considered that greater efforts need to be made with respect to such areas, and that a special emphasis should be placed on topics than enable the potential effects of contaminants on human health to be assessed, in addition to soil sealing and providing tools to assist decision-makers to effectively plan land use.

Although there appears to be a consensus about the minimum dataset required, the list of soil attributes currently available in geographical soil DBs needs to be extended and densified, either by realizing new measurements (this is especially the case for contaminants, but also for some oligo- or major elements) or by establishing more efficient PTFs (this is mainly the case for soil structural and hydrological attributes). In addition, some very important attributes (such as soil thickness) require more research attention to enable their eventual prediction. Furthermore, the spatial resolution provided by current maps is not fine enough for the needs of many users, and sampling sites thus need to be densified and DSM approaches developed to provide fine grids pertaining to soil attributes that have a satisfactory precision.

More data on soil attributes are required, as are data on related fields linked to changes in the soil 'Condition', such as land use changes, soil management and agricultural practices.

There is also a need to move from maps predicting soil 'Capability' to maps describing and forecasting changes in soil 'Condition', and a need to integrate the dimensions of soil 'Capital' and 'Codification'. It is not possible for all the dimensions of Global Soil Security to be addressed only by soil science research and the development of DSMs.

There is a strong need for capacity building with respect to DSMs; in particular, the development of cost-effective methods for estimating and mapping uncertainties should be pursued, and it is necessary to address the question of how to communicate the meaning of uncertainties and how to use them in further modeling and decision making. End-users will also need to consider the use of new concepts, and short technical training courses could be used as a tool-kit for end-users to employ the use of new mapping techniques. Finally, the need for better communication about DSMs and uncertainty is evident, especially with respect to decision makers, but also for all end-users and producers. This communication could be a way of improving soil 'Connectivity' in the global framework of soil security.

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