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ABSTRACT

Life on earth depends on soil health. However, soils are threatened across the world. To respond to the challenges posed by climate change and soil degradation, there is a need to better integrate scientific soil knowledge into the practice. The aim of this paper is to better understand the access to soil knowledge in France and identify opportunities for further improvement, with a particular focus on the difference of point of view between six categories of stakeholders. This study is based on 1951 responses from a participatory stakeholders' consultation we conducted in France. Our results showed that most stakeholders considered the knowledge they have access to as not adapted to their needs. They also expressed that knowledge sharing between stakeholders was not sufficient. To improve access to soil knowledge, stakeholders suggested adapting at the territorial level the content of soil knowledge shared and transferred, as well as improving ways of sharing and transfer soil knowledge. Additionally, stakeholders valued different exchange networks based on their type of knowledge. Stakeholders with more theoretical soil knowledge (public authorities, NGOs, researchers) stated being more interested in networks between policy, science and society. However, networks with farmers and advisors were more favored by stakeholders with empirical soil knowledge. Considering our findings, in order to strengthen knowledge transfer and sharing, we encourage the promotion of the profession of scientific mediator, as well as the implementation of Living Labs and Lighthouse farms to bring together various stakeholders at a local level towards innovation, training and education. This will ensure a transition towards a more sustainable soil management in Europe.

1. Introduction

Life on earth depends on soil health. Soil provides a number of essential services, such as provisioning (food, fibers and fuel), regulating (air quality and water purification), supporting (soil formation and nutrient cycling), and cultural services (recreation and aesthetic value) (Dominati et al., 2014). However, soils are threatened all over Europe and globally due to a number of factors. The demand for food, fibers and fuel has been steadily increasing leading to an ever-growing pressure on soil and land resources (Popp et al., 2014). Additionally, soil and land degradation has increased, caused among others by unsustainable management practices in agriculture and forestry, contamination and soil sealing due to urbanization and infrastructure development (Veerman et al., 2020). Worldwide, at least one third of the soils are considered as moderately to heavily degraded (FAO and ITPS, 2015). It reaches 60 to 70% of the European soils (Veerman et al., 2020). To prevent further degradation, it is essential to implement sustainable soil management practices, such as proper land management, crop rotation, and the use of organic fertilizers (Lal et al., 2021). This will not occur unless greater awareness and education on the importance of soil health and the consequences of unsustainable practices are implemented in order to ensure that soils are healthy and productive for future generations (Bouma, 2019).

Soil science research is therefore essential for understanding and addressing the complex challenges that are faced in the current agricultural landscape. However, to effectively bridge the gap between our current state of knowledge and societal needs, a joint effort involving a diverse set of stakeholders is required (Mol and Keesstra, 2012). This includes researchers, public authorities, farmers, and other stakeholders who all have a role to play in advancing soil science research and

translating it into meaningful solutions. It is important to consider the point of view of these stakeholders and their level of soil knowledge. The European Joint Soil Programme 'Towards climate-smart and sustainable agricultural soil management' (EJP SOIL, 2020–2025) is a major initiative of the European Union to develop an integrated European system of sustainable agricultural soil research. EJP SOIL is dedicated to optimize the soil knowledge management life-cycle (adapted after Dalkir, 2005). This includes activities such as (i) knowledge development; (ii) harmonization, organization and storage of knowledge; (iii) knowledge sharing and transfer; and (iv) knowledge application. To achieve these objectives, the initiative takes a participatory approach which relies on the collaboration between scientists from 24 European countries who hold different interests in soil-related topics, and stakeholders from both a national and regional level. Stakeholders' consultations represent an effective tool to identify critical aspects in the knowledge life-cycle, to ensure that soil science can best meet the needs of society (Richer-de-Forges et al., 2019). Through stakeholders' consultations, stakeholders can provide valuable input on how to improve the knowledge system and maximize its potential.

A stakeholder consultation in 20 countries within the EJP Soil consortium was conducted to identify and prioritize the main barriers and opportunities for soil knowledge at a national and European level (Heller et al., 2021; Ruysschaert et al., 2021; Vanino et al., 2022; Vanino et al., 2023). Stakeholders' points of view on how to optimize the life-cycle management of soil knowledge were explored and compared between countries. Findings from Vanino's study (Vanino et al., 2023) clearly suggest that, across Europe, an increase in research funding and the strengthening of exchange networks and interlinked national and European infrastructures can contribute to the creation of healthy, resilient and sustainable soil ecosystems. To get a deeper insight of the difference of point of view between categories of stakeholders, we performed a complementary large-scale survey with a focus on six categories of stakeholders, taking France as an example.

The overall aim of this paper is to better understand the access to soil knowledge in France and identify opportunities for further improvement, with a particular focus on the difference of point of view between six categories of stakeholders, i.e. public authorities, NGOs, researchers, farmers, advisors and agricultural schools. To achieve this, we conducted a participatory stakeholders' consultation. We considered stakeholders' level of soil knowledge and the sources used to access soil knowledge. We also explored opportunities and exchange networks to strengthen in order to increase stakeholders' access to soil knowledge. By doing this, we provide a comprehensive overview of the existing access to soil knowledge in France, and suggest ways to improve it.

2. Material and methods

2.1. Questionnaire design and dissemination

A participatory stakeholders' consultation was conducted. Targeted stakeholders were: farmers, public authorities (i.e. from the municipality, departmental and regional level, and ministries), scientific researchers, NGOs, advisors, and agricultural schools (i.e. high schools and higher education). The questionnaire (**in appendix**) was designed to collect stakeholders' point of view on the access to soil knowledge in France and more specifically on: i) stakeholders' level of soil knowledge; and ii) ways to improve stakeholders' access to soil knowledge. The questions and the framing of the questions were based on the EJP SOIL guidelines (Thorsøe, 2021) and modified to suit the French context. Multiple choice questions were asked to the stakeholders. The questionnaire, in French, started with a range of questions used to define the profile of the respondents (stakeholder's category including for farmers the agriculture type, i.e. organic farming, conventional farming and conservation agriculture, and the type of production, i.e. field crops, livestock or mixed crop-livestock farming, market gardening, and perennial crops; age; department; education level). Secondly,

stakeholders were asked to estimate their level of knowledge on soil as well as their access to soil knowledge with a choice of "insufficient", "medium" or "sufficient". Thirdly, two questions addressed whether stakeholders considered that soil knowledge was adapted to their needs and whether the knowledge sharing among stakeholders was satisfying. Fourth, the sources used to access soil knowledge were asked for. Options were given: "social networks", "electronic newsletters", "web pages & blogs", "printed media", "scientific literature", "technical literature", "technical reports", "peer-to-peer groups", and "agricultural advisory services". Fifth, stakeholders were asked to identify six barriers ("cost of training", "lack of time", "lack of connection between stakeholders", "lack of structures that share knowledge", "lack of training on how to communicate", and "lack of adapted training") and six opportunities to access to soil knowledge ("promote participatory research", "enable all funded projects to share their results", "identify training content needs", "support the development of demonstration activities", "promote appropriate sharing", and "promote knowledge at the territorial level"). Finally, stakeholders were asked to opt for two exchange networks to be strengthened out of a list of nine in order to increase stakeholders' access to knowledge: "policy-society", "science-society", "policy-science", "farmer-society", "farmer-policy", "farmer-science", "peer-to-peer", "advisor-science", and "farmer-advisor". The questionnaire was first tested on a sample of various stakeholders and was adjusted according to feedbacks. The questionnaire took about 15 min to be answered. The study was carried out from December 2020 to September 2021 using an online survey tool and disseminated by various means (via networks, direct contact, via advisors for farmers, etc.).

2.2. Data analysis

A total of 2202 visitors to the survey were registered. During data preparation, we excluded all cases in which the respondents had answered less than 80% of the questions. We included only respondents who were part of our list of targeted stakeholders. This left us with 1951 cases for analysis.

To ensure the representativeness of our response sample per category of stakeholder, we used a saturation approach. A sampling is considered as representative when the contribution of new observations (in our case responses to the questionnaire) does not modify the results previously obtained (Savoie-Zajc, 2007). We compared results gathered until June 2021 (1610 responses) to results gathered in September 2021, our up-to-date data set of 1951 responses. As there was no significant difference in the results between the two dates, we considered our sampling as representative. In addition, Ramsey and Hewitt (2005) considered that above 350 responses a category is reasonably represented, which is the case for advisors and farmers.

In order to identify relationships between answers and stakeholders' categories, a correspondence analysis (CA) was performed for each question or group of questions and for stakeholders' categories with more than eight occurrences. To identify similarities among different stakeholders' categories, an agglomerative hierarchical cluster analysis (AHC) was performed on the two first components of the CA. All statistical analyses were performed using the XLSTAT software (Addinsoft, 2016).

3. Results

3.1. Characterization of survey respondents

37% of the 1951 responses came from farmers (720 responses), 20% from advisors (383), 18% from public authorities (352) (Fig. 1a). Other stakeholders' categories, such as agricultural schools (10%, 206), researchers (10%, 198) and NGOs (5%, 92) were less represented. For the category public authority, the more local the level was, the higher the number of responses, with 47% of public authorities from the
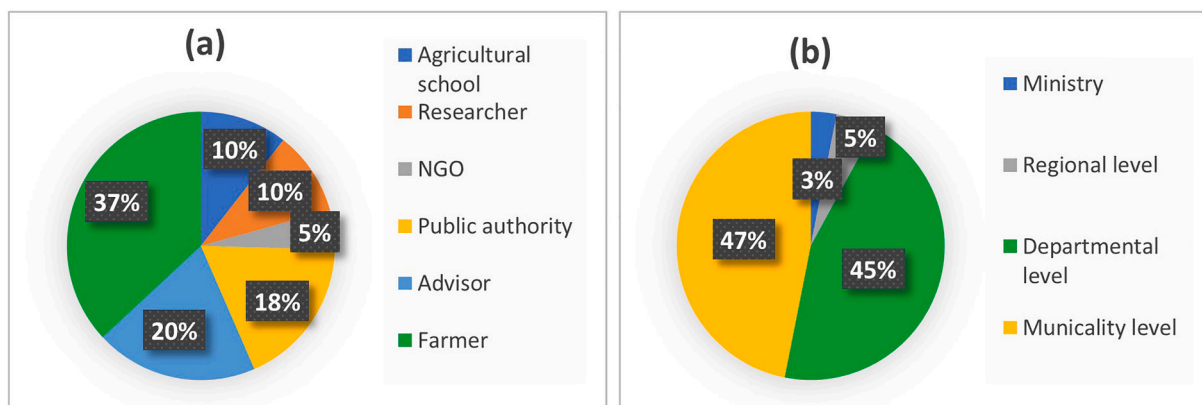
Fig. 1. Distribution of respondents in percentage per category of stakeholder (a) and breakdown per public authority (b).

municipality level (165 responses) and 10% from ministries (11, Fig. 1b). Considering the agriculture type, organic farming (41%, 295) was the most represented, followed by conventional farming (40%, 289) and conservation agriculture (30%, 215) (Fig. 2a). Considering the type of production, responses were more heterogeneous with 261 answers for livestock or mixed crop-livestock farming (35%), followed by field crops (34%, 250), perennial crops (20%, 147) and then market gardening (11%, 85) (Fig. 3).

The profile of the farmers from our pool was compared to French national statistics (MTES, 2018; Agreste, 2022). In our survey, we observed an over-representation of farmers under 50 years old, with a university degree (Table 1). Additionally, organic farming was strongly over-represented in our survey since, in 2021, only 13.4% of French farms were organic farms according to MTES (2018), whereas in our study 41% of the farmers indicated being organic (Fig. 2). Similarly, market gardening was also over-represented while livestock or mixed crop-livestock farming responses were under-represented in our survey (Fig. 3). Furthermore, the advisors from our pool were mainly advisors in animal and crop production.

All French departments were represented in the consultation with a variation in the number of responses per department (Table 2). In one department 70 responses were obtained, whereas in another department only 3 responses were received. Responses were provided mainly by farmers in most of the departments, with the exception of five departments. One department obtained up to 30 responses from farmers.

Our survey was conducted on a voluntary basis and was not systematic in nature, it is possible that respondents with a greater consideration of soil-related issues were more likely to participate. This could explain why we have an over-representation of young graduates and

organic farmers in our survey. This has to be kept in mind while interpreting the results as it may induce a potential bias.

3.2. Stakeholders' level of soil knowledge, a self-assessment

In order to analyze the link between the stakeholders' level of soil knowledge and their access to soil knowledge, we performed an analysis of correspondence (CA) on these two points (Fig. 4). The two first components of the CA explained nearly 90% of the total variance. The agglomerative hierarchical clustering (AHC) identified two different categories of stakeholders: (i) organic and conservation agriculture farmers, agricultural schools, researchers, advisors and NGOs generally considered that they had a good level of knowledge on soil and that their access to knowledge was medium or sufficient; (ii) conventional farmers and public authorities mainly considered that they had a basic level of knowledge and a medium to insufficient access to knowledge. This analysis showed that stakeholders who considered their level of knowledge on soil as good, considered their access to knowledge as sufficient and vice versa. Important is to note that conventional farmers, who represent more than 80% of the farmers in France, generally considered their soil knowledge as basic and their access to soil knowledge as insufficient. They also had the lowest level of education but have generally higher empirical soil knowledge, showing here that the type of knowledge taken into account by farmers when replying the questionnaire was theoretical and probably not empirical.

In order to understand the situation of insufficient soil knowledge for certain categories of stakeholders, notably conventional farmers, further questions were addressed to the stakeholders. The objective was to evaluate whether they considered that soil knowledge they had access to
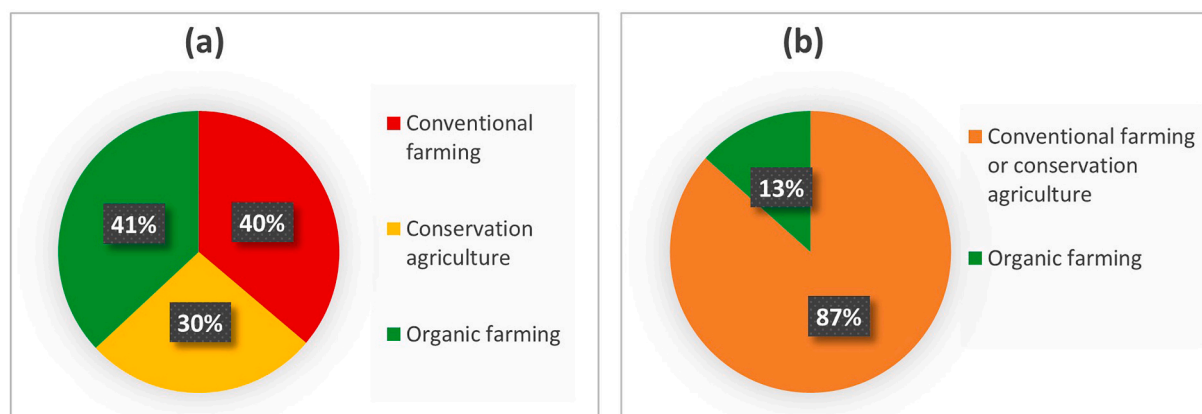

Fig. 2. Comparison between our survey responses (a) and French national statistics (b) (Agreste, 2022) regarding the agriculture type. To be noted that French national statistics do not separate conservation agriculture from conventional farming.
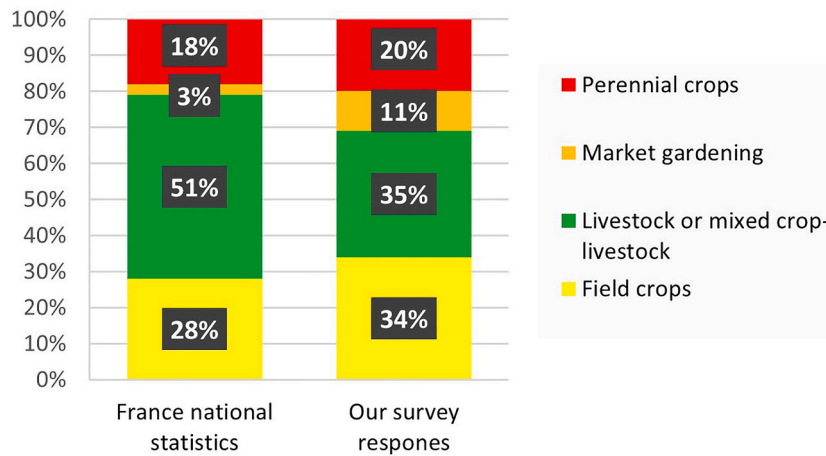
Fig. 3. Comparison between our survey responses and French national statistics (Agreste, 2022) regarding farmers' production.

Table 1
Comparison between our survey responses and French national statistics (MTES, 2018) regarding farmers' age and education level.

		Representation of farmers		
		In our study		In France
		Number	%	%
Age	50 years old and above	312	43%	55%
	Less than 50 years old	408	57%	45%
Education	University degree	454	63%	28%
	Certificate or associate degree	97	13%	34%
	High school diploma	166	24%	25%
	No diploma	3	0%	13%

was adapted to their needs, if knowledge sharing among stakeholders was satisfying and which sources stakeholders used to access soil knowledge. 60% of the stakeholders considered knowledge to be moderately (49%) or not at all (11%) adapted to their needs (Fig. 5a). 90% of respondents rated knowledge sharing among stakeholders as average or insufficient (44% and 46% respectively) (Fig. 5b). All stakeholders used all sources available to access soil knowledge but in different proportions (Fig. 6). Farmers mostly used peer-to-peer groups (16%) to access knowledge while they did not use much social networks, web pages & blogs, and scientific literature. Agricultural advisory services were mainly used by farmers.

In order to analyze the link between knowledge adapted to stakeholders' needs and the sources used to access soil knowledge, we performed an analysis of correspondence (Fig. 7). The two first components of the CA explained nearly 70% of the total variance. The agglomerative hierarchical clustering identified three different groups of stakeholders: a group formed by researchers, NGOs, agricultural schools and advisors, while farmers and public authorities formed the two other groups. The first group generally considered that soil knowledge they had access to, was more adapted to their needs. They used more scientific literature and technical reports than the two other groups. Farmers used more agricultural advisory services and public authorities printed media.

Most stakeholders considered the soil knowledge they had access to, to be moderately or not at all adapted to their needs and rated soil knowledge sharing among stakeholders as average or insufficient. Stakeholders (farmers and public authorities) who declared the most that soil knowledge was moderately to not adapted to their needs, mainly used agricultural advisory services and printed media respectively, and scarcely scientific literature.

3.3. Ways to improve stakeholders' access to soil knowledge

In order to improve the current situation, we tried to understand what the stakeholders considered as barriers to access soil knowledge, as well as the opportunities and the exchange networks that should be strengthened.

The barriers only slightly differed between the categories of stakeholders, therefore the results were presented aggregating all stakeholders (Fig. 8). For one quarter of the stakeholders (25%), the lack of time was a barrier. The cost of training was not considered as a major barrier (6%). The four other barriers (68%) referred to the way soil knowledge transfer and sharing takes place.

In analogy to the perceived barriers, the opportunities to improve access to soil knowledge did not significantly differ between the categories of stakeholders (Fig. 9). The three opportunities most often listed by the stakeholders concerned the way soil knowledge is shared and transferred ("support the development of demonstration activities", "promote appropriate sharing", and "promote knowledge at the territorial level"). They received 64% of the responses. Opportunities linked to research ranked high in the stakeholder's choices with 28% for promoting research and enabling projects to share their results (17% and 11%, respectively). The identification of training content needs did not seem to be a major opportunity.

Finally, a CA was performed to analyze the exchange networks to strengthen according to stakeholders' point of view. The two first components of the CA explained 73% of the total variance (Fig. 10). The agglomerative hierarchical clustering identified three different categories of stakeholders: (i) a first group composed by conventional

Table 2
Distribution of the number of stakeholders responding to the consultation per department.

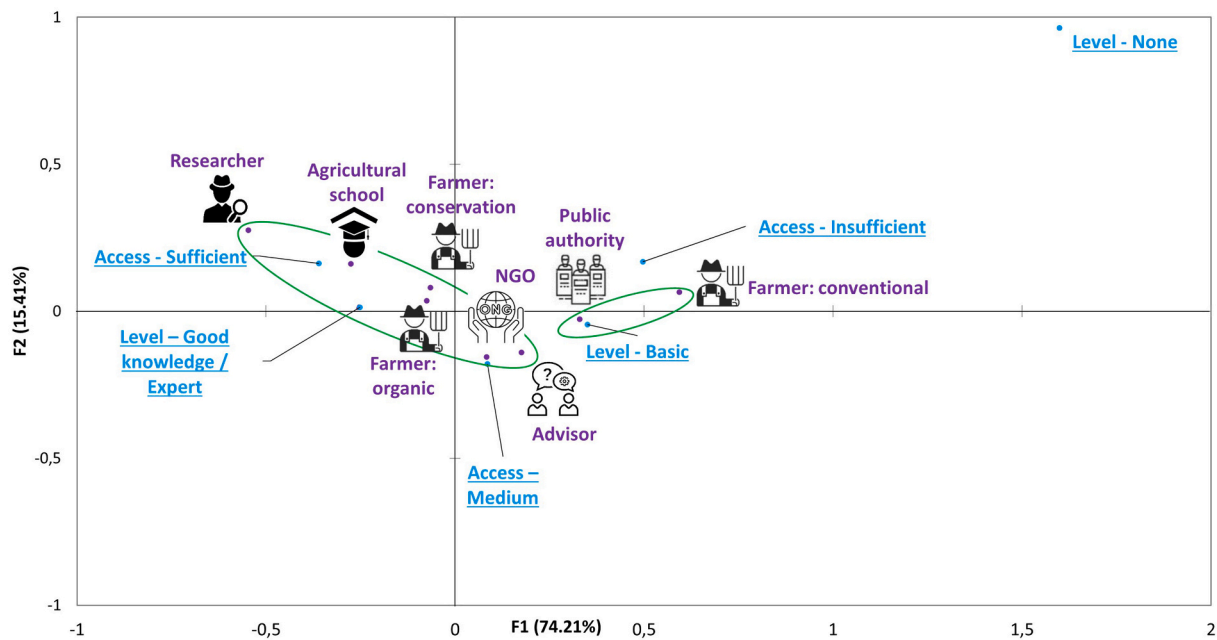| Value per department	All stakeholders	Farmers	Advisors	Researchers	NGOs	Agricultural school	Public authorities
Minimum	3	0	0	0	0	0	0
First quartile	13	3	2	0	0	1	2
Median	18	6	4	0	1	2	3
Third quartile	26	11	6	1	1	3	6
Maximum	70	30	12	24	7	10	13
Mean	21	8	4	2	1	2	4

Fig. 4. Two first components of the CA performed on the level of soil knowledge and the access to soil knowledge of the different categories of stakeholders. Stakeholders' responses to both questions are underlined in blue, whereas stakeholders are represented in purple. The closer points are from one another, the more the responses are alike. Green ellipses represent the results of an AHC made on the two first components of the CA.
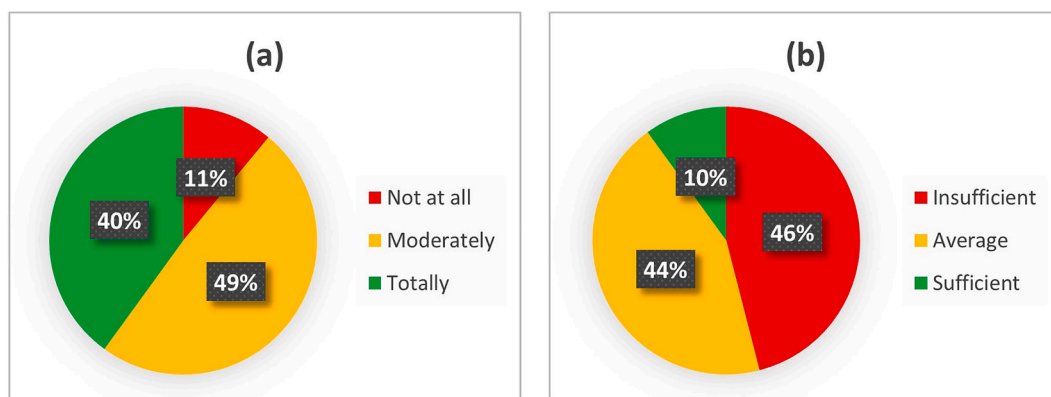

Fig. 5. Knowledge adapted to stakeholders' needs (a) and quality of soil knowledge sharing (b) reported by stakeholders.
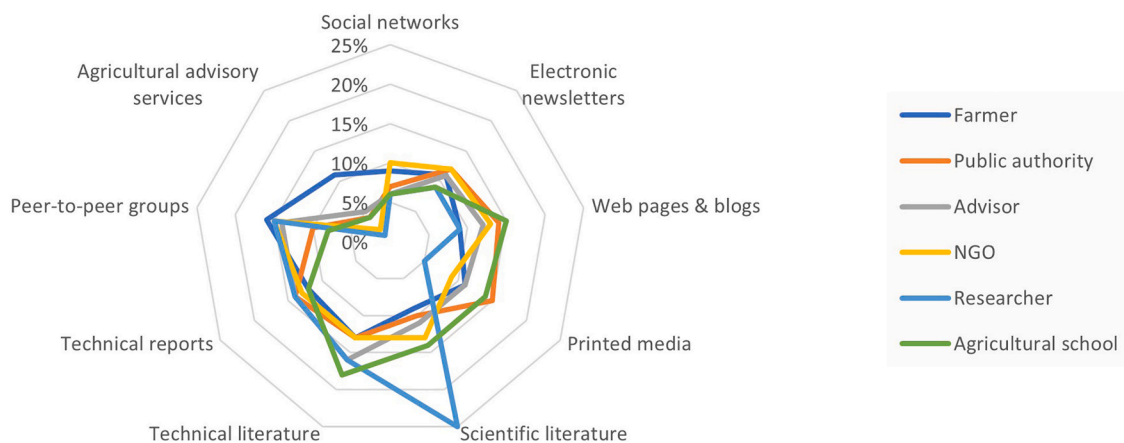

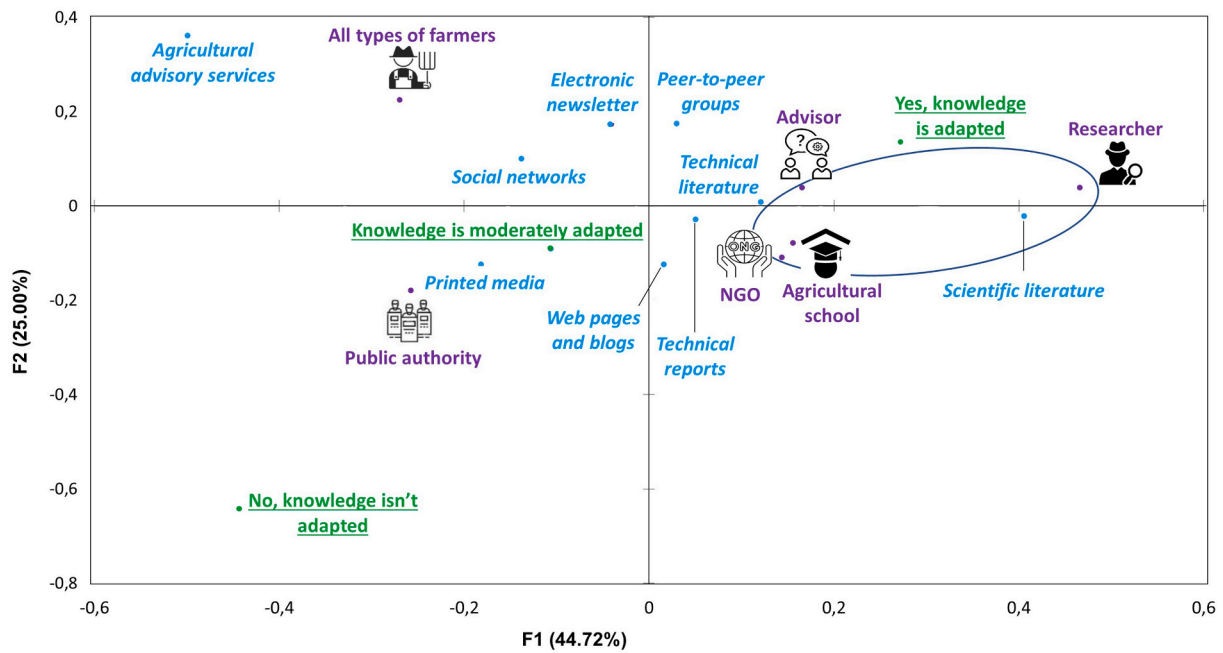**Fig. 6.** Sources used to access soil knowledge per stakeholder.

Fig. 7. Two first components of the CA performed on the sources used to access soil knowledge and knowledge adapted to stakeholders' needs. Stakeholders' responses regarding soil knowledge adapted to their needs are underlined in green, whereas in italic blue the sources used are represented. Stakeholders are represented in purple. The ellipse represents the results of an AHC made on the two first components of the CA.
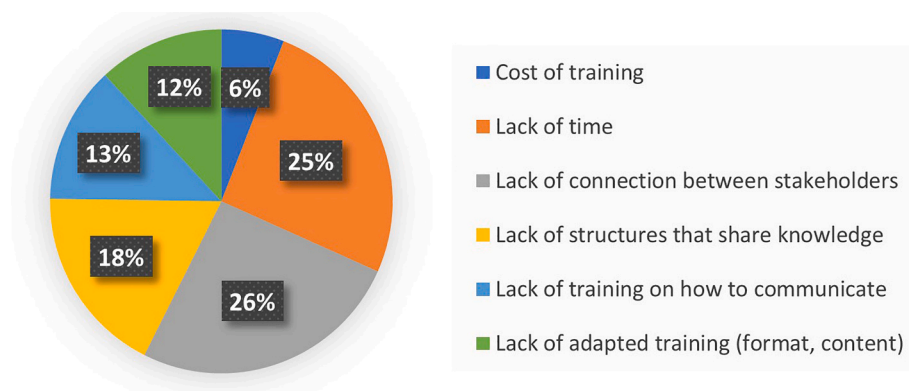

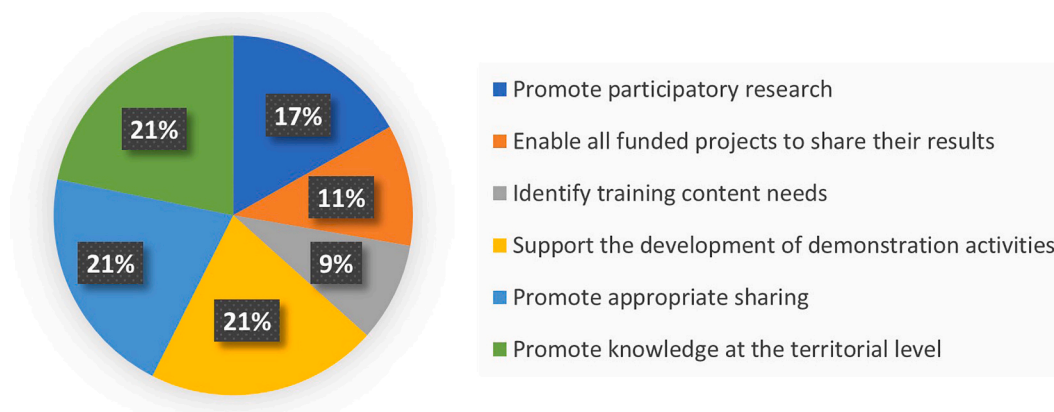**Fig. 8.** Main barriers access soil knowledge.

Fig. 9. Reported main opportunities to improve access to soil knowledge.
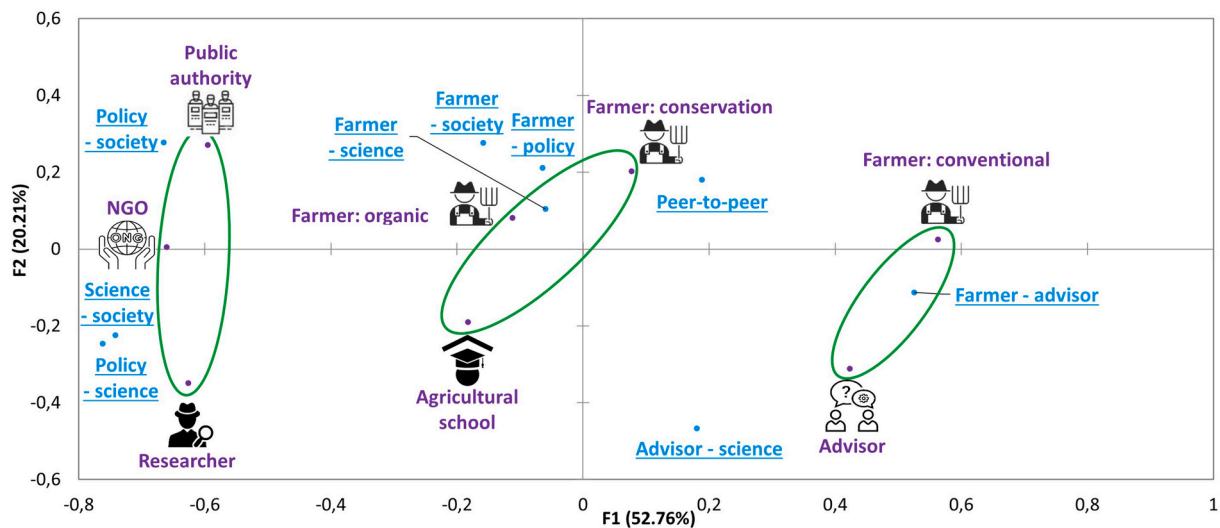
Fig. 10. Two first components of the CA performed on the exchange networks to strengthen according to stakeholders' point of view. Exchange networks to strengthen are underlined in blue. Stakeholders are represented in purple. Green ellipses represent the results of an AHC made on the two first components of the CA.

farmers and advisors; (ii) a second group composed by researchers, NGOs and public authorities; and (iii) a last group composed of organic and conservation agriculture farmers and agricultural schools. The first group was more in favor of strengthening farmer-advisor networks; the second preferred policy-society, policy-science and science-society networks; and the last one farmer-science and farmer-policy networks. Peer-to-peer networks were also important to be strengthened according to all farmers. It should be noted that conventional farmers were more in favor of farmer-advisor networks, while organic and conservation agriculture farmers were more in favor of peer-to-peer networks as well as farmer-society, −policy or -science networks.

4. Discussion

4.1. Not adapted soil knowledge and insufficient soil knowledge sharing

In our study, most stakeholders considered the soil knowledge they had access to, as not adapted to their needs and rated soil knowledge sharing among stakeholders as average or insufficient (Fig. 5). Researchers generally considered their level of soil knowledge and access to soil knowledge as sufficient but in the meantime, they rated soil knowledge sharing among stakeholders as average or insufficient. Since researchers play a significant role in the production of knowledge, when responding to this question, they may have considered the way soil knowledge is shared/transferred to other stakeholders, while other stakeholders' categories responded probably to the question considering the knowledge that was shared/transferred to their category.

Important is to note that conventional farmers, that directly manage soil, generally considered that they neither had a good knowledge on soil nor had a sufficient access to soil knowledge. This raises the question of how knowledge is transferred to stakeholders and the different sources used to access soil knowledge. Stakeholders who reported the most that soil knowledge was moderately to not adapted to their needs, farmers and public authorities, mainly used agricultural advisory services and printed media as information sources, respectively (Fig. 7). Feo et al. (2022) underlined that farmers preferred peer-to-peer groups, newsletters and visual materials. In our study, practitioners (farmers and advisors) and public authorities indicated scarcely using scientific literature, as Ugolini et al. (2015) also observed. On the other hand, scientific literature is the main source used by researchers (Fig. 6).

Another outcome of this research on access to soil knowledge was the consensus on the main barriers and opportunities perceived by the stakeholders (Figs. 8 and 9). The main barriers to access soil knowledge

were related to knowledge transfer and sharing, such as the lack of connection between stakeholders, and the lack of structures that shared knowledge. Similarly, in a survey in 20 countries from Vanino et al. (2023), the main barrier highlighted by stakeholders was the lack of established exchange networks.

4.2. Stakeholders value different exchange networks based on their type of knowledge

Exchange networks to strengthen in order to improve soil knowledge transfer and sharing is stakeholder dependent and based on the stakeholders' type of knowledge. The type of knowledge on soil of researchers, public authorities and NGOs is theoretical, whereas farmers have a more empirical knowledge on soil. Agricultural schools and advisors have both types of soil knowledge, theoretical and empirical.

In our study, stakeholders with theoretical knowledge (public authorities, NGOs, researchers) were more interested in reinforcing networks between policy, science and society (Fig. 10). Researchers were very much focused on their relationship towards public authorities as well as raising society awareness. Other studies also highlighted the need for soil researchers to reinforce science-policy networks (Campbell et al., 2017; Amundson, 2020; Okpara et al., 2020; Vanino et al., 2023) and science-society networks (Bouma et al., 2012).

On the other side, stakeholders with empirical knowledge such as conventional farmers and advisors indicated being more in favor of peer-to-peer networks as well as farmer-advisor networks (Fig. 10). They mentioned science-advisor networks as well, which interestingly has not been mentioned as strongly by the researchers. Conventional farmers and advisors valued positively the traditional model of knowledge transfer from researchers to advisors and finally to farmers, in a top-down linear format. The disadvantage of this traditional model is its lack of feedback from farmers to advisors and researchers (Kania and Żmija, 2016). Key et al. (2016) highlighted the importance of a two-way knowledge exchange between farmers and researchers.

We identified another group of stakeholders. Agricultural schools and organic and conservation agriculture farmers featured the need for dialogue between farmers and society, policy and science stakeholders (Fig. 10). Interesting was the clear difference observed among farmer between organic and conservation agriculture on the one hand and conventional farming on the other. We have here to remember that organic and conservation agriculture farmers who responded to our questionnaire were generally more educated than conventional farmers, explaining maybe their higher expectation from network with science,

policy and society, while conventional farmers, less educated, preferred mediation through agricultural advisory services. The use of technical terminology and scientific jargon by researchers can make it difficult for a less educated audience to understand the messages, leading to the discrepancies in the responses between organic and conservation agriculture farmers and conventional farmers regarding networks involving science. As such, it is important for researchers to deliver clear and understandable messages for farmers and advisors (Sharon and Baram-Tsabari, 2014; Hou et al., 2020). Indeed, advisors, despite being often highly educated, have generally basic knowledge in soil science as their educational background is mostly in animal and crop production.

Therefore, to strengthen knowledge transfer and sharing, three ways should be developed: (i) a traditional way of knowledge transfer in a top-down linear format by strengthening the profession of scientific mediator, distinct from the profession of researcher. It would be the responsibility of the scientific mediator to bridge the gap between academic research and the various stakeholders, as well as to provide a more comprehensive understanding of the research results; (ii) the establishment of Living Labs to bring stakeholders together around soil knowledge co-construction, since Living Labs are collaborative spaces where researchers, farmers, and other stakeholders can co-develop together solutions with a tangible impact and share already existing sustainable practices (Veerman et al., 2020); and (iii) the strengthening of peer-to-peer interactions through the establishment of Lighthouse farms, that is to say farms that have achieved exceptional results in terms of soil health, and serve as models for other farmers to follow. As a matter of fact, the European Commission, aware of current communication gaps between practitioners, researchers and public authorities, promoted the establishment of "Living Labs" and "Lighthouses".

4.3. The content of the theoretical knowledge transferred must be adapted to pedo-climatic conditions

Beside the ways of sharing and transfer soil knowledge (discussed above), important was also according to stakeholders, to promote soil knowledge at the territorial level (Fig. 9). Pedo-climatic conditions, land use and farming systems varying considerably between countries and regions across Europe (Metzger et al., 2005; CIRCASA, 2017; Hessel et al., 2022), each region faces particular soil challenges. For instance, in the study of Vanino et al. (2023), "improving SOM & peat soil conservation" was the major concern for most zones, while in Southern Europe "improving water storage capacity" was recognized as the main soil challenge. This situation also applies to a territory as France that encompass seven distinct environmental zones, out of the 13 environmental zones identified in Europe (Metzger et al., 2005). Therefore, increased attention to the context-specificity is needed, as standard agricultural solutions are inadequate. The content of the theoretical knowledge transferred should be adapted to specific pedo-climatic conditions. Living Labs that develop location specific solutions and knowledge for sustainable soil and land management that include socio-economic drivers, incentive mechanisms, and local pedo-climatic conditions (Löbmann et al., 2022), could once again represent an ideal tool to that respect.

4.4. Limit of our approach

The work we conducted was underpinned by effective consultation with a variety of stakeholders. However, some limitations should be noted. Online surveys are conducted on a voluntary basis and are not systematic in nature. Therefore, it is possible that the respondents with a greater knowledge of soil-related issues were more likely to participate, as shown by the over-representation of young graduates and organic farmers in our survey. Furthermore, conducting an online survey might have caused our sample to be biased towards more digitally advanced

stakeholders, potentially missing out on insights from older farmers. Finally, the use of a questionnaire with predetermined answers, which has the advantage of being quick to complete, has the disadvantage of limiting the diversity of possible responses. As such, it is possible that important points of view were not included in the research.

5. Conclusion and final recommendations

Stakeholders largely answered our survey, with 1951 answers, including 720 from farmers. By responding to the survey, farmers showed that they were committed to improving their access to the latest information and research on soil. Our results suggested that stakeholders consider the soil knowledge they have access to as not adapted to their needs. They also revealed that soil knowledge sharing between stakeholders was not sufficient. Stakeholders valued different exchange networks based on their type of knowledge. Stakeholders with more theoretical soil knowledge (public authorities, NGOs, researchers) stated being more interested in networks between policy, science and society. However, networks with farmers and advisors were more favored by stakeholders with empirical soil knowledge. There is a need to strengthen exchanges at a local level, as well as networks between peers and in relation to science. Research is not always sufficiently anchored at a local level and with practitioners, such as farmers and advisors.

Therefore, to bridge the gap of knowledge transfer and sharing, three ways should be developed. Firstly, the profession of scientific mediator should be further strengthened. It would be the responsibility of the scientific mediator to bridge the gap between researchers and the various stakeholders, as well as to provide a more comprehensive understanding of the research results. Stakeholders could be better informed and then make more informed decisions. Secondly, Living Labs should be established. Living Labs can be used to create a platform for co-creation between various stakeholders mixing both theoretical and empirical soil knowledge for a research more anchored at a local level allowing to bring together stakeholders. Finally, Lighthouse farms, places for demonstration of solutions and exemplary achievements, should be established. Through the use of demonstration activities, soil knowledge can be made more accessible and concrete, allowing it to be more readily understood by a wider range of people and to initiate valuable exchanges between theoretical and empirical soil knowledge. Only a combination of these three ways of knowledge sharing and transfer will ensure a transition towards a more sustainable soil management in Europe.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

Data will be made available on request.

Appendix. Questionnaire sent to the stakeholders

Section 1 - Your profile

In which age group do you fall? *(please tick one box)*

❑ Under 25 years old
❑ Between 25 and 34
❑ Between 35 and 49
❑ Between 50 and 65
❑ Over 65

What is the highest degree you have obtained? *(please tick one box)*

❑ No diploma
❑ CAP, BEP or equivalent
❑ Baccalauréat (A-level equivalent)
❑ Bachelor degree
❑ Master degree
❑ Doctorate
❑ Other

In which department do you work? *(select your department from the drop-down list).*

What types of soil are you confronted within your activities? *(tick one or more boxes as appropriate)*

❑ Urban / peri-urban soils
❑ Agricultural soils
❑ Forest soils
❑ Industrial and mining soils
❑ All soil types
❑ Other

How important is the role of soil in your work? *(please tick one box)*

❑ Big
❑ Medium
❑ Little
❑ None
❑ I don't know / hard to say

In which field do you work? *(please tick one box)*

❑ Public authority
❑ Researcher
❑ Agricultural school
❑ NGO
❑ Farmer
❑ Advisor

Section 1 – Your profile – You are a farmer
What type of farming do you do? *(tick one or more boxes as appropriate)*

❑ Conventional farming
❑ Organic farming
❑ Conservation agriculture

What kind of production do you do? *(tick one or more boxes as appropriate)*

❑ Field crops
❑ Animal husbandry
❑ Mixed farming - livestock
❑ Vegetable growing
❑ Arboriculture
❑ Viticulture

❑ Horticulture
❑ Other

What is the useful agricultural area of your holding? *(tick any box - the unit is the hectare)*

❑ Less than 5 ha
❑ Between 5 and 20 ha
❑ Between 20 and 50 ha
❑ Between 50 and 100 ha
❑ Between 100 and 200 ha
❑ More than 200 ha

Section 1 – Your profile – You are an advisor.
What type of agriculture are you working on? *(tick one or more boxes as appropriate)*

❑ Conventional farming
❑ Organic farming
❑ Conservation agriculture

What kind of production do you work on? *(tick one or more boxes as appropriate)*

❑ Field crops
❑ Animal husbandry
❑ Mixed farming - livestock
❑ Vegetable growing
❑ Arboriculture
❑ Viticulture
❑ Horticulture
❑ Other

Section 1 - Your profile – You are a public authority.
In which organization do you work? *(please tick one box)*

❑ Town hall of a rural commune
❑ Town hall of an urban commune
❑ Department level
❑ Regional level
❑ Ministry
❑ Other

Section 1 - Your profile – NGO.
What type of agriculture are you promoting? *(tick one or more boxes as appropriate)*

❑ Conventional farming
❑ Organic farming
❑ Conservation agriculture

What is the purpose of the NGO you work for? *(tick one or more boxes as appropriate)*

❑ Land protection
❑ Environmental protection
❑ Capacity building
❑ Promotion of sustainable agricultural practices
❑ Other

Section 2 - Your access to knowledge on soil

How would you rate your level of knowledge on soil? *(please tick one box)*

❑ I am an expert
❑ I have good knowledge
❑ I have some knowledge
❑ I know nothing

Which sources do you used to access soil knowledge? *(tick one box per line).*

	Used	Little used	Not used
Social networks	☐	☐	☐
Electronic newsletters	☐	☐	☐
Web pages and blogs	☐	☐	☐
Printed media	☐	☐	☐
Scientific literature	☐	☐	☐
Technical literature	☐	☐	☐
Technical reports	☐	☐	☐
Peer-to-peer groups	☐	☐	☐
Agricultural advisory services	☐	☐	☐
Other	☐	☐	☐

How would you rate your access to soil knowledge? *(please tick one box)*

☐ Sufficient
☐ Average
☐ Insufficient
☐ Hard to say

Is the knowledge you have access to adapted to your needs? *(please tick one box)*

☐ Totally
☐ Moderately
☐ Not at all
☐ Hard to say

How would you describe the sharing of knowledge between soil-related stakeholders (farmers, researchers, public authorities, agricultural advisors, etc)? *(please tick one box)*

☐ Sufficient
☐ Average
☐ Insufficient
☐ Hard to say

In your opinion, what are the main barriers to access soil knowledge? *(please tick one to three boxes)*

☐ Training not adapted (format, content)
☐ Lack of training for stakeholders on how to communicate
☐ Lack of structures that share knowledge
☐ Lack of connection between stakeholders
☐ Lack of time
☐ Cost of training
☐ Other

In your opinion, what are the main opportunities for promoting access to knowledge? *(please tick one to three boxes)*

☐ Identify training content needs
☐ Promote participatory research
☐ Support the development of demonstration activities
☐ Enable all funded projects to share their results
☐ Promote appropriate sharing
☐ Promote knowledge at the territorial level
☐ Other

In your opinion, which exchange network should be strengthened? *(select an answer from the drop-down list)*

☐ Peer to peer network (farmers - farmers; advisors - advisors; science - science, etc)
☐ Farmers - advisors network
☐ Farmers - policy network
☐ Farmers - science network
☐ Farmers - society network
☐ Farm advisor - science network
☐ Policy - science network
☐ Policy - Society network
☐ Science - society network

❑ Other

In your opinion, what would be a second exchange network to be strengthened? *(select an answer from the drop-down list)*

❑ Peer to peer network (farmers - farmers; advisors - advisors; science - science, etc)
❑ Farmers - advisors network
❑ Farmers - policy network
❑ Farmers - science network
❑ Farmers - society network
❑ Farm advisor - science network
❑ Policy - science network
❑ Policy - Society network
❑ Science - society network
❑ Other

Thank you very much for taking the time to complete the survey! The results of the survey will be published. If you would like to know the results of the survey, you can leave your email address.

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