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Stakeholders' Perspectives on the Current State and Transition to Sustainable Soil Management Across Europe

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ABSTRACT

Implementing sustainable soil management practices to enhance soil health is a priority in research and policymaking across Europe. There is a need to identify the main soil challenges faced by different European stakeholders and the critical threats limiting the adoption of sustainable management of agricultural soils. The present study analyses stakeholders' perspectives on key soil challenges, knowledge gaps, and priorities for agricultural soil research across partner countries that participated in the European Joint Programme on Soil (EJP SOIL) 2020–2025. Two complementary stakeholder activities—a survey and a workshop—were conducted across 24 partner countries (divided into four regions: Central, Northern, Southern, and Western Europe) of the EJP SOIL consortium in 2024. Among 10 pre-identified soil challenges, the findings highlight that maintaining or increasing soil organic carbon, avoiding soil sealing, and avoiding soil erosion are the top three priorities across Europe. However, the perceived prioritisation of soil challenges differed both between and within regions, reflecting each country's specific soil health context. Divergences in perceptions between practitioners and other stakeholder groups underscore the need to develop actions aimed at better understanding the rationale behind such discrepancies and how to overcome

them. In addition, other key challenges for achieving sustainable soil management across Europe include limited funding, policy incoherencies, poor knowledge dissemination and co-creation, and insufficient soil monitoring. Environmental factors influencing soil health, including climate change, together with governance and economic models, were perceived to be critical limitations to the adoption of sustainable management of agricultural soils. This study also emphasises the need for a diversity of engagement methods, policies, and system approaches to support a transition towards sustainable soil management. These findings underscore the need for future research agendas that focus on integrated knowledge and participatory approaches, and strategies involving societal awareness and policy alignment—key elements that have also informed broader strategies involving societal awareness and engagement towards sustainable soil management in Europe.

1 | Introduction

Soil health is integral to both human and planetary well-being, supporting broad sustainability goals (Lehmann et al. 2020). Societies face the challenge of preserving soil health and recovering degraded soils to ensure sufficient food production while protecting natural resources (Bampa et al. 2019). Maintaining healthy soils involves minimising or preventing soil threats and the development and implementation of sustainable soil management practices. This calls for raising awareness of soil threats among all key actors in society (Katikas et al. 2024). To address this need, the EJP SOIL programme (2020–2025) assembled 26 research institutes across 24 countries to develop a sustainable European integrated research community with a diverse range of actors across the EU. The main objective of EJP SOIL was to create enabling environments to enhance the contribution of agricultural soils to key societal challenges such as climate change adaptation and mitigation, sustainable agricultural production, ecosystem services provision, and prevention and restoration of land and soil degradation. While previous studies in EJP SOIL identified general knowledge gaps, there remains a need to understand the divergent perspectives among a wider, more representative array of stakeholders, which is critical for effective co-production of solutions. The present study in the final year of the EJP SOIL programme (2024) addressed this gap by gathering a diverse group of stakeholders' perspectives on sustainable soil management, key challenges for future soil research, and their implications for prioritising sustainable soil management.

Awareness of soil threats and their environmental impacts is an important priority in research and innovation programmes and policies across the European Union (EU) (Montanarella and Panagos 2021; Panagos et al. 2022). The European Green Deal, which aims for Europe to become the first climate-neutral continent by 2050, emphasises the crucial role of healthy soils in achieving this goal, recognising that healthy soils are essential for climate neutrality, a clean circular economy, and preventing desertification and land degradation.

Adopted in 2021, the EU Soil Strategy for 2030 (EC 2021c) supports the Green Deal by outlining steps to protect and restore soils to ensure sustainable use and achieve healthy soils across Europe by 2050. Actions on European soil policies have also been taken, including supporting and contributing to the Soil Monitoring Law proposal (EC 2023), which sets out to monitor and assess soil health, sustainable soil management, and remediation of contaminated sites. Stakeholder engagement is in focus within the EU Mission 'A Soil Deal for Europe' (EC 2021a) with a goal to establish 100 Living Labs and Lighthouses by 2030, promoting sustainable land and soil management in urban and rural areas.

Previous research conducted in EJP SOIL identified knowledge gaps and barriers to sustainable soil management across Europe (e.g., Don et al. 2021; Farina et al. 2021; Munkholm et al. 2021; Thorsøe et al. 2021; Paz et al. 2024) involving stakeholder consultations with target groups (scientists, policymakers, and practitioners) and literature reviews. These studies highlighted how interventions could foster healthy, resilient, and sustainable soil ecosystems across Europe (Vanino et al. 2023). Perceived knowledge gaps were also explored to guide research and support a transition to more sustainable soil management, highlighting priorities for European policymakers (Thorsøe et al. 2023). Strengthening capacity and expertise in current and future generations of European research and practitioners was also explored (Villa et al. 2025; Veenstra et al. 2024).

Building on the progress made since the EJP SOIL programme was initiated in 2020, significant changes have occurred in European research and policy, alongside evolving public discussions on the importance and foundational role of soil health. By further examining perspective divergences related to sustainable soil management among various stakeholder groups, knowledge exchange and building trust among key actors can be more effectively promoted (Ingram et al. 2016; Weninger et al. 2024). Assessing stakeholder perspectives can also play an important role in co-producing technical solutions and shared visions, fostering lasting commitments to sustainable soil management and soil health (Krzywoszynska 2019). Compared to the initial syntheses of the EJP SOIL programme (Thorsøe et al. 2023; Vanino et al. 2023), the present analysis provides detailed descriptions of perceptions to uncover differences across stakeholder categories (Ingram et al. 2016; Krzywoszynska 2019; Weninger et al. 2024). Overall, this study aims to improve understanding of the current state of knowledge and highlight knowledge gaps and key challenges related to sustainable soil research and management in 24 European countries.

2 | Materials and Methods

This section outlines the overall data collection (Section 2.1), as well as the survey structure (Section 2.2) and workshop structure (Section 2.3), followed by an overview of the stakeholder representation (Section 2.4) and a description of the overall data treatment (Section 2.5).

Summary

- Identifies key soil challenges across 24 European countries and 9 stakeholder types.
- Addresses lack of region-specific insight on sustainable agricultural soil management across Europe.
- Limited funding, poor policy coherence, and weak knowledge exchange hinder adoption.
- Highlights need for integrated, participatory, and place-based soil strategies.

2.1 | Data Collection

In 2024, data were collected in the 24 partner countries using a common methodological framework to improve understanding of stakeholders' perceptions of the state of knowledge and knowledge use concerning sustainable soil management (Figure 1). This included guidelines as well as templates for implementing the consultations (Appendices A and B). The data that constitute the basis of this article were acquired through surveys and workshops conducted in 2024, utilising the EJP SOIL national hubs of 24 partner countries in the EJP SOIL consortium. At the beginning of the program period (2020), each EJP SOIL partner country established an EJP SOIL National Hub with key stakeholders. Hub participation was open, and assemblages were different across countries. However, the core idea was for hubs to represent soil communities, which include farmers, advisors, policymakers, NGOs, etc. EJP SOIL hubs were not established for the purpose of this study; instead, they provided continuous input on various agricultural soil-related topics and were a central component of the EJP SOIL programme (for more information, please see https://ejpsoil.eu/).

Partner countries were grouped into regions as follows (Figure 2):

- Central Europe was represented by Austria (AT), Czech Republic (CZ), Germany (DE), Hungary (HU), Poland (PL), Slovakia (SK), Slovenia (SI), and Switzerland (CH).
- Northern Europe was represented by Denmark (DK), Estonia (EE), Finland (FI), Latvia (LV), Lithuania (LT), Norway (NO), and Sweden (SE).
- Southern Europe was represented by Italy (IT), Portugal (PT), Spain (ES), and Türkiye (Turkey, TR).
- Western Europe by Belgium-Flanders (BE-VLG), Belgium-Wallonia (BE-WAL), France (FR), Ireland (IE), the Netherlands (NL), and the United Kingdom (UK).

EJP SOIL participating countries engaged stakeholders in a consultation at national level using an online survey and participation in EJP SOIL national hub workshops, with the exception of Belgium, which reported based on two regions (Flanders and Wallonia) due to differing administrative structures and knowledge networks that influence soil research and management. Guidelines for the survey (Appendix A) and workshop (Appendix B) were designed and distributed to support uniformity across participating countries (Paz 2021). The survey and workshop were completed throughout winter and spring of 2024.

2.2 | Survey Structure

The survey was structured to assess stakeholders' perspectives to assist the EJP SOIL programme in proposing relevant interventions to improve the availability and use of knowledge on sustainable soil management (Table 1). The survey began

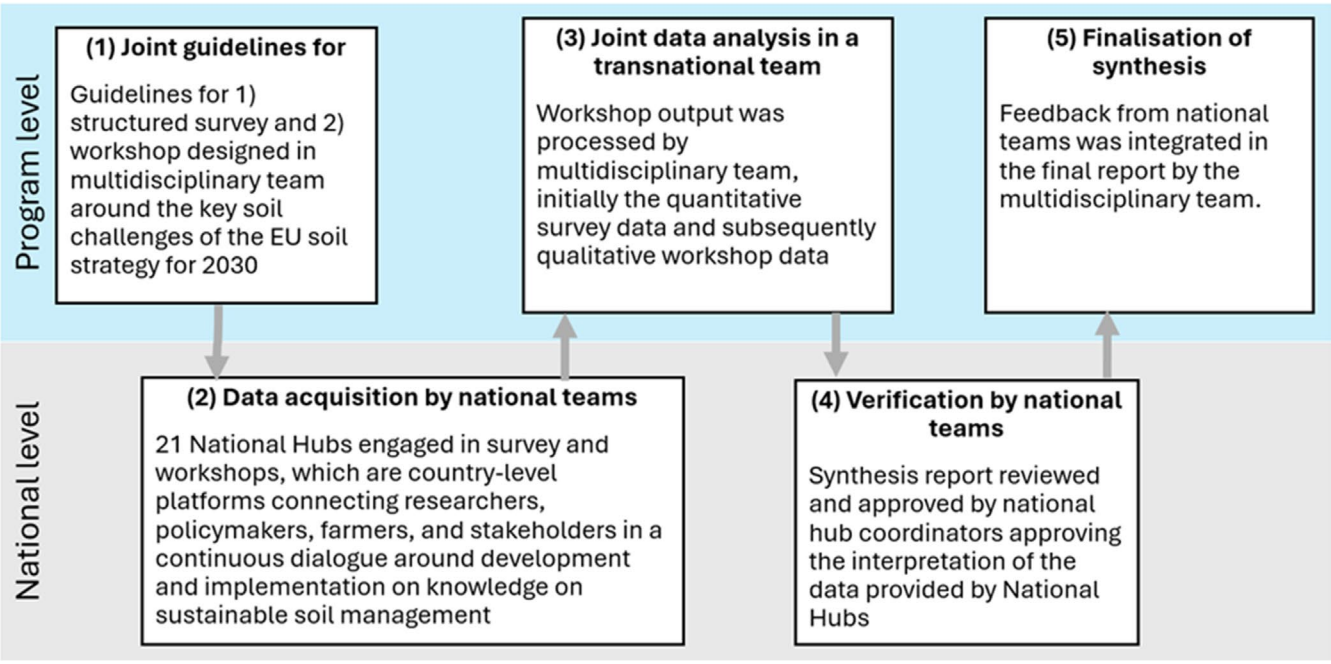

FIGURE 1 | Research design overview for the analysis in five stages.

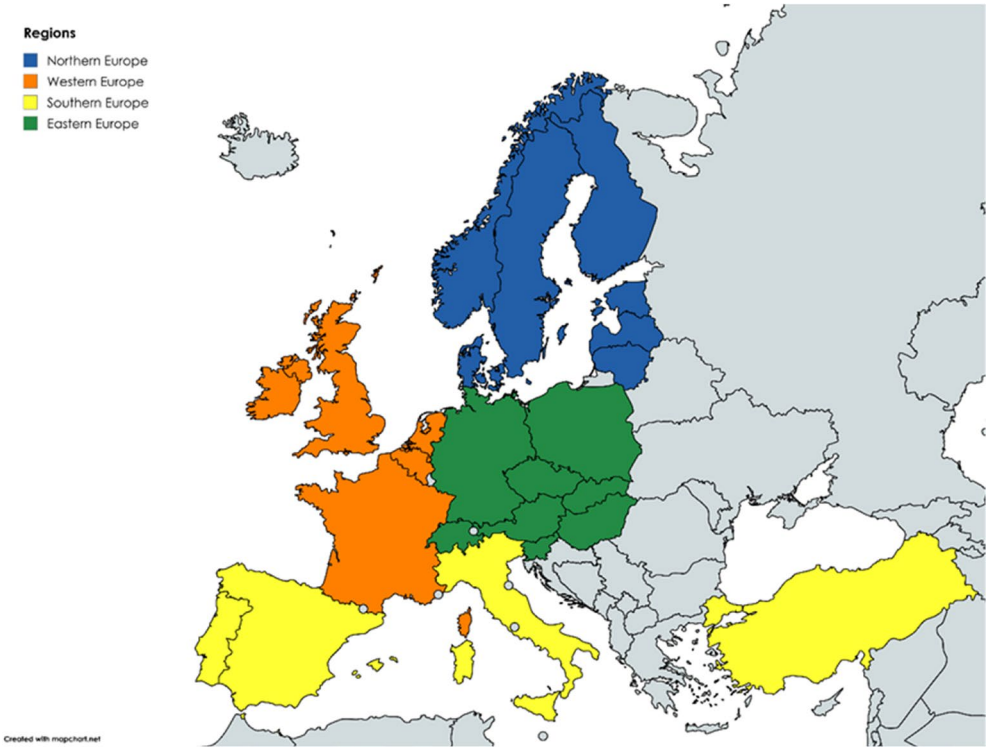

FIGURE 2 | Map of the four European regions: Central Europe (green), Northern Europe (blue), Southern Europe (yellow), Western Europe (orange); small states are represented by grey dots but were not separately analysed in the present study. Adapted from Vanino et al. (2023).

with a General Data Protection Regulation statement from the European Commission, followed by a questionnaire designed to capture stakeholders' perceptions of key soil challenges and knowledge gaps.

The first section of the questionnaire asked stakeholders to select their affiliation from a predefined list of 12 stakeholder categories (Table 1). Second, stakeholders ranked the three most important soil challenges for sustainable soil management in their country from a list of 10 pre-identified challenges originating from the European Commission and were then further sub-set based on expert input (Table 1). Third, stakeholders were asked to rank knowledge gaps by importance. For this question, we revisited seven knowledge gaps identified in the first year of the EJP SOIL, adding two more: improving the relevance of future research activities for practitioners and improving the research infrastructures (Thorsøe et al. 2023; Table 1). Finally, barriers to sustainable soil management were rated using a five-point Likert scale. For this question, six of the seven were selected based on Vanino et al. (2023); (Table 1): lacking capacity, lacking knowledge communication, limited financial resources, underdeveloped soil network, inadequate policies, and lack of relevant technology. Stakeholders were additionally asked if conditions for sustainable soil management had improved over the past 5 years, using a five-point Likert scale to measure their responses.

Each participating country was asked to report their national inputs from the survey using a common template for the quantitative data and assess the selection and representativeness of the participating stakeholders, based on country reporters' familiarity with local conditions and discussions. The survey was translated from English into the respective national language when needed and conducted on a voluntary basis. Stakeholders were primarily consulted online via web-based questionnaires or email (except in Latvia, where consultations took place in person).

2.3 | Workshop Structure

The aim of the workshops was to assess stakeholders' perspectives to identify opportunities, strategies, and enabling conditions for transitioning to sustainable soil management using qualitative insights to build on the quantitative information collected in the survey through a mixed-method approach. The workshop discussions were designed to engage stakeholders in identifying the most relevant soil knowledge gaps and the underlying mechanisms and mitigation options of the most relevant soil challenges.

The workshop guidelines suggested that the country partners initiated the activity with a moderator presenting and discussing the survey results, followed by two exercises (Appendix B). First, a group discussion was held on the Strengths, Weaknesses, Opportunities, and Threats (SWOT) associated with the transition to sustainable soil management. Strengths and Weaknesses were defined as internal factors that can be influenced by stakeholders (e.g., level of collaboration, farming skills, and accessible technology), and Opportunities and Threats were defined as

TABLE 1 | Survey structure.

Survey sections	Response categories
Stakeholder categories	i. Policymakers ii. Research communities iii. Research funders iv. Educational institutions and agricultural schools v. National science testing and verification centres vi. Advisors vii. Farmer and demonstration farms: farmers' organisations viii. Agro-industry ix. Supply and retail; laboratories x. National science testing and verification centres xi. NGOs xii. Others
Soil challenges	i. Maintain/increase soil organic carbon (SOC) ii. Avoid N_2O/CH_4 emissions iii. Avoid peat degradation iv. Avoid soil erosion (water/wind/tillage erosion) v. Avoid soil sealing vi. Avoid salinisation vii. Avoid contamination viii. Optimal soil structure ix. Enhance soil biodiversity x. Enhance soil nutrient retention/use efficiency
Knowledge gaps (Thorsøe et al. 2023)	i. Raising awareness ii. Strengthening knowledge brokers iii. Improving the relevance of research activities and resource allocation for land users iv. Peer-to-Peer communication v. Targeted advice and information vi. Improved knowledge access vii. Providing incentives
Barrier categories (Vanino et al. 2023)	i. Capacity building ii. Communication iii. Economic iv. Networks v. Political vi. Social vii. Technical

external factors that cannot be controlled by these actors (e.g., soil type, climate, and market trends).

The outcomes of SWOT analyses were discussed, addressing two open questions:

1. What are the most pressing knowledge needs for practitioners to address the most important soil challenges in a 10-year perspective?
2. Aside from filling knowledge gaps, what are the most important initiatives to address the barriers to sustainable soil management?

The workshop discussions were conducted in the local language and designed to last about 90 min. Workshops were conducted with voluntary participation via in-person, online, or hybrid mode (in-person and online) across countries. The workshops were documented by the national hub coordinators through audio recordings, structured notetaking, and photos of group outputs such as flip-overs or whiteboards. Summaries of discussions (around 500 words per theme) were prepared to capture stakeholder perspectives, including SWOT analyses and strategy proposals. These outputs were then consolidated into national reports following a standardised reporting template for cross-country synthesis. Each country was asked to summarise and report its national inputs from the workshop using a common template to support cross-country comparison and analysis (Appendix B). Hence, the data collected were sourced from a summary of participants in the workshops.

2.4 | Stakeholder Representation

The number and category of stakeholders in the national inputs varied across countries due to stakeholder availability and specificity of national stakeholder involvement in soil management or knowledge distribution. To support broad engagement across all partner countries, National Hubs were created following criteria regarding type of stakeholder. Despite limitations, the data were seen by the national representatives as providing a comprehensive view of national perspectives with diverse and sufficient participation across all stakeholder categories. Some of the 12 stakeholder categories were regrouped into broader categories to facilitate analysis. The stakeholders selecting either research communities or research funders options were grouped as 'Researchers'. The stakeholders who selected either 'Laboratories' or 'National science testing and verification centres' were grouped as 'Service providers'. The stakeholders selecting either 'Educational institutions and agricultural schools' or 'Advisors' were grouped as 'Knowledge communicators'. The stakeholders who selected either 'Farmer and demonstration farms' or 'Farmers' organisations' were grouped as 'Practitioners'. Respondents who selected multiple stakeholder categories were categorised as 'Multiple categories' The 'Agro-industry, supply and retail' category is called hereafter as 'Supplier'.

2.4.1 | Stakeholder Representation in the Survey

A total of 1123 responses were collected across the 24 participating countries. The number of participants ranged from 7 (IE) to 211 (IT) (Table 2), and among different stakeholder categories within each country, no assessment was made regarding the weight of participation by country. The number of participants varied significantly both across countries and among different stakeholder categories within each country. Among the respondents across countries, the largest stakeholder groups were Knowledge communicators at 25%, Researchers at 22%, and Practitioners at 21%. Less represented categories included

TABLE 2 | Composition of stakeholders and total survey respondents by category and country participating.

Region	Country	Policymakers	NGO	Researchers	Service providers	Suppliers	Knowledge communicators	Practitioners	Multiple categories	Other	Total
Central Europe	AT	0	3	34	2	7	24	34	0	30	134
	CH	2	0	4	1	0	0	0	0	1	8
	CZ	6	0	4	1	0	15	21	12	0	59
	DE	4	0	6	1	1	4	8	0	5	29
	HU	1	0	22	0	0	4	4	0	0	31
	PL	33	1	18	6	1	25	13	0	7	104
	SI	2	2	3	1	2	9	18	0	0	37
	SK	6	2	4	0	3	8	7	1	3	34
Northern Europe	DK	0	2	7	0	2	14	8	0	9	42
	EE	1	1	4	1	1	3	8	0	0	19
	FI	0	1	9	0	0	1	1	2	0	14
	LV	2	0	3	1	0	1	0	4	2	13
	NO	2	0	5	0	1	3	2	0	0	13
	SE	12	1	24	1	6	31	45	0	7	127
Southern Europe	ES	3	0	27	0	0	0	1	0	4	35
	IT	1	3	24	5	2	112	42	0	22	211
	PT	3	0	4	2	0	4	10	0	1	24
	TR	0	1	12	0	1	5	0	0	0	19
Western Europe	BE-VLG	8	0	9	0	0	1	1	18	0	37
	BE-WAL	0	1	5	3	1	5	1	20	2	38
	FR	6	12	13	0	3	4	3	0	8	49
	IE	2	0	0	0	1	0	3	0	1	7
	NL	3	0	3	0	2	2	1	0	0	11
	UK	6	3	8	1	0	5	1	0	4	28
	Total	103	33	252	26	34	280	232	57	106	1123
	%	9	3	22	2	3	25	21	5	9	

Abbreviations: AT, Austria; CH, Switzerland; CZ, Czech Republic; DE, Germany; DK, Denmark; EE, Estonia; ES, Spain; FI, Finland; Flanders BE-VLG and Wallonia BE-WAL regions, Belgium; FR, France; HU, Hungary; IE, Ireland; IT, Italy; LV, Latvia; NL, the Netherlands; NO, Norway; PL, Poland; PT, Portugal; SE, Sweden; SI, Slovenia; SK, Slovakia; TR, Turkey; UK, United Kingdom.

Suppliers, NGOs, and Service providers, each accounting for 3%, 3%, and 2% of the total respondents, respectively (Table 2).

Considering the representation within countries, in CH, HU, FI, ES, and TR, Researchers was the category most represented (≥ 50%). Practitioners (farmers and demonstration farms, and farmers' organisations) had the largest representation in CZ, SI, EE, SE, PT, and IE, ranging from 35% to 49% of the national respondents, while there were no farmer participants in CH, LV, and TR. The highest proportion of respondents identified as multiple stakeholder categories was for Belgium, BE-VLG (49%) and BE-WAL (53%).

2.4.2 | Stakeholder Representation in the Workshops

A total of 1494 stakeholders participated in the group discussions across the 24 countries, ranging from 6 (FI) to 570 (IT) (Table 3). The number of participants for the focus groups exceeded the number of participants in the survey in most countries. In BE-WAL, CH, DE, HU, NL, SE, TR, and UK, all workshop participants also completed the survey. In the other countries, some or none of the workshop participants completed the survey.

Workshop participants were not asked to identify their stakeholder category. Thus, it was not possible to assess stakeholder representativeness in cases where the stakeholders differed from those in the survey. Though no assessment was made regarding the weight of participation by country, the national representatives noted that a diverse range of stakeholders—including those focused on policy, research, and practical soil management—were engaged.

2.5 | Data Treatment

The survey data from each country were analysed without national or European region pre-aggregation. Quantitative elements are presented using descriptive statistics. For the question related to the selection of the three most important challenges, responses were averaged by calculating the weighted mean of the importance score. Weights were assigned to each challenge based on the respondents' reported importance: 3 for challenge 1, 2 for challenge 2, and 1 for challenge 3 (inverted weights). The final score represented the relative importance of each challenge after considering the respondent count for each country to ensure comparability, with the three challenges with the highest weighted mean selected.

All Likert scale questions (Soil challenges and knowledge gaps, Actions to improve the general state of soil knowledge, Barriers to address soil challenges, Improvements in sustainable soil management conditions) were analysed by calculating the weighted mean, and results were represented in heatmaps. For these questions, the weighted mean was calculated by combining the frequency of responses at each Likert level with their corresponding weights (on an inverted scale, so that higher values consistently indicate greater importance). The calculation also includes a normalisation step, using the total responses as the denominator, to account for differences in group sizes and ensure that the scores are comparable across regions, countries, and challenges (or stakeholder categories). Data cleaning was performed for each question to exclude responses that did not comply with the reporting guidelines and instances where questions were left unanswered. When assessing the implications of stakeholder categories on the rating, the data were grouped by European region. However, some countries within a region may not have had representatives for certain stakeholder categories (Table 2).

The reports from the national workshops included only qualitative data. The national workshop summaries were split into single ideas, hereafter referred to as comments. Similar comments were grouped into a single entry per country to minimise repetition and reduce the impact of uneven numbers across countries. Then, all unique comments were categorised by theme (Appendix C). The 'theme' refers here to a broad category that brings together related ideas or comments, representing a shared concept or underlying connection among various comments. The identified themes were then grouped into larger topics to enable more effective analysis and visualisation. The 'topic' here acts as a higher-level category to organise the themes into larger, more comprehensive areas for analysis.

Final topics and theme names, as well as final comment placements, were coded thematically by four researchers and grouped and re-grouped in a method of constant comparison (Clark and Creswell 2008; Appendix C). Regarding the SWOT analysis, the themes selected for this synthesis were those mentioned in more than one national report ($n = 137$ themes included, $n = 42$ themes omitted). A cross-check validation process, including justification and argumentation of themes and topics comparing the SWOT dataset and the knowledge gaps/initiatives dataset, was completed by four researchers.

Across both activities, a total of 137 themes and 9 topics were identified. Common topics were economy and labour, education, environment, farmer perceptions, governance, knowledge, methods and practices, networking, and system. The topic system is characterised by system thinking including holistic, interconnected, and long-term perspectives (Meadows 2008). From the workshop discussions, 627 comments were identified for the SWOT analysis, categorised into 110 themes and 9 topics. While for the knowledge gaps and initiatives analysis, 423 comments (147 for knowledge gaps and 276 for initiatives) were identified and categorised into 39 themes, grouped in 9 topics.

For the two qualitative data analyses related to SWOT and knowledge gaps/initiatives, the same topics were useful, but more specific themes were generated in the SWOT analysis. For example, in the topic economy and labour, incentives and financing, market uncertainties, and profitability were identified for both. However, participants additionally highlighted carbon markets, financial models, fair compensation, and value creation in the SWOT analyses. These differences are likely related both to differences in the coding practices of the researchers and differences in the data itself.

TABLE 3 | Workshop type and stakeholder participation by country in the 2024 consultation.

Region	Country	Workshop type	Number of participants	Workshop participants answered the survey
Central Europe	AT	Online	83	No
	CH	Online	7	Yes
	CZ	In-person	24	Some
	DE	In-person	14	Yes
	HU	In-person	86	Yes
	PL	In-person	43	Some
	SI	Online	13	Some
	SK	Hybrid	36	Some
Northern Europe	DK	In-person	40	Some
	EE	In-person	32	Some
	FI	Online	6	Some
	LT	In-person	88	Some
	LV	Hybrid	36	Some
	NO	In-person	22	Some
	SE	Online	31	Yes
Southern Europe	ES	In-person	90	Some
	IT	Hybrid	570	Some
	PT	In-person	44	Some
	TR	Online	20	Yes
Western Europe	BE-VLG	In-person	17	Some
	BE-WAL	Online	39	Yes
	FR	Hybrid	100	Some
	IE	In-person	12	Some
	NL	Hybrid	13	Yes
	UK	In-person	28	Yes

Abbreviations: AT, Austria; CH, Switzerland; CZ, Czech Republic; DE, Germany; DK, Denmark; EE, Estonia; ES, Spain; FI, Finland; Flanders BE-VLG and Wallonia BE-WAL regions, Belgium; FR, France; HU, Hungary; IE, Ireland; IT, Italy; LV, Latvia; NL, the Netherlands; NO, Norway; PL, Poland; PT, Portugal; SE, Sweden; SI, Slovenia; SK, Slovakia; TR, Turkey; UK, United Kingdom.

3 | Results

3.1 | Perspectives on the Status of Knowledge of Sustainable Soil Management—Survey

3.1.1 | Pressing Soil Challenges and Knowledge Gaps

Prioritisation of soil challenges varied across and within the four European regions, with unique challenges selected by countries reflecting their specific contexts. However, the most frequently selected soil challenge across all countries was 'maintain/increase soil organic carbon (SOC)', followed by 'avoid soil sealing' and 'avoid soil erosion' (Figure 3). Additionally, 'enhance soil nutrient retention/use' was particularly important for the Northern Europe region, and 'enhance soil biodiversity' was important in the Southern and Western Europe regions.

Stakeholders were also asked to assess the importance of knowledge gaps in addressing national soil challenges. Similar to selected soil challenges, 'maintain/increase SOC' was also identified as a pressing knowledge gap across all countries, while the perceived importance of knowledge gaps for 'avoid soil erosion' and 'avoid soil sealing' was region-specific (Figure 3). Correspondingly, 'optimal soil structure', 'enhance soil biodiversity', and 'enhance soil nutrient retention/use efficiency' were perceived to have pressing knowledge gaps across all regions. In the Southern European region, knowledge gaps to 'avoid soil salinisation', 'avoid soil contamination', and 'avoid soil erosion' were prioritised. Other soil challenges, such as 'enhance water storage capacity' (SK, DK, SE, IT, and PT) and 'avoid soil acidification' (DK, LV, and SE), were either included in the survey questions or mentioned as additional challenges by some countries as needing assessment in their national contexts.

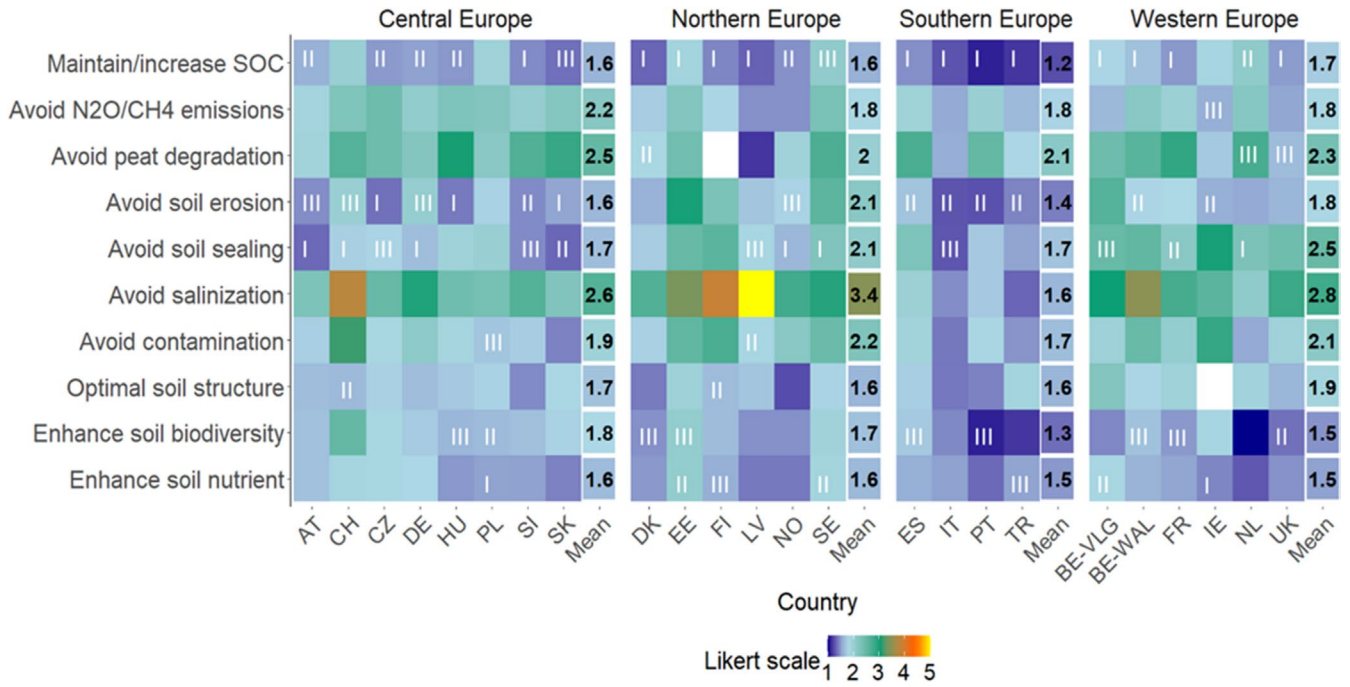

FIGURE 3 | Pressing soil challenges and knowledge gaps across different regions according to 2024 stakeholder participants. This Figure overlays two questions from the survey: (1) 'How important are the knowledge gaps for the following soil challenges within your country?' with colour gradient reflecting the Likert scale ratings, ranging from 1 = highly important (dark blue), 2 = important (light blue), 3 = neutral (green), 4 = somewhat important (orange), and 5 = not important at all (yellow), with missing data (white); and (2) 'What are in your perspective the three most important challenges to sustainable soil management in your country?' with labels (I, II, and III) within each tile showing the priority level of the selected soil challenges per country. SK, DK, SE, IT and PT introduced 'enhance water storage capacity/improve water regulation capacity' to the list of questions in the survey and DK, LV and SE introduced 'avoid soil acidification'. In DK, SE and IT water issues were ranked top three and in LV acidification, meaning that the challenge ranked number III in the figure was actually number IV.

By region, Southern Europe highlighted the most knowledge gaps, having the highest number of average values for gaps by country (> 2.0). When assessing how stakeholder categories influence the ranking of pressing knowledge gaps, divergences emerged in the perceived importance of certain soil challenges across regions (Figure 4). In Western Europe, Service providers, Knowledge communicators, Multiple categories, and Other assigned it lower priority. Additionally, in Northern Europe, Service providers consistently rated knowledge gaps for most soil challenges as less important than other stakeholder groups, except for maintaining or increasing SOC. Conversely, respondents in the Multiple categories group rated most knowledge gaps as important.

3.1.2 | Action Needed to Improve Soil Knowledge

Stakeholders ranked the importance of various actions to improve soil knowledge, with most actions rated from neutral to important (Figure 5). Some differences emerged between stakeholder groups. For example, in Northern Europe, Knowledge communicators highlighted increasing the availability of existing research, improving the cooperation between stakeholders, and increasing the relevance of future research for Practitioners. In contrast, Researchers identified the need to develop more strategies. In Southern Europe, Knowledge communicators identified new strategies, and both Knowledge communicators and Researchers highlighted the need for increasing the availability of existing research and improving coordination among stakeholders as the most relevant actions, while Researchers in both Southern and Western Europe highlighted the need for improving soil monitoring.

In the Northern Europe region, service providers assigned lower importance to all actions, contrasting with multiple categories group's responses (Figure 5). In Southern Europe, NGOs generally rated actions as more important than other stakeholder groups. The need for improving soil monitoring was highly rated, especially in Southern and Western Europe. Producing new soil knowledge was still evaluated as a very important tool; however, making the knowledge more available for practitioners and policymakers was even more expected.

3.1.3 | Barriers to Knowledge Development, Availability, and Transfer

Overall barriers to addressing soil challenges included 'lack of knowledge communication', 'inadequate policies', and 'limited financial resources'. Divergences between regions were observed for 'avoid peat degradation', 'avoid soil sealing' and 'avoid soil salinisation' regarding their importance as barriers (Figure 6). For instance, to address soil sealing, 'inadequate policies' was a key issue in Central, Northern, and Western Europe Central, Northern, and Western Europe, while 'lack of relevant technology' was rated the least important. To prevent soil salinisation, the main barriers were 'limited financial resources' and 'lack of relevant technology' in Central Europe; 'lack of capacity'

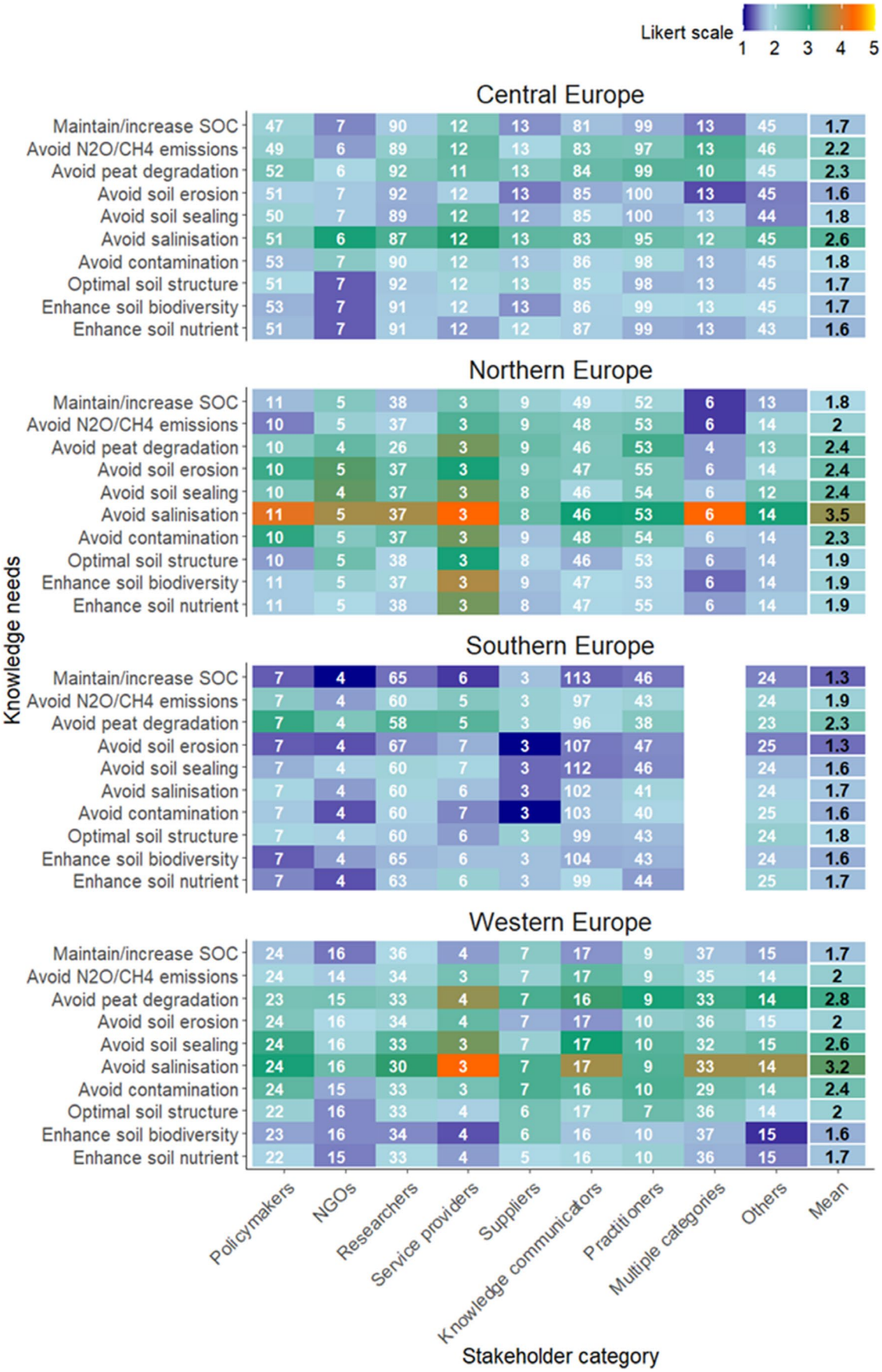

FIGURE 4 | Legend on next page.

FIGURE 4 | Weighted mean of responses to the question: 'In your perspective how important are the knowledge needs for the following soil challenges within your country?' The colour gradient reflects the Likert scale ratings, ranging from 1 = highly important (dark blue), 2 = important (light blue), 3 = neutral (green), 4 = somewhat important (orange), and 5 = not important at all (yellow), cells with missing data (white). White numbers within each tile show the count of respondents per stakeholder category. Black numbers within the tile show the mean of importance across stakeholder categories.

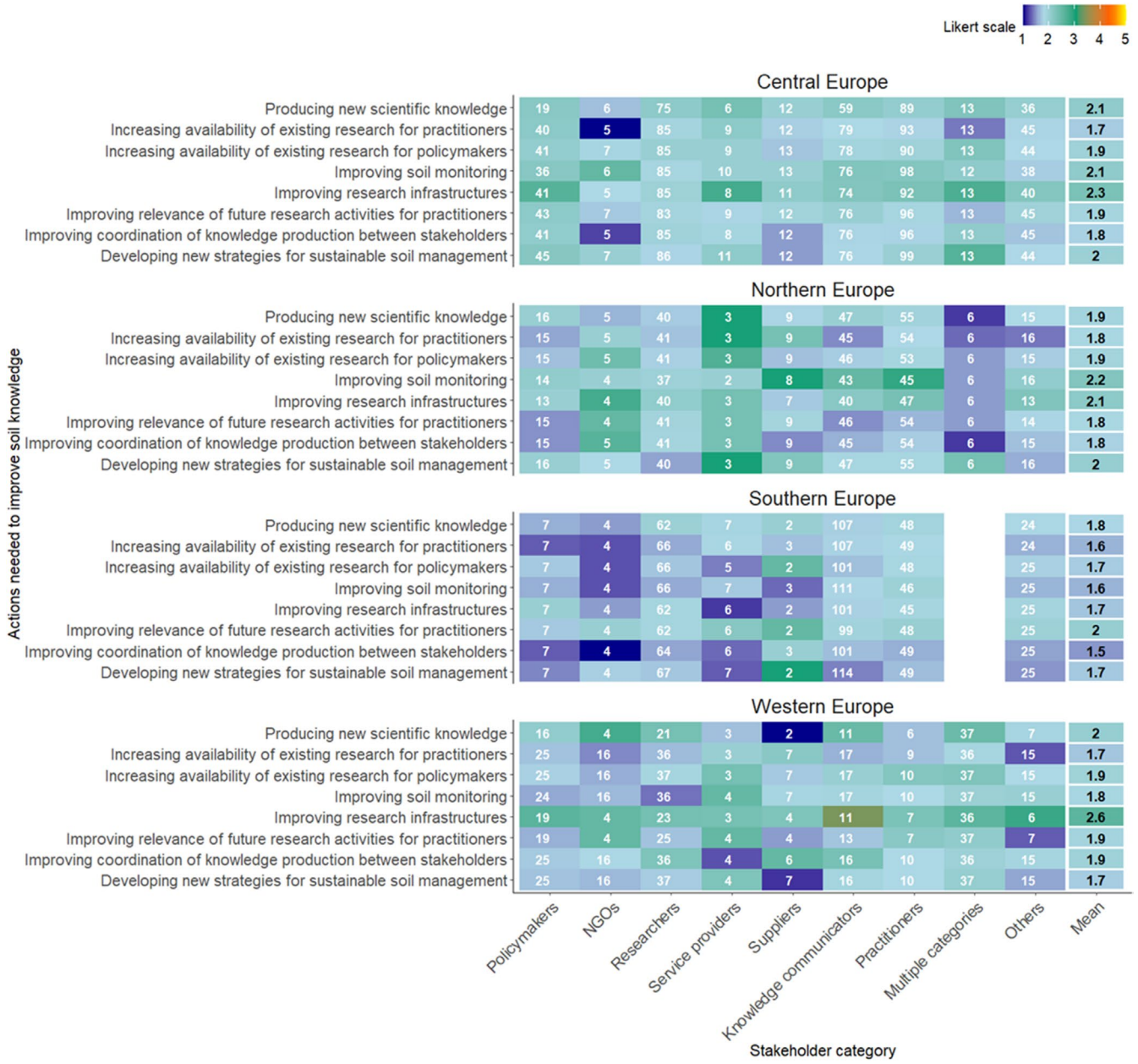

FIGURE 5 | Weighted mean of the responses to the question: How important are the following tasks to improve the general state of soil knowledge in your country. The colour gradient reflects the Likert scale ratings, ranging from 1 = highly important (dark blue), 2 = important (light blue), 3 = neutral (green), 4 = somewhat important (orange), and 5 = not important at all (yellow), cells with missing data (white). White numbers within each tile show the count of respondents per stakeholder category. Black numbers within the tile show the mean of importance across stakeholder categories.

and 'lack of relevant technology' in Northern Europe, 'lack of knowledge communication' in Western Europe (although the sample size was $n < 5$ in Central, Northern, and Western Europe). Lacking knowledge and communication was defined as a major barrier for better management and understanding of soil biodiversity.

3.1.4 | Changes to the Conditions for Sustainable Soil Management in the Past 5 Years

Across all regions of Europe, stakeholders expressed that conditions for sustainable soil management did not improve over the last 5 years (Figure 7). Policymakers, researchers, knowledge

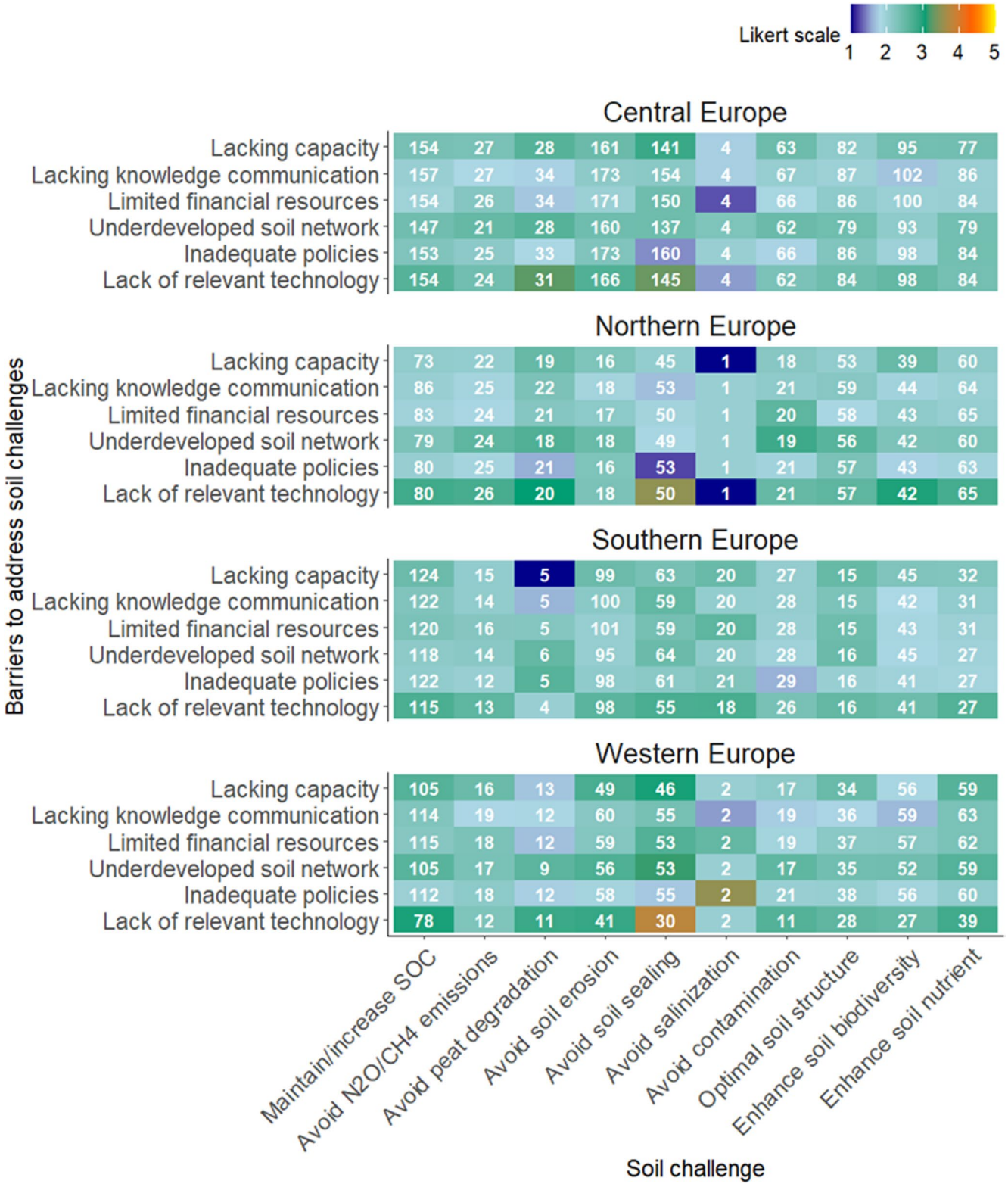

FIGURE 6 | Weighted mean of responses to the question: 'Please indicate the importance of removing various barriers in relation to the three main soil challenges you have identified'. The colour gradient reflects the Likert scale ratings, ranging from 1 = highly important (dark blue), 2 = important (light blue), 3 = neutral (green), 4 = somewhat important (orange), and 5 = not important at all (yellow), cells with missing data (white). White numbers within each tile show the count of respondents.

communicators, and practitioners were generally optimistic about improvements in European soil policies, except in Western Europe, where researchers and knowledge communicators were less positive. In Southern Europe, NGOs had the highest agreement with improvements. In Western Europe, policymakers were more inclined to agree.

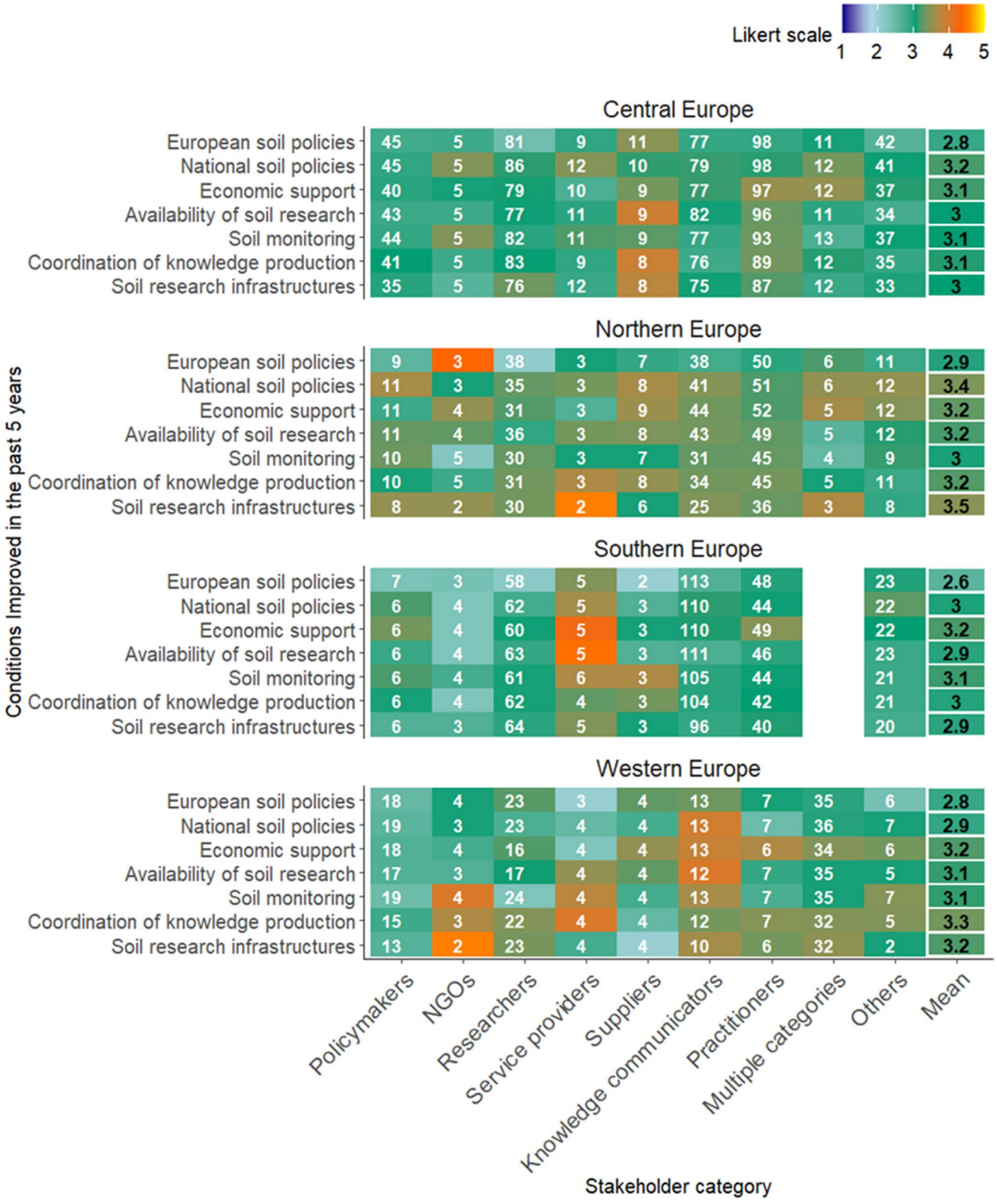

FIGURE 7 | Weighted mean of responses to the question: 'To which extent do you agree with the following statements regarding the changes to the conditions for sustainable soil management in the last 5 years?' The colour gradient reflects the Likert scale ratings, ranging from 1 = highly agree (dark blue), 2 = agree (light blue), 3 = neutral (green), 4 = somewhat agree (orange), 5 = disagree (yellow), cells with missing data (white). White numbers within each tile show the count of respondents per stakeholder category. Black numbers within the tile show the mean of importance across stakeholder categories.

In general, there was a lower level of agreement with improvements for all listed conditions by most of the stakeholder categories in Northern Europe, and by Suppliers and Practitioners in Central Europe and Southern Europe. In Western Europe, Practitioners, Knowledge communicators, and Researchers were less positive particularly about advancements in economic support, knowledge coordination, and soil research infrastructure.

National soil policies were rated less favourably in Central and Northern Europe compared to European-level policies. For the other listed conditions, stakeholder perceptions varied, particularly in Southern and Western Europe.

3.2 | Perspective on Transitioning to Sustainable Soil Management—Workshop

3.2.1 | SWOT Analyses to Identify Risks to Sustainable Soil Management

The analysis of Strengths, Weaknesses, Opportunities, and Threats (SWOT) revealed nine critical topics for addressing the most important soil challenges across the participating countries: economy and labour, education, environment, farmer perceptions, governance, knowledge, methods and practices, networks, and system (Figure 8). Regional differences emerged in the number of comments per topic and how topics were classified as strengths, weaknesses, opportunities, or threats, offering insight into stakeholder perceptions of sustainable soil management. Overall, Northern and Western Europe had more comments across all SWOT factors than Central and Southern Europe (Figure 8).

Some topics lacked comments across all four SWOT factors. For instance, no Threats were identified for networks in any regions, or for education, except in Western Europe. Similarly, Threats were absent for methods and practices in Southern Europe and farmer perceptions in Western Europe. Opportunities related to farmer perceptions were not noted in any region, nor for systems in Southern Europe. Conversely, a larger proportion of comments classified as Weaknesses and Threats were on the topics of systems, governance, networks, methods and practices, environment, economy and labour, and knowledge across regions—except for knowledge in Central and Southern Europe.

Grouping insights from all participating countries enabled a broader analysis of the components (Figure 9). The following list synthesises the relative importance of the identified topics and the themes involved, organised in descending order, highlighting key risks (Weaknesses and Threats) and assets (Strengths and Opportunities) that can impact sustainable soil management:

a. *Environment*: Comments in this category primarily identified threats related to climate change and soil degradation, including soil erosion, compaction, structural loss, salinisation, contamination, biodiversity loss, and soil sealing. Weaknesses comments were also centred on climate change concerns (e.g., difficulties of practices by farmers to adapt or mitigate climate change impacts or to fulfil climate change policy requirements). However, soils were seen as having the potential to enhance climate adaptation and mitigation through improved soil health (Opportunities). Strengths were noted in specific regions or under particular management practices.

b. *Governance*: Comments primarily identified Threats and Weaknesses, with concerns over administrative complexities, bureaucratic hurdles, and inconsistent regulations eroding farmers' trust in the government. Weaknesses included inadequate legislation, unclear frameworks, and political distrust among farmers. Additional Threats included insufficient political ambition, lack of long-term planning, absence of EU-driven national policies, and lack of site-specific policies that consider best management practices. Opportunities were particularly highlighted in Northern, Central, and Western Europe, including hedgerow-planting programs, organic agriculture initiatives, and peat restoration plans. Suggestions included harmonising regulations across soil, climate, fertilisation, and water, as well as rethinking incentives, subsidies, and tax credits to support farmers in the green transition. Strengths were linked to growing policy recognition of soil health, with some countries implementing measures such as erosion reduction (Ireland) and enforcement of soil-friendly regulations (Switzerland).

c. *Economy and labour*: This was the third-largest topic, with comments primarily categorised as Threats. Key concerns included a lack of incentives and financial viability due to unstable markets for sustainable cropping systems (e.g., agroforestry, mixed cropping) and profitability challenges. Weaknesses identified included insufficient financing, inadequate compensation for soil management changes, leased land issues, and lack of financial models. Financial uncertainty and pressure on farmers were seen as both a Weakness and a Threat to sustainable soil management. The high cost of inputs, particularly mineral fertilisers, was noted as an Opportunity to promote sustainable practices. Business models that add value to sustainably produced food through cooperatives and improved value chain communication were also highlighted as key Opportunities.

d. *Knowledge*: Comments on this topic were seen both as Weaknesses and Threats. Weaknesses included knowledge gaps, lack of soil data, observation systems, and biological indicators, as well as insufficient field-level data and trade-off information of relevance to the science-policy-practitioner nexus. Misinformation and non-science-based communication were also noted. Threats involved the absence of soil data and methodologies at the national level, weak research coordination, and scientific uncertainties about soil health practices (except in Northern and Western Europe). As Strengths, an increased quantity and quality of advice, research, and peer exchanges were highlighted. Opportunities included a few comments on growing societal awareness of soil's importance.

e. *System*: This topic was primarily seen as a Weakness, with concerns over the lack of a holistic, long-term perspective, low awareness among stakeholders, and inadequate

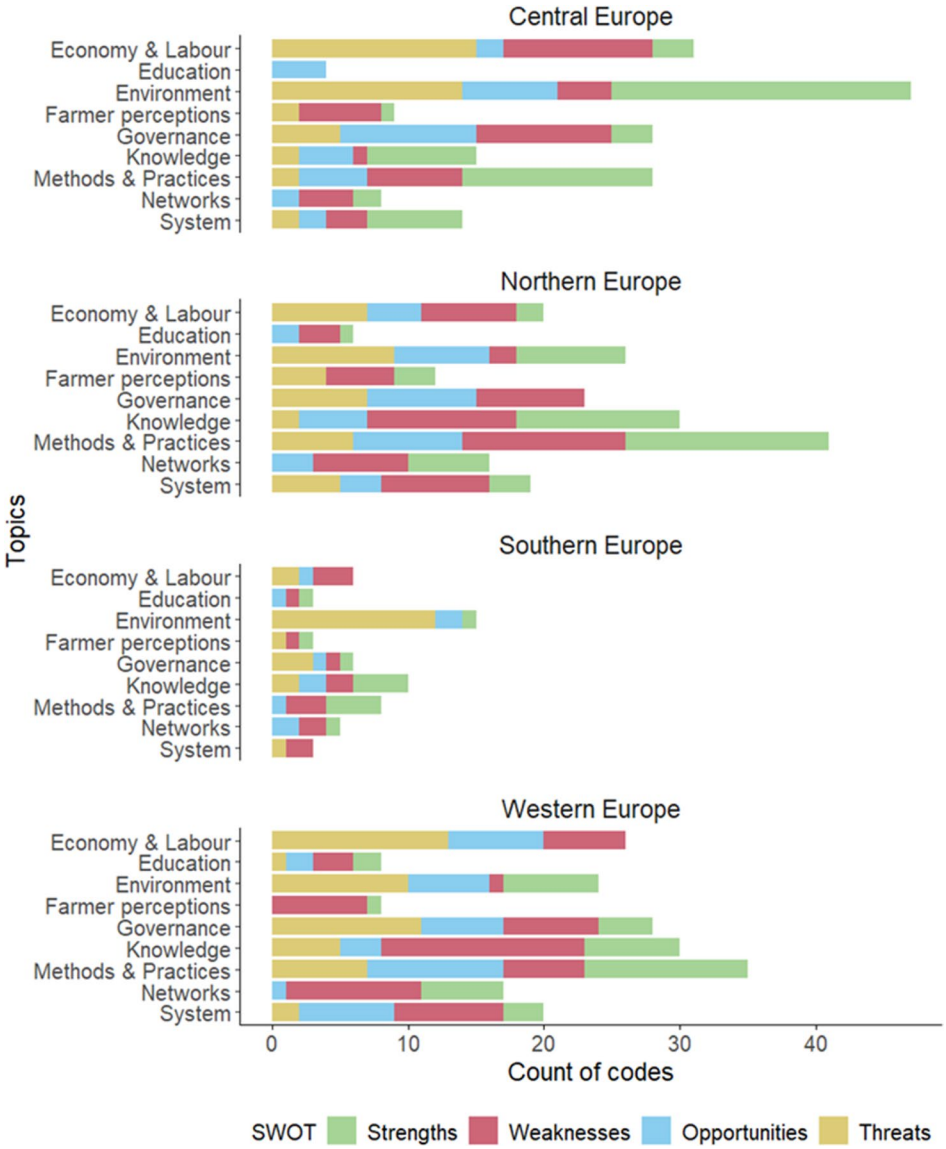

FIGURE 8 | Number of the Strengths, Weaknesses, Opportunities and Threats (SWOT) analysis codes related to soil management in 24 countries of the EJP SOIL consortium grouped by region. Southern Europe in the context of this synthesis includes Turkey. Codes represent single comments identified from the focus group discussion. Topics (displayed on the y-axis) encompass multiple themes, forming broader areas for analysis. Codes referring to the same theme were grouped per country, so the number of reported comments does not correspond to the total unique codes.

systems for managing environmental changes. Threats and Weaknesses included challenges to sustainable land management due to ownership issues; for example, private family farms take care of soil conditions, as land is transferred to successors, while leasing of agricultural land or ownership of land by large companies as a business/investment option can lead to exploitation of land resources. Other Threats were societal resistance to change, rural–urban disconnections, and an overemphasis on high-yield crops. Opportunities focused on ecosystem co-benefits such as increased soil organic carbon, carbon sequestration, nitrogen supply, biodiversity, and pest suppression, as well as promoting soil health narratives to address environmental and social drivers of soil degradation.

f. *Methods and practices*: This topic had more Threats than Weaknesses, and more Strengths than Opportunities. Weaknesses included limited or region-specific digital technology use, infrastructure, research implementation, and inadequate indicators. Threats included competing interests, such as carbon farming vs. nitrous oxide emissions, land use vs. industry impacts on land prices, and soil vs. water quality trade-offs. Strengths included advanced digital infrastructure, technology use, and soil monitoring in some countries. Opportunities focused on holistic, well-communicated soil health frameworks.

g. *Farmer perceptions*: This topic was equally seen as a Threat and a Weakness. A key Threat was the risk of reduced yields pushing farmers towards soil-degrading practices to meet contracts. Weaknesses included administrative and economic burdens, farmers' resistance to change, and lack of time. Opportunities were focused on new agricultural approaches (e.g., agroecology, regenerative agriculture) for soil preservation, bottom-up capacity building through advisory services and pioneering farmers, and broader

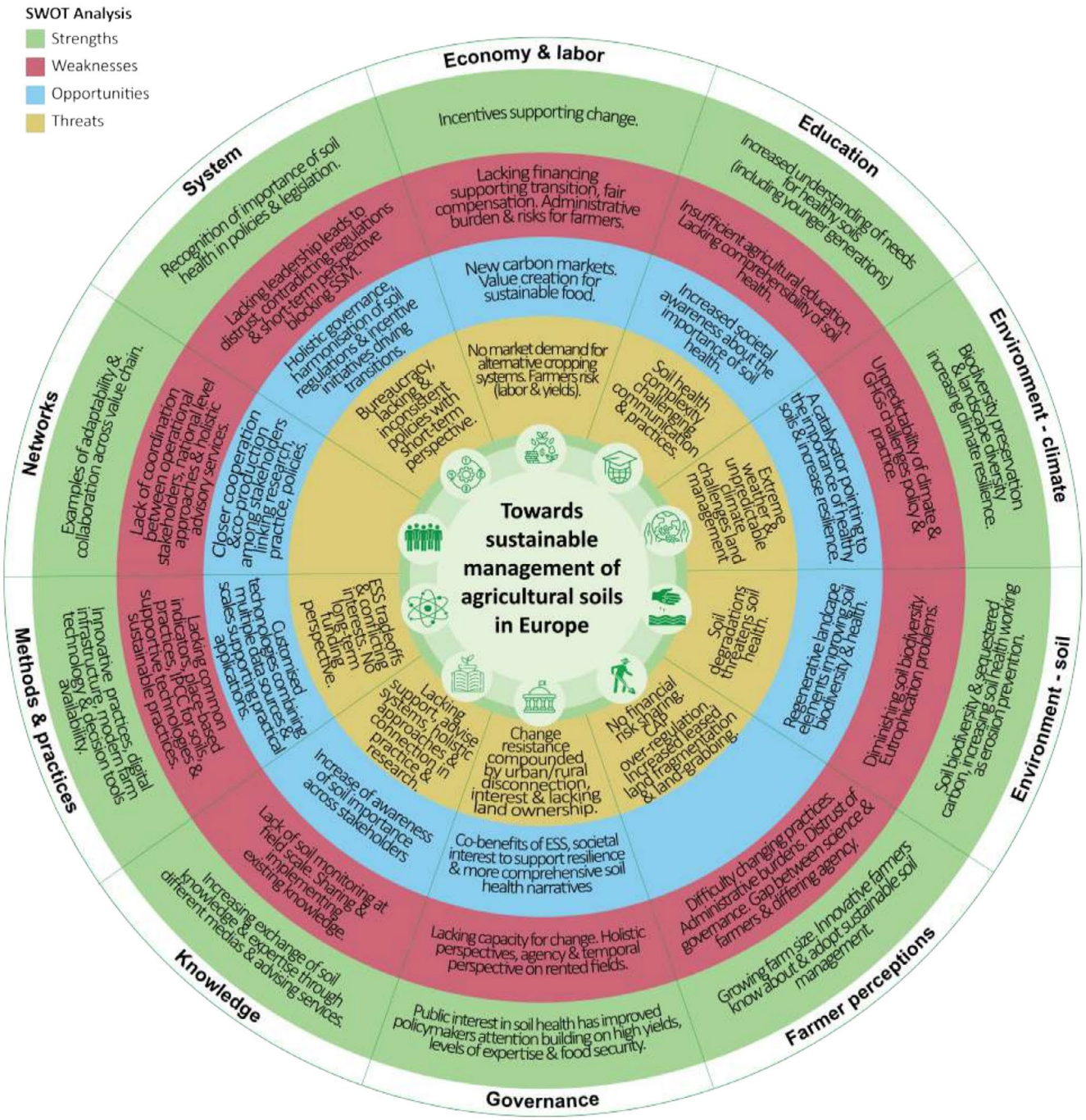

FIGURE 9 | Summary of SWOT (Strengths, Weaknesses, Opportunities and Threats) analysis related to soil management in 24 countries of the EJP SOIL consortium. The outer white sections represent topics, and the main underlying themes are organised in rings by Strengths (green), Weaknesses (red), Opportunities (blue) and Threats (yellow). CAP: common agricultural policy; ESS: ecosystem services; GHGs: greenhouse gases; SSM: sustainable soil management.

stakeholder involvement to support farmers in overcoming financial and technological barriers.

h. *Networks*: Negative comments on this topic were primarily classified as Weaknesses, with concerns over limited collaboration and knowledge exchange between farmers, scientists, and policymakers (except in Northern and Western Europe), and poor communication of soil health and soil biodiversity knowledge. Opportunities focused on networks bridging research and practice (e.g., Horizon Europe Mission 'A Soil Deal for Europe', SoilHUB, Living Labs).

i. *Education*: This topic had fewer negative comments, classified as Weaknesses. These included themes such as insufficient agricultural education and lack of comprehensive information on soil health. Opportunities comments focused on raising societal awareness, building new knowledge with farmers, and educating soil experts to support sustainable soil management.

3.2.2 | Stakeholder Perceptions on Pressing Knowledge Gaps and Desired Actions to Address Key Soil Challenges—A 10-Year Perspective for Europe

The majority of participating countries perceived environment, knowledge, and economy as key topics with significant knowledge gaps.

a. *Environment*

The comments categorised under the environment topic covered a wide range of themes, with stakeholders identifying 11 key environmental areas (Appendix C, See Environment Topic for 11 themes and definitions). Particular emphasis was placed on soil biodiversity, soil health and fertility, soil water, and soil organic carbon, highlighting a practice-oriented perspective.

Stakeholders underscored the need for deeper insights into soil biodiversity, including benchmarking ecological interactions and assessing sustainable agricultural practices. They called for clear guidance on improving and measuring soil biodiversity. Another key concern was the need to better understand the link between SOC and its effects on soil fertility, yield stability, and water retention, with a focus on providing farmers with measurable benefits of increasing soil organic carbon. The role of organic matter in enhancing soil quality and supporting ecosystem functions was highlighted, along with the importance of soil and water conservation practices, such as no-till and minimum tillage.

b. *Knowledge*

Several interconnected themes within the Knowledge topic highlighted the need for fundamental soil research and effective knowledge sharing, application, and development. In particular, the theme of scientific knowledge emphasised foundational research, soil health indicators, and harmonised research efforts. Knowledge transfer was also key, as stakeholders stressed that generating knowledge alone is insufficient—it must be accessible and actionable for farmers, practitioners, and policymakers. Stakeholders were also asked to identify key initiatives to overcome barriers to sustainable soil management. Unlike knowledge gaps, the most discussed topic across regions was knowledge, followed by Economy and labour, highlighting a strong preference for knowledge-based interventions. Priorities included knowledge transfer, scientific research (data, analysis, monitoring, indicators, and harmonisation), co-production, and effective dissemination and capacity-building.

c. *Economy and labour*

Economy and labour, while a lower priority, focused on economic drivers and viability factors (incentives and financing, market and profitability). Stakeholders emphasised the need for financial support for long-term soil conservation, incentives, and viable short- and long-term financing mechanisms.

d. *Divergences across European regions*

European regional differences were evident in less-discussed topics. Notably, in Northern and Western Europe, the System emerged as a key focus for future soil sustainability efforts. These regions prioritised a holistic, systemic approach that integrates diverse perspectives to address soil challenges, emphasising long-term planning, sectoral cooperation, ecosystem services, and socio-economic barriers. In Western Europe, stakeholders highlighted the importance of Governance, which included responses related to the regulation and control by public authorities of various issues, ranging from soil practices and knowledge to public support of farmers, power division, and the harmonisation of national initiatives. Stakeholders suggested simplifying bureaucracy and increasing efficiency. In Central Europe, stakeholders emphasised investing in Education to raise soil awareness among farmers, practitioners, schools, and society. They also recommended developing innovative methods, including practical implementation and technological advancements.

4 | Discussion

In this paper, a diverse group of stakeholders from 24 European partner countries of the EJP SOIL programme have provided their insights on soil challenges, highlighting the most pressing research needs and priorities for sustainable soil management at both regional and national levels.

In this assessment, stakeholders included policymakers, NGOs, researchers, service providers, suppliers, knowledge communicators, practitioners, and others. However, some countries lacked representation from certain stakeholder categories, and not all European countries were included, potentially resulting in additional challenges and knowledge gaps specific to national contexts, as noted by Thorsøe et al. (2023) in their analysis of data collected during the first year of the EJP SOIL programme. In contrast to Thorsøe et al. (2023), at the time of this consultation, National Soil Hubs had already been established in countries participating in EJP SOIL, which fostered stronger interactions with national soil stakeholders. This study involved this broader and more diverse group of stakeholders, including farmers (practitioners), who participated in discussions across most countries.

4.1 | Prioritising Key Soil Challenges for Future Soil Research in Europe

In the present study, increasing/maintaining SOC was highlighted as a central soil challenge across Europe, necessitating further research efforts. This widespread perception of SOC was also highlighted in the first year of the EJP SOIL programme (Thorsøe et al. 2023; Vanino et al. 2023) and aligns with the current European political priorities (EC 2021b). In recent years, extensive research has been conducted on SOC (e.g., Chenu et al. 2019; Don et al. 2024; Wiesmeier et al. 2019), and several initiatives have been developed to increase SOC storage and understanding of SOC dynamics (e.g., EC 2021a; European Union 2024). The consistent prioritisation of SOC by stakeholders closely aligned with initiatives such as the EU Mission 'A Soil Deal for Europe', which underscores a strong mandate for policy makers to maintain and expand investments, as well as to design targeted incentives that promote sustainable SOC management. Such alignment not only supports existing strategies

but also highlights emerging research needs to strengthen soil health across Europe. However, the present findings highlight the importance of sustained comprehensive research on SOC, alongside more effective communication of knowledge to improve the adoption of strategies for increasing and maintaining SOC. Beyond SOC, stakeholders identified soil sealing and soil erosion as critical research priorities for future soil sustainability efforts across Europe.

This differed from the consultations in the first year of the programme (Thorsøe et al. 2023; Vanino et al. 2023), which involved fewer stakeholders and less diversity. By collecting and analysing survey data based on stakeholder type, this paper also showed divergences in perspectives on soil challenges, actions, and barriers to sustainable soil management that varied not just by European regions (and countries) but also by stakeholder type. Thus, research projects with an integrated, context-specific focus are needed, as soil challenges are influenced by local environmental conditions, land use practices, and socio-economic factors.

To address regional priorities effectively, soil research should focus on the development or selection of soil indicators tailored to specific regional contexts. Prioritizing the selection of such indicators is a critical need. It can, for instance, be used to guide the implementation of place-based monitoring systems aligning with the proposed Soil Monitoring Law (EC 2023).

As noted by Techen et al. (2020), the identification of soil research challenges from the perspective of agricultural management facilitates cooperation between key actors, which is essential for sustainable agricultural production.

4.2 | Strengthening Communication: Divergent Soil Stakeholder Perceptions

To address governance, communication, and funding barriers related to pressing soil challenges across Europe requires an integrated approach. These integrated approaches include enhancing advisory systems to provide local-specific guidance to farmers; adopting holistic approaches that integrate long-term management strategies with environmental, economic, and social considerations; and bridging gaps between research, practice, and policy by creating platforms for knowledge exchange and fostering stronger stakeholder engagement in decision-making.

Aligned with Thorsøe et al. (2023) and Vanino et al. (2023), stakeholders in most countries prioritised research results accessibility for stakeholders, including policymakers, and improved coordination between all stakeholder categories as critical needs towards sustainable soil management. Cimpoiasu et al. (2021) additionally highlight better communication by soil scientists with other stakeholders, including the importance of dialogue between soil scientists and stakeholders, and especially practitioners, to disseminate science-based solutions to soil challenges. These findings reveal persistent communication gaps, particularly regarding the prioritisation of barriers and actions among different stakeholder categories.

One key limitation identified by many workshop participants was the lack of communication between researchers and end-users as a major limitation to the development and adoption of sustainable soil management practices. Similar concerns have been highlighted in the literature, where a disconnect between scientific objectives and the practical needs of end-users has been noted (Cimpoiasu et al. 2021; Ingram et al. 2016). One key action is to strengthen communication between academics, policy, and practice already at educational levels, as proposed in studies of soil science in higher education and future needs of capacity (Villa et al. 2025; Veenstra et al. 2024). Additionally, as divergence between stakeholder perceptions varied by region, particularly in Northern and Western Europe, these findings underscore the need for tailored communication strategies and stakeholder-specific programs to ensure effective knowledge transfer and engagement across a wide and diverse group of European stakeholders.

4.3 | Overcoming Governance, Communication, and Funding Barriers

Several barriers to climate-smart and sustainable management of agricultural soils were identified in this study, including inadequate policies, inconsistent governance, poor knowledge transfer, and limited financial resources that hinder long-term investment. Practitioners identified economic barriers as a key limitation to implementing sustainable soil management practices (Strauss et al. 2023). Stakeholders in the workshops raised concerns about governance challenges, particularly the lack of consistency and clear targets affecting economic feasibility. They also highlighted deficiencies in data sharing, education, and farmer engagement, which could support overcoming key barriers.

To overcome barriers in communication, it is essential to disseminate findings using methods and outlets that are well-established and trusted by the target stakeholder group. For most groups, these would not be scientific publications but instead newspapers, practitioner journals, specialised magazines, websites, or social media platforms (Rust et al. 2022). Farmers, in particular, rely on fellow farmers or local agricultural advisors as trusted sources for information (Wood et al. 2014; Alexopoulos et al. 2021). To effectively engage this group of stakeholders, researchers need to adopt more end-user relevant dissemination strategies (Reed et al. 2014; Cvitanovic et al. 2016; Mason et al. 2023).

Our findings could also be understood as a call to soil scientists to take a more proactive communication role, addressing governance and funding barriers. However, it also challenges the traditional academic model, suggesting that effective soil research should not only be assessed for its scientific rigour but also by its societal impact. These tasks go beyond the traditional scope of soil research, towards improving the accessibility of research for other stakeholders or facilitating a change in soil management practices. One crucial step would be to enhance the participation of all relevant stakeholders, particularly farmers, for instance by involving them earlier in the research process, possibly even during the conceptual stage (Reincke et al. 2020).

Farina et al. (2021) identified similar barriers, such as inadequate communication, inconsistent terminology, and poor data

sharing. This reinforces the need for initiatives such as Living Labs and Lighthouses within the Mission 'A Soil Deal for Europe' (EC 2021a), which are expected to make an important contribution in closing knowledge and communication gaps, particularly through better societal education, strengthening Agricultural Knowledge and Innovation Systems, and other open-innovation, co-creative, and co-learning approaches like agroecological living labs (Potters et al. 2022; Rastorgueva et al. 2025). Prior research similarly emphasises that inclusive engagement helps align scientific goals with practical needs by enhancing the credibility and relevance of evidence for end users (Ingram et al. 2016). Our multi-stakeholder analysis hence provides potential inputs for national and European areas of soil research, particularly for Living Labs and Lighthouses projects focused on sustainable soil management. Additionally, these insights align with international efforts, such as the Coalition of Action for Soil Health (CA4SH), launched in 2021 as part of the United Nations Food Systems Summit. This initiative advocates for multi-stakeholder action to guide and catalyse public and private investments in soil health.

4.4 | Towards Integrated and Future-Oriented Strategies

4.4.1 | Progress and Challenges for the Implementation of Sustainable Soil Management Strategies

Stakeholder responses to what constitutes soil management improvements under the EJP SOIL programme were mixed. While stronger European and national policies and improved research accessibility were acknowledged, unmet needs varied across regions and stakeholder groups. Lange et al. (2015) also found that in Northern Germany, sustainable land management perceptions varied greatly between stakeholder types. And while sustainable farming practices can provide financial advantages for farmers, they may also result in increased time and labour requirements, the need to replace equipment and tools, and reduced crop yields, which can lead to economic setbacks (Van der Ploeg et al. 2019). Other reflections underscored the need for more precise and actionable methods to monitor and improve soil health over time. Additionally, ensuring consistent and comparable data across regions is essential for developing more coherent and effective place-based strategies.

One goal of this study was to support identifying future priorities for agricultural soil research. When applying a 10-year perspective, stakeholder discussion groups highlighted the significant potential for enhanced coordination among stakeholders to identify and address sustainability challenges across Europe. Co-developing insights with diverse stakeholders can build trust, improve decision-making, drive future policy actions, and encourage commitment.

From our findings, the main priorities for adopting sustainable soil management practices in Europe fall into four areas: environmental management, economic and social sustainability, governance, and knowledge and innovation. Addressing these challenges requires diverse engagement strategies, coherent policies, and comprehensive methods that consider all parts of a system working together to overcome barriers, enhance education, and support farmers.

Therefore, increased stakeholder coordination and increasingly place-based strategies are needed to address soil challenges. By coordinating knowledge production in place-based contexts, soil research infrastructures can better support availability of soil research results, soil monitoring, and promote appropriate economic support.

4.5 | Policy Implications and Future Directions

In parallel to research advances, the European soil policies have been evolving rapidly. For example, actions on European soil policies have been taken, including supporting and contributing to the Soil Monitoring Law proposal (EC 2023), which sets out to monitor and assess soil health, sustainable soil management, and remediation of contaminated sites. Further, the Nature Restoration Law (EC 2024) was agreed upon in 2024, which sets binding targets to restore degraded ecosystems, in particular those with the most potential to capture and store carbon and to prevent and reduce the impacts of natural disasters.

To advance sustainable soil management, decision-makers must address financial constraints, enhance knowledge communication, and improve policy coherence (Hessel et al. 2022; Piñeiro et al. 2020). Stakeholders highlighted the need for well-designed and non-conflicting policies to guide soil management, alongside funding schemes, targeted financial incentives, and regulatory frameworks to encourage farmers and landowners to adopt sustainable soil practices and greater integration of sustainability principles into agricultural policies. Stakeholders in discussion groups further called for future actions leading to closing the gap between research and practical implementation. For example, by enhancing European Long-Term Experiments and Living Labs, strengthening cross-sector collaboration to support knowledge transfer and co-production, and addressing scientific gaps and investing in technical innovation and capacity building.

Financial support remains essential to adopt sustainable practices in the coming 10 years, as high costs and uncertain returns challenge adoption. Profitability and market conditions will significantly influence the success of sustainable soil management initiatives. Findings from our stakeholder consultations emphasise the need for future research to align practitioners, researchers, and policymakers. Future research projects should focus on integrating research insights with practical applications, ensuring effective soil management strategies across Europe.

4.6 | Limits of Our Study

We acknowledge that the composition of the stakeholder groups has shaped our findings, as some underrepresented groups could be excluded or misrepresented. Such an imbalance can limit the study's effectiveness in informing inclusive decision-making or policy development. However, the relative consistency in responses suggests a broad consensus across stakeholder types, indicating shared concerns and priorities concerning key soil challenges. Nevertheless, we have considered these aspects in our interpretation of the results by prioritizing clarification of different perspectives and exploring underlying perspectives of stakeholders and drivers of change.

5 | Conclusion

This study provides a comprehensive identification of perceived national and European threats to sustainable soil management, offering guidance on how to monitor and address soil challenges. It also highlights potential divergences in perceptions between stakeholder categories, which could guide communication programs and action plans to build trust among stakeholders and improve knowledge flows. Findings thus emphasise the importance of involving all relevant stakeholder groups in shaping future actions at the science-policy-practitioner nexus. Reducing network barriers and fostering co-learning and co-design across stakeholder groups and EU countries are crucial for improving sustainable soil management. As future challenges are expected to be both environmental and social, a more integrated approach will be essential. The adoption of sustainable soil management was perceived to be hindered by economic factors and farmers' perceptions. To overcome these barriers, balancing environmental and societal trade-offs, implementing coherent policies, strengthening market infrastructure, promoting place-based practices, facilitating risk-sharing, and improving knowledge communication are all essential. Ultimately, achieving sustainable soil management will only be possible through a collaborative effort aligned across the science-policy-practitioner nexus.

Author Contributions

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Conflicts of Interest

The authors declare no conflicts of interest.

Data Availability Statement

The data that support the findings of this study are available from the corresponding author upon reasonable request.

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Appendix A

Guidelines and Template for Survey

Survey

The following chapter contains the template for a survey among members of the EJP SOIL National Hubs and additional relevant stakeholders. Please note that the reporting template contains a few additional questions regarding the context of the data acquisition that we ask a national representative to complete, while we need an entry for each of the questions outlined for the survey for the comparative analysis.

Introduction

The text below provides some background to the survey for participants, describing the context of the survey and some general instructions for participants. Please feel free to use and modify as you see fit in your interaction with local stakeholders.

Dear 'Name' (if you have), alternatively just 'Stakeholder'
A sustainable use of agricultural soils is proposed as a way to improve yields, mitigate climate change and minimise the environmental footprint of farming, but changing practice is also challenging for farmers, advisors, input providers and policymakers. To provide a sound knowledge basis for future priorities of research funding and policy initiatives, we kindly invite you to take part in this survey. It seeks to clarify your perspectives on the most pressing soil challenges in relation to knowledge gaps, research needs, and barriers for the implementation of sustainable soil management. Your answers will assist us in proposing relevant interventions to improve the availability and use of knowledge on sustainable soil management in support of the green transition.
You can also include a short statement regarding your national workshop, for instance here.
The survey was developed in the EJP SOIL program. EJP SOIL is a research programme on agricultural soil management (2020–2025) co-funded by the EC and the participating European countries (24 in total). EJP SOIL contributes to develop knowledge, tools and an integrated research community to foster climate-smart sustainable agricultural soil management, you find more information about the EJP SOIL program here.
Please note, your reply will be treated with strict confidentiality. Your reply will only be used for research purposes and your identity will not be disclosed in any form. All data acquisition, processing and storage is carried out according to the General Data Protection Regulation (GDPR) of the European Commission, see further details here 'please add other national or institutional regulation, if relevant'. During and after your completion of the survey, you can always withdraw from the survey. If you do so, your data will be erased. By completing the survey consent to our use of the data for research purposes.
This survey is carried out by 'Name of National partner' and it is divided into four sections, you can expect that it will take approximately 10–15 min to complete. For further information, please contact 'Name of national contact person'.
Your participation is greatly appreciated.
Sign here

Section #1 Background Information (for Stakeholder Survey)

1. Which category of stakeholder do you belong to? (please tick the box that matches your stakeholder category).

- Policymakers
- Research communities
- Research funders
- Educational institutions and agricultural colleges
- Farmers and demonstration farms
- Advisors
- Farmers' organisations
- Agro-industry, supply and retail
- Laboratories
- National science testing and verification centres etc.
- NGOs
- Others

2. On a scale from 1 to 5 to which extent do you agree with the following statements regarding your own knowledge of agricultural soils?

	1 Highly agree	2 Agree	3 Neutral	4 Somewhat agree	5 Disagree	X I don't know
I have a very good overview of agricultural soils in my entire country						
I have a very good overview of agricultural soils in the region where I am based						

Section #2 Status on Knowledge of Sustainable Soil Management in Relevant Environmental Zones (for Stakeholder Survey)

In this section, we ask for your assessment of the knowledge needs in the country. The soil and climatic conditions differ quite a lot across countries, and the knowledge gaps therefore may differ accordingly. Here, we ask you to reflect on your country as a whole, even though some challenges are not found throughout the country.

3. What are in your perspective the three most important challenges to sustainable soil management in your country? (select and rank the three most important soil challenges).

	Most important	Second most important	Third most important	I don't know
Maintain/increase SOC				
Avoid N_2O/CH_4 emissions				
Avoid peat degradation				
Avoid soil erosion (e.g., water/wind/tillage erosion)				
Avoid soil sealing				
Avoid salinisation				
Avoid contamination				
Optimal soil structure				
Enhance soil biodiversity				
Enhance soil nutrient retention/use efficiency				
Other (please specify)				

4. On a scale from 1 to 5, how important are the following tasks to improve the general state of soil knowledge in your country?

	1 Highly important	2 Important	3 Neutral	4 Somewhat important	5 Not important at all	X I don't know
Producing new scientific knowledge on the prevalence of key soil challenges						
Develop new strategies for sustainable soil management						
Improve soil monitoring						

	1 Highly important	2 Important	3 Neutral	4 Somewhat important	5 Not important at all	X I don't know
Increasing availability of existing research for practitioners (farmers)						
Improving the relevance of future research activities for practitioners						
Increase availability of existing research for policy makers						
Improving the coordination of knowledge production between stakeholders						
Improve the research infrastructures						
Other (please specify)						

5. On a scale from 1 to 5, in your perspective how important are the knowledge needs for the following soil challenges within your country?

	1 Highly important	2 Important	3 Neutral	4 Somewhat important	5 Not important at all	X I don't know
Maintain/increase SOC						
Avoid N_2O/CH_4 emissions						
Avoid peat degradation						
Avoid soil erosion (e.g., water/wind/tillage erosion)						
Avoid soil sealing						
Avoid salinisation						
Avoid contamination						
Optimal soil structure						
Enhance soil biodiversity						
Enhance soil nutrient retention/use efficiency						
Other (please specify)						

6. On a scale from 1 to 5 to which extent do you agree with the following statements regarding the changes to the conditions for sustainable soil management in the last 5 years?

	1 Highly agree	2 Agree	3 Neutral	4 Somewhat agree	5 Disagree	X I don't know
European soil policies have been strengthened						
National soil policies have been strengthened						
Economic support for practitioners to adopt sustainable soil management has improved						

	1 Highly agree	2 Agree	3 Neutral	4 Somewhat agree	5 Disagree	X I don't know
The availability of soil research for practitioners has improved						
Soil monitoring has improved						
The coordination of knowledge production between stakeholders has improved						
The soil research infrastructures have been improved						
Other (please specify)						

Section #3: Barriers to Knowledge Development, Availability, and Transfer

7. Please indicate the importance of removing various barriers in relation to the three main soil challenges you have identified. For each soil challenge please rate the importance of removing the following specific barriers on a scale from 1 to 5.

	Most important soil challenge					
	1 Highly important	2 Important	3 Neutral	4 Somewhat important	5 Not important at all	X I don't know
Lacking capacity						
Lacking knowledge communication						
Limited financial resources						
Underdeveloped soil network						
Inadequate policies						
Lack of relevant technology						
Other (please specify)						

	Second most important soil challenge					
	1 Highly important	2 Important	3 Neutral	4 Somewhat important	5 Not important at all	X I don't know
Lacking capacity						
Lacking knowledge communication						
Limited financial resources						
Underdeveloped soil network						
Inadequate policies						
Lack of relevant technology						
Other (please specify)						

	Third most important soil challenge					
	1 Highly important	2 Important	3 Neutral	4 Somewhat important	5 Not important at all	X I don't know
Lacking capacity						
Lacking knowledge communication						
Limited financial resources						
Underdeveloped soil network						

	Third most important soil challenge					
	1 Highly important	2 Important	3 Neutral	4 Somewhat important	5 Not important at all	X I don't know
Inadequate policies						
Lack of relevant technology						
Other (please specify)						

Section #4: Ending

This is the final section of the survey; if you have additional reflections regarding knowledge and use of knowledge on sustainable soil management, or knowledge needs in your country, please provide these in the box below.

1. Other reflections? (Open).

When the survey is complete, results will continuously be published on the webpage of the EJP SOIL programme, which is available here.

'You can add another section with specific questions that are relevant in your national context if relevant'.

Reporting Template

Please find below the reporting template for the exercise. Please add more rows if necessary; if you have many respondents, it may be easier to manage by copying/pasting the template onto an Excel spreadsheet.

	General questions for the reporter	
Introduction	Which country do you report from?	
	Who completed the national report?	(Name for contributor list and e-mail for internal communication)
	Survey type (how was input gathered?)	(Select between: Phone, face-to-face, email survey, other specify)
	Reflections regarding the selection and representativeness of stakeholders?	Open question, max 500 words. Did you manage to include all relevant stakeholders in this analysis or is someone not involved, and which perspective is lacking?

Appendix B

Guidelines and Template for Workshops

Workshop and Discussion—Guidelines

The following chapter describes the guidelines for national workshops. The survey outlined in Section 2 serves as the backdrop for the workshop and initially, we ask that you present the results of the survey for verification and discussion with the members of the national hubs.

Please also note that the discussion that we have outlined below is designed to last for about 90 min. This should allow partners to outline an attractive program for the stakeholders that, for instance, also presents results from internal EJP SOIL projects or other relevant research projects that make the event attractive for participants. The workshop discussion should fall into two parts: initially (1) a presentation and discussion of the results of the survey and (2) a SWOT exercise to identify the most important barriers to the adoption of sustainable soil management.

Presentation and Discussion of Survey Results

Initially present the outcomes of the survey in the forum (5–10 min). This presentation can be done either on the fly if you complete the survey at the venue, or you can circulate beforehand and prepare a presentation of results. Please discuss the following two questions with the stakeholder group (5–10 min):

1. Do they agree with the survey results or do they see other significant soil challenges in the country?
2. How is the regional distribution of soil challenges?

For these questions, please prepare a short summary of the discussions of about 500 words.

Using a SWOT Analysis to Identify Opportunities and Barriers

Subsequently, we ask you to divide the workshop into smaller groups of 6–8 participants for discussion of the strengths, weaknesses, opportunities, and threats (SWOT) of transitioning to sustainable soil management.

We often work with a SWOT methodology in interactions with stakeholders because it is simple and great for discussions, and because it draws some clear distinctions between different elements that are central for decision-makers.

The SWOT analysis distinguishes between four different components that provide an overview of the strategic response to particular challenges (see the illustration below). In the context of the current exercise, it is relevant to use the agri-food system as the boundary of the organisation.

	Helpful	Harmful
Internal	S (Strengths)	W (Weaknesses)
External	O (Opportunities)	T (Threats)

- Strengths and weaknesses: Includes internal aspects that are within influence of the stakeholder and thus may be modified, such as level of collaborations, farming skills and technology, and so on.
- Opportunities and threats: Includes external aspects that are beyond the control of the stakeholder and thus cannot be influenced by decision-making. It includes wider structural aspects like soil type, climate, market trends, legislation, and so on.

There are various ways to collaborate about a SWOT analysis in a group setting, so feel free to adjust according to your local needs and opportunities bearing in mind that the discussion should result in a short report on a set of predefined themes. This is what we recommend to do, but please note that the schedule is indicative:

Introduction

A moderator presents the purpose of the exercise and the structure of the discussion. It is great to work in groups of 6–8 people so that participants have a good opportunity to share their reflections. Therefore, if more participants are attending the session, please divide into two or more groups, and allow time towards the end for joint discussion of the findings. When dividing the group, it can be useful to divide according to stakeholder category (i.e., farmers discuss with farmers, consultants, etc.) and if you have several groups of farmers, then it might be helpful for organic farmers and conventional farmers to be put in separate groups, and also arable/mixed farmers.

Step #1: Identifying Barriers and Enablers (40 min)

- Frame the discussion around the question: 'In your perspective which strengths and weaknesses do you see with respect to addressing the most important soil challenges in your region?' and introduce the exercise.
- Allow participants 3–5 min reflection time initially, for participants to gather their thoughts and write reflections on a note or a post-it. One reflection per post it.
- Always have a facilitator present in the groups to moderate discussions and keep the time to ensure that participants stay on the right track and understand the exercise.
- Go through the SWOT one quadrant at a time, and allow individual participants time to share their reflections. Bring a whiteboard, a printout, or a sheet from a flip-over with the four quadrants of the SWOT, and ask participants to post their reflections when going through the quadrant.
- Towards the end of the first session, moderator and/or participants should group statements that are similar, producing a consolidated set of categories and ranking their 3 most important statements in each quadrant.

Step #2: Strategies to Move Forward

After completing the SWOT, please gather the groups again in plenum (if you have worked with several subgroups) and allow the facilitator of each group to present the outcome of the discussions.

1. What are the most pressing knowledge needs for practitioners to address the most important soil challenges in a 10-year perspective?
2. Aside from filling knowledge gaps, what are the most important initiatives to address the barriers to sustainable soil management?

Your Roles

We suggest that for each group, two persons will facilitate discussion, a moderator and a note taker. (1) The role of the moderator is to ensure that the discussion stays on track, keeps time and facilitates the dialogue among partners. (2) The role of the note taker is to keep a record of the discussion and to summarise key conclusions from the day. If you are short of staff or have many groups, one person may fulfil both roles, but it is good to have two people there as it can be difficult to remember discussions when also facilitating.

Outputs

We need to synthesise experiences from the national engagement events. Therefore, it is important that you keep a record of the activities and outputs of the workshops, taking notes, photos of the whiteboard/flip-over, etc.

A short national report based on a joint template will be developed that synthesises your experiences gathered. If you plan that farmers should be more involved in the project in later stages, it may be useful to provide some sort of summary of discussions as feedback to your stakeholders or present in newsletter articles, but we have not specified any general format for this.

With a basis in this workshop, we ask that you write a short summary of the discussions, about 500 words for each of the questions outlined above, which will feed into a comparison across the countries. Themes are rather broad and should be relevant for each national hub and the initial discussions with the stakeholders in the project.

Reporting Template for Workshop

Step #1 SWOT analysis	Most important strengths	(Please note and rank the most important categories)
	Most important weaknesses	(Please note and rank the most important categories)
	Most important threats	(Please note and rank the most important categories)
	Most important opportunities	(Please note and rank the most important categories)
	Please summarise the discussions regarding the content of the four SWOT elements	(Please provide a short summary of discussions ~500 words)
Step #2: Strategies	What are the most pressing knowledge needs for practitioners to address the most important soil challenges in a 10-year perspective?	(Please provide a short summary of discussions ~500 words)
	Aside from filling knowledge gaps, what are the most important initiatives to address the barriers to sustainable soil management?	(Please provide a short summary of discussions ~500 words)

Appendix C

Topics and Themes Used to Categorise Perceptions of Sustainable Soil Management

Single ideas or quotes from respondents comments, were grouped into Themes (a category encompassing various related ideas). Themes were grouped into Topic, larger grouping for more comprehensive areas for analysis.

Topic	Theme	Definition
Economy and Labour	Incentives and financing	Financial mechanisms and economic incentives that support or hinder sustainable practices in agriculture
	Market	Market conditions and dynamics influencing agricultural practices, such as demand, pricing, and supply chains
	Profitability	Economic viability and financial returns of implementing sustainable farming practices
	Carbon markets	Markets for carbon farming and carbon credit programs
	Financial models	Developing financially viable business models for the adoption of sustainable soil management practices particularly at the farm scale
	Fair compensation	Fair compensation related to providing farmers with financial support and incentives for adopting costly sustainable soil management practices
	Value creation	Value creation including developing supply chains that provide a premium to farmers that use sustainable soil management practices
	Uncertainties	Related to farmers' risk to changing practices as well as the demographic and geopolitical uncertainties that influence agricultural investments
	Contract agriculture	Tenure of land and its impact on limiting farmer decision-making
	Farmer risks	Lack of farmer financing options and time for the adoption of sustainable soil management practices
Education	Education and training	Initiatives aimed at improving knowledge and skills for sustainable agricultural practices, to practitioners, students, farmers
	Improving education	Educating advisory systems and new soil experts in sustainable soil management
	Social awareness	Educational initiatives aimed at the general public to raise awareness about the critical importance of soil health

Topic	Theme	Definition
Environment	Soil biodiversity	Variety and variability of living organisms within soils
	Landscape biodiversity	Variety and variability of species, ecosystems, and ecological processes within a given landscape
	Carbon farming	Agricultural practices designed to capture and store carbon in soils
	Soil compaction	Problems with soil compaction due to environmental conditions and heavier machinery
	Soil contamination	The presence of contaminants (e.g., heavy metals, and pesticides) in the soil affecting crop yields and ecosystem health
	Soil erosion/degradation	The loss of soil quality and productivity due to factors like wind, water, and poor management practices
	Nutrient retention	Optimising the use of plant nutrients
	Soil salinisation	The accumulation of soluble salts in the soil, which can degrade soil quality
	Soil sealing	The process by which the soil surface becomes impermeable and reduces its ability to absorb water, support vegetation, and maintain biodiversity
	Soil health and fertility	The soil condition (physical, chemical, and biological properties) and ability to support plant growth, maintain biodiversity, and function as an ecosystem
	Soil organic carbon	The carbon stored in the form of organic matter in the soil
	Soil water	The capacity of soil to store and maintain water, as well as the quality of water available for agricultural use
	Eutrophication	Eutrophication problems caused by excessive nutrients leaching from managed soils
	Geographical conditions	Place-based conditions that create favourable conditions for sustainable soil management
	Climate change	Resilience to changes in climate
	Climate adaption and mitigation	Strategies to adjust ag practices to changing climatic conditions (adaptation) and to reduce its impact (mitigation)
	Nutrient management	Management of soil nutrients to optimise crop production and reduce environmental impact
	Soil organic carbon	Maintaining or increasing soil organic carbon
	Soil water (storage, quality)	Water retention and storage in soils
	GHGs emission	Greenhouse gases (e.g., CO_2, methane, nitrous oxide) emitted from agricultural practices and their impact

Topic	Theme	Definition
Farmer Perceptions	Change resistance (Farmer behavioural resistance)	Farmer resistance to changing soil management practices due to perception of additional work and administrative burdens
	Sustainable management	Management practices minimising negative environmental impacts or enhancing soil health
	Farming skills	The skills and practices of farmers to enhance
	Geographical conditions	Farmers perceive various barriers and opportunities for sustainable soil management based on geographical conditions
	Management innovation	Farmers use of innovative soil practices to support sustainable soil management
	Place-based practices	Practices adapted to specific soil conditions
	(Un)sustainable practices	Use of unsustainable soil practices
	Soil perception	Farmers perception of soil health as a valuable and central part of their farming system
	Uncertainties	Farmers uncertainties concerning both their farm system and consequently their soil management
	Farmer agency	The ability of farmers to make decisions about their farming practices and system
	New generation of farmers	New interests of a new generation of farmers
	Land ownership/use	The legal and practical aspects of farmland ownership (how land is used and managed) including the increasing proportion of leased land
	Farmer behavioural resilience	The ability and willingness of farmers to adapt to changing conditions and challenges
Governance	Adequate governance	The involvement by authorities is perceived as adequate to support farmers and soil health
	Bureaucracy	The complex administrative procedures and regulations that may affect the implementation of agricultural policies and practices
	Contradictory regulations	The lack of harmonisation of regulations across topics (e.g., soil, biodiversity, water, climate)
	Distrust	Farmer distrust primarily related to political systems
	Frameworks unclear	Unclear frameworks or not having a clear definitions of sustainable soil management that clarify who is responsible for delivering desired impacts (e.g., landowner, leaser)
	Governance	The structures, processes, and institutions that oversee agricultural practices
	Incentives	Agri-environmental policies or subsidies to support sustainable soil management
	Inconsistent policies	Lack of consistency across policies related to soil management
	Insufficient legislation	Lack of appropriate legislation to support sustainable soil management
	Lacking place-based policies	Lack of policies that flexibly respond to local soil condition
	Land not protected	Agricultural land not being protected from other interests
	Pesticide lobby	The pesticide lobby and pesticide producers as influencers of policies
	Protection laws	The lack of laws protecting agricultural soil
	Time horizon	Insufficient time horizons in policymaking
	Policies	Laws, regulations, and strategies that guide agricultural practices
	Wholesalers and market laws	Political influence of wholesalers and market laws

Topic	Theme	Definition
Knowledge	Deep carbon storage not recognised	Knowledge limitations related to deep carbon storage in the soils
	Exchange (dissemination, peer-to-peer)	Exchange of knowledge includes peer-to-peer and effective organisations and advisory systems that gather farmer information and exchange it with others
	Field biodiversity data (lacking)	Highlights need for highly nuanced field-scale biodiversity data
	Knowledge gaps	Gaps in scientific knowledge broadly and related to biodiversity
	Local data	Lacking local data related to sustainable soil management
	Soil data	Soil data availability or unavailability at decision-making scales
	Soil education	Education and knowledge exchange related to soil
	Soil observation system	Lack of soil observation systems
	Soil research (knowledge generation)	Soil knowledge generation
	Data/Lacking data	Data or lack of data that is coordinated utilisable
	Inconsistent support	Lacking support, technically experienced soil experts and holistic approaches
	Soil information incomprehensible	Soil information currently available is incomprehensible to some stakeholders
	Scientific knowledge	The availability of scientific knowledge to support sustainable soil management
	Disinterest	Disinterest in sustainable soil management across food system actors
	Expertise	Soil management expertise by various stakeholders
	Capacity building	The improvement of skills, knowledge, and abilities of individuals and organisations involved in sustainable agriculture (e.g., practitioners, sectoral experts, farmers)
	Knowledge co-production	The collaborative creation of knowledge across multiple stakeholders
	Knowledge transfer	The process of transferring knowledge and making it actionable, typically from researchers to practitioners
	Knowledge dissemination	The sharing and spreading of specialised knowledge to a broader audience, in a formal and structured way
	Scientific knowledge	Scientific data, analysis, monitoring and harmonisation
	Communication and dissemination	Effective communication and knowledge dissemination

Topic	Theme	Definition
Methods and Practices	Carbon sequestration trade-offs	Trade-offs between carbon sequestration, nitrous oxide emissions, and biodiversity measures
	Change cooperation	Conflicting objectives and competition limiting cooperation
	Digital tools	Digital tools displaying soil data and for decision support
	Farm-level research	Research and information available and applicable for use at the farm-scale
	Frameworks	Mapping and soil health frameworks agreed upon across stakeholders
	Governance support	Governance support related to new ideas and strategies related to methods and practices
	Indicators	Quantitative and qualitative indicators across scale
	Innovation	Practice innovations for sustainable soil management
	Intergovernmental Panel on Climate Change (IPCC) equivalent for soil	Intergovernmental Panel on Climate Change (IPCC) equivalent for soil health, to enhance global research and implementation
	Lacking industry support	Industry support related to sustainable soil health measures
	Land use trade-offs	Trade-offs between agricultural land us and other high value land uses (e.g., urban)
	Lacking long-term experiments	Lacking long-term experiments related to sustainable soil management
	Monitoring	Strategic and harmonised soil monitoring at appropriate scales
	Research	Lack of implementable methods for farmers coming from research
	Scientific knowledge	Need for scientific knowledge to identify sustainable soil management practices
	Small processors	Purchase agreements between producers and processors
	Sustainable management	Novel sustainable practices for soil management
	Technology/Technological knowledge	Utilisation of technologies and technological measures
	Water quality trade-offs	Trade-offs between soil nutrient retention and water quality
	Perennials value	The positive impacts of perennial land cover
	Improve Information-Technology aspects	Enhancing the role of information technology (e.g., data management, digital tools) to support ag practices and decision-making
	Practical implementation	The application of research findings in real-world agricultural practices, by means of in-field experiments and trials over long time periods
Networks	Collaboration	The multi-level and multi-sectoral cooperation and networking between different stakeholders (e-g., European projects)
	Exchange	Exchanges of information facilitated across groups
	Land use	Actors with different land use types in different networks
	Soil biodiversity knowledge	The emphasis on soil biodiversity in actor networks
	Soil health focus	The emphasis on soil health in actor networks
	Science to policy	The translation of scientific research and findings into practical policy recommendations and decisions

Topic	Theme	Definition
System	Change capacity	The ability to create changes within systems
	Co-benefits	Benefits of changes in one system improving conditions in another (e.g., soil health and water quality)
	Disconnection	Disconnections across systems e.g., urban/rural, animal production/society
	Food security	Providing and adequate, sate food supply
	Holistic perspective (lacking)	The integration of different systems and their interests
	Long-term goals (lacking)	Goals for agricultural systems that include long-term goals for sustainable soil management
	Long-term perspective (lacking)	Considering the future and long-term impacts of current policies and practices for sustainable soil management
	Narrative	The perspectives and stories different stakeholders tell in relation to soil health
	Soil suitability	Land suitable for many societal purposes
	Structural transformation	Structural transformations supporting system changes
	Synergies	Synergies across different systems (e.g., food and energy systems)
	Time horizon	Appropriate time horizons for facilitating system level changes
	Ecosystem services assessment	Evaluating the benefits that soil provides to ecosystems and society by quantifying the role of soil in maintaining environmental health and sustainability
	Sectoral cooperation	The collaboration across different economic sectors (e.g., agriculture, environment, energy) to address challenges and create synergies
	Systemic perspective	An approach that views agriculture as part of a larger, interconnected system, considering the interplay between various factors like ecology, economy, and society
	Socio-economic barriers	The social and economic challenges that hinder the adoption of sustainable farming practices, such as poverty, inequality, and lack of access to resources