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SURVEY ARTICLE

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A European stakeholder survey on soil science skills for sustainable agriculture

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Abstract

The European Union's soil strategy for 2030 has set the objective of achieving 'healthy soils' in Europe by 2050. To achieve this ambitious goal, dedicated soil science skills will be needed in the future. This article presents the results of a survey on soil science skills for the future conducted within the framework of the European Joint Program—EJP SOIL. The survey was distributed online in the 24 countries participating in the EJP SOIL. The skills were expressed as having knowledge in particular topics related to soils, practical know-hows or abilities or outcomes of knowledge and know-hows put into action. No significant differences in the importance of soil-science related skills were found between countries or stakeholder categories. The two groups of skills that ranked at the top of stakeholders' concern were '*Having a scientific basis of knowledge on soils and their functioning*' and '*Knowing how to mobilise agronomic drivers to manage and protect soils*'. This means that there is a need for people with an in-depth knowledge in soil science, but also soil scientists with integrated knowledge in agronomy and crop production. Three important findings relate to the knowledge of soil science itself: (i) there is a clear need to develop the knowledge of the biological and ecological functioning of soil; (ii) this should not happen at the expense of a strong general knowledge of the fundamentals of soil science; (iii) future soil scientists should be trained to have a more holistic appreciation of soil rather than be trained as a specialist of a specific aspect of soil science only. Being able to exchange knowledge with farmers, knowing how to assess soil fertility, quality or health and how to improve them are viewed as essential skills for the future. These findings offer a clear path for the evolution of soil science education curricula across Europe.

KEYWORDS
agricultural soils, competences, education, prospective study, soil fertility, soil health, stakeholders

1 | INTRODUCTION

The topic of soil has been back on the European Union (EU) agenda for a few years now. After the failure of the Directive proposal establishing a framework for the protection of soil and its withdrawal by the EU Commission on 24 April 2014, concerns about soils in the EU have gained a new momentum thanks to the dynamics created by the EU Green Deal (Panagos et al., 2022). The concept of 'soil health' is at the centre of the EU soil strategy for 2030 (European Parliament resolution, 28 April 2021, on soil protection (2021/2548(RSP)) - Official Journal of the European Union, 2021b), and a proposal for a new Soil Health Law is currently under preparation by the EU Commission. The EU communication on healthy soils stresses the need for an increased knowledge of soils, as highlighted in paragraph 5 entitled "*we need to know more about soils*" (European Commission communication COM(2021) 699). This is in line with one of the objectives of the Mission 'A soil deal for Europe', which is to "*improve soil literacy in society*" (European Commission, 2021a, 2021b). The literature available from the EU institutions does not say much about the specific skills that will be needed by all the actors that will be involved in accomplishing this ambitious goal of having healthy soils throughout the EU by 2050. The objective of the work presented in this article was to collect information from European stakeholders on the soil science skills that will be needed in the future to implement sustainable management of agricultural soils.

Although there is no consensus on their definition and their measurement (van Loo & Smeijn, 2004), skills have been at the heart of the construction of the European Higher Education Area (EHEA) since the Bologna Process, created in 1999. In its communication COM(2016) 381 entitled 'A new skills agenda for Europe', the European Commission (2016) defines 'skills' in a very broad way as "*what a person knows, understands and can do*". In this article, we have adopted this very broad definition. The Council of Europe defined some basic skills, grouped into eight key competences, in its recommendation of 22 May 2018 on key competences for lifelong learning (2018/C 189/01) (Official Journal of the European Union, 2018). The more recent Council of Europe resolution 2021/C 66/01 gives great importance to digital skills, and to the concepts of upskilling and reskilling as a lifelong educational process (Official Journal of the European Union, 2021a). Three types of skills have been most commonly recognised:

- Technical or specific skills, which are most often at the basis of diplomas and listed in their description,

Highlights

- European stakeholders were surveyed for their views on the soil science skills needed in the future.
- A total of 669 responses were collected from 24 European countries.
- Dual agronomy-soil science profiles are needed, with strong soil science skills.
- Soil science is an interdisciplinary subject and should be taught in a holistic way.

- Transverse skills, which are not specific to a diploma or a qualification, but rather correspond to a level of education (Belchior-Rocha et al., 2022),
- Personal and interpersonal skills (often referred to as "soft" skills), which are nonacademic skills, related to social, behavioural or emotional registers (Andrews & Higson, 2006; Heckman & Kautz, 2012).

In this study, we defined two types of skills:

- Specific skills, related to soil, such as "knowing how to describe a soil",
- General skills, not specific to soil science education, such as written and oral communication.

Further, we attempted to classify the skills according to whether they correspond to:

- The mastering of a knowledge area, such as "having a scientific basis of soil physical functioning",
- An ability, a know-how, such as "knowing how to interpret soil analyses",
- The outcome of knowledge and/or know-hows put into action, such as "improving soil biological activity".

Similarly as in the political agenda, soil is experiencing renewed attention in higher education after years of declining numbers of students and educational programmes. Several studies (Baveye et al., 2006; Havlin et al., 2010) reported a declining trend in soil science higher education at the end of the 20th and beginning of the 21st century. This trend seemed to have levelled out in the 2010s (Diochon et al., 2016). Today, soil science is getting more attention as people recognise its importance especially since the development of the United Nations Sustainable Development Goals (Bouma, 2019; Bouma et al., 2019; Keesstra et al., 2016). A recent synthesis survey of the soil science capacity in Higher Education in Europe, conducted within the framework of the EJP SOIL (Villa Solis et al., 2021), has confirmed a change of trend in job opportunities with an increase in offers over the past 10 years.

In view of this generally favourable trend for soil science, we set up a prospective survey about the soil science skills that would be useful, or even necessary, to support this development in the future (within about 20 years from now). The aim of this survey was to gather and analyse the views of European stakeholders on which soil science skills would be required. Professional profiles based on these skills are discussed on a companion paper (Walter et al., 2024).

2 | MATERIALS AND METHODS

The survey was conducted online using LimeSurvey™ among a closed panel of European stakeholders. In what follows, we present the structure of the survey, the survey management, including the recruitment of participants and the methods used to analyse the data.

2.1 | Survey design and content

The survey was divided into five sections (Figure 1). The first section focused on the characterisation of the participants, including the role of soils in their professional activities. The three following sections were made to gather the stakeholders' views on the soil science skills they considered important for the future. Skills were expressed as having knowledge in particular topics (e.g., knowledge of soil physicochemical functioning) or practical know-hows, abilities or competences to fulfil soil-related tasks (e.g., implementing soil quality indicators and knowing how to diagnose the state of a soil).

In Part I, the participants were asked to provide between 3 and 10 skills that they considered important in the future (open question). Then, in Part II, they were asked to rank 66 suggested skills from 1 (not required) to 8 (essential) with an 'I don't know/no answer' (DK/NA) option. Skills sharing a theme or topic were aggregated into groups as listed in Table 1. In Part III, the participants were asked to select the overall three most important skills from the list of skills they had previously ranked as essential. In Part IV, the objective was to identify future soil science skills related to professional profiles. Here, participants could provide up to three professional profiles and match them with the skills that they had ranked 5 or higher in the previous parts of the survey. Participants also had to specify the required level of studies for each professional profile they suggested. The results in Part IV of the survey are presented in another article in this issue (Walter et al., 2024).

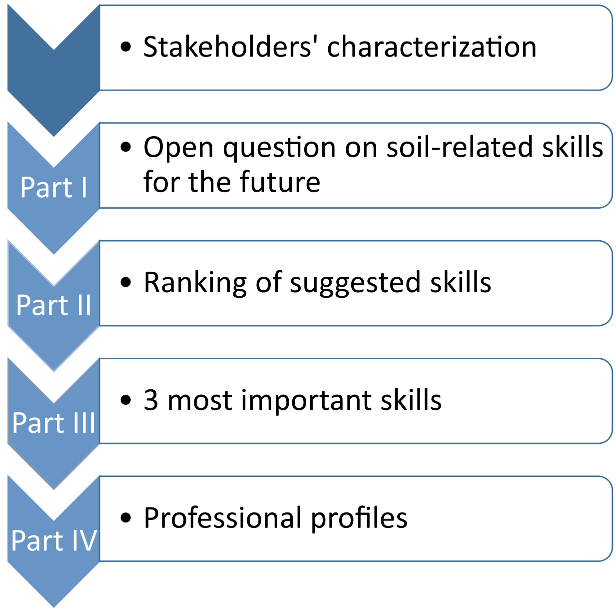

FIGURE 1 Sections of the survey.

TABLE 1 Skill groups suggested in Part II of the survey.

Having a scientific basis of knowledge on soils and their functioning (6)
Know-how about soils (4)
Valuing the ecosystem services provided by soils (4)
Assessing soil quality (2)
Knowing how to mobilise agronomic drivers to manage and protect soils (8)
Proposing innovative strategies for the management of agricultural soils for other purposes (5)
Using soil classification systems (1)
Mapping soils (3)
Accessing soil information (1)
Knowing the legal framework of soils (1)
Knowing how to reconstruct soils and restore the quality of degraded soils (4)
Knowing how to work with people with different backgrounds (4)
Knowing how to assess economic value of soils (2)
Knowing the international context related to soils (3)
Generic skills (10)
Other technical skills (8)

Note: Numbers in parenthesis indicate the number of skills in each of the 16 groups (see Table SM1 in the Supplementary Material for the detailed list of skills).

Participants were able to leave a final statement and contact details for follow-up studies. The latter information was collected in a separate database to ensure anonymity of the responses provided in the main survey.

The survey was created in English and translated into the national languages of the 24 countries participating in EJP SOIL. Translations were verified by the National Hubs of the EJP SOIL. The original English version was visible in all translations, and stakeholders were able to answer in their national language or in English. The English version of the survey was first tested on a panel of French and Swedish stakeholders. Feedback on survey structure and content was integrated into the final version of the survey. The questionnaire was designed to be completed within 30–45 min. Nonetheless, the participants were able to save their responses and carry on at a later time.

The mandatory questions included the stakeholders' professional field, their country of main activity, three responses in Part I and all rankings in Part II. The other questions were optional. Stakeholders were asked for their personal opinions but not as a spokesperson for their institution. The survey can be viewed in the Supplementary Material.

2.2 | Participant recruitment and survey management

Participant recruitment was based on the EJP SOIL stakeholder panels set up by the National Hubs. Efforts were made to balance participation between countries and stakeholder categories. In order to do so, we set a target for the number of participants per country proportional to its number of NUTS 2 regions. However, to take into consideration the representation of smaller countries better, a minimum of 18 invitations per country was set. The target number of invitations per country is listed in Table 2. For some countries, additional stakeholders were contacted directly by the research team or through the National Hubs, exclusively to participate in the survey, in order to reach the target number of invitations.

Stakeholders were recruited as belonging to one of the following categories:

- Farmers, advisors and farmer organisations (practitioners),
- National administrations,
- Local and regional public bodies,
- Research and educational institutions,
- Civil society and general public, including NGOs,
- Industry and agri-business.

In this study, we considered any person involved in the creation and valuation of soil-related skills as 'stakeholders'. This is a broader perspective than restricting the definition of stakeholders to actual end-users of soil skills. In particular, this allows to involve educational staff as stakeholders, as they play a major role in the implementation of soil skills in society.

The survey was distributed through personal email invitations. The email included a short summary of the purpose of the invitation, a link to the survey, contact details of the research team and an opt-out option. By following the survey link, stakeholders were provided with further information about EJP SOIL and the purpose of the survey. Finally, stakeholders had to agree to a consent form prior to accessing the questionnaire. All interactions with stakeholders were performed in their national language. However, participants could change their language options.

The survey was launched on 24 August 2021 and remained active until 27 October 2021. Due to the delay in translations and the ongoing recruitment of stakeholders, not all the participants benefited from the full timespan. The first available languages were English (original), Czech, Danish, Finnish, French, Italian, Latvian and Lithuanian (24 August). Consecutively, Norwegian, Portuguese, Slovak and Slovenian (3 September); Dutch, German, Estonian, Hungarian, Polish, Swedish and Turkish (9 September); and Spanish (20 September) translations were made available.

The survey was performed in accordance with the ethical rules in force at INRAE (see https://www.inrae.fr/en/ethics-scientific-integrity-and-code-conduct-research-projects). Responses were anonymous, although participation was recorded through unique token codes. No link between the list of stakeholders and their corresponding answers was generated. However, through the token system it was possible to monitor participation.

TABLE 2 Target of invitations per country.

Austria	57	Netherlands	71
Belgium	66	Norway	49
Czech Republic	53	Poland	93
Denmark	40	Portugal	49
Estonia	22	Slovakia	36
Finland	40	Slovenia	27
France	136	Sweden	53
Hungary	53	Switzerland	49
Ireland	31	Turkey	132
Italy	110	UK	198
Latvia	22	Spain	101
Lithuania	27	Germany	185
Total			1500

Note: Minimum 18 plus a variable number depending on the number of NUTS 2 regions of the country.

Additionally, reminders to complete the survey were sent to the participants who had neither submitted their answers nor opted out.

Spanish and German stakeholders' participation was managed directly by National Hubs. In order to enable this, Spanish and German surveys were designed as open access surveys (independent from the main survey). It was therefore not possible to track participation in these cases.

2.3 | Data analysis

The survey responses were downloaded from LimeSurvey™ as SPSS data files and comma-separated values (csv) files. A joint database from the three surveys (main survey, German and Spanish) was created, with an identifier field for each participant. All responses that had fulfilled the mandatory questions were included in the analysis. Responses to open questions were translated from original languages into English by the research team with the National Hubs' support when necessary. Original responses were maintained in the database, but analysis was performed on the English translations.

Statistical analysis was performed with SPSS (IBM, 2023) and R (Venables et al., 2023). Additionally, Microsoft Office® was used for data analysis, visualisation and storage. Stakeholders' characteristics were analysed through descriptive statistics and frequency tables.

In Part I, the open list of soil-related skills for the future was analysed semi-quantitatively using thematic coding and then quantifying the code occurrences. A preliminary analysis of the codes that were derived from the data showed similarities to the existing Part II structure of skills and groups of skills. Consequently, Part I was coded with the code tree stemming from Part II structure (Table SM1). Additional skills and groups of skills were created when necessary. Each response was coded to at least one skill and group. The questionnaire allowed 10 responses, and stakeholders provided between 2 and 10 valid responses (responses that were neither words nor phrases were considered nonvalid). Quantitative analysis was performed on the codes, returning as result the number of stakeholders that provided answers related to a particular skill or group of skills. Additionally, subthemes emerged from the qualitative analysis and representative quotes were selected. The analysis focused on the quantification of responses related to a particular skill or group of skills as an indicator of their future importance and on the identification of innovative skills.

In Part II, the ranking of suggested soil-related skills was analysed as categorical data. Frequency tables were created including each ranking from 1 (not required) to 8 (essential) and DK/NA option. Hierarchical Ascending Clustering (or Agglomerative Hierarchical Clustering, AGNES) was performed with the R cluster package to identify clusters of stakeholders providing similar responses (Hastie et al., 2009; Kaufman & Rousseeuw, 2005). A dissimilarity matrix was built based on Gower distance, suitable for categorical variables (where 1 is different and 0 is equal) and clustering followed complete linkages, through which the distance between clusters equalled the distance between the two elements (one in each cluster) that were the farthest away from each other (Gower, 1971). The selection of the number of clusters was done by visually analysing the dendrogram or silhouette graph, which measures similarity of an object within its own cluster (cohesion) compared to other clusters (separation) and visualising the within-cluster sum of squared errors ('elbow method'; Umargono et al., 2020; Wu, 2012). Cluster membership was added to the database, and random forest was used to explore the importance of stakeholders' characteristics in each cluster and the partial dependence of cluster membership (based on response behaviour) on stakeholders' characteristics. For the random forest model, due to the differences in cluster sizes, stratified sampling was used, and the number of trees and the number of variables tested per split were tuned to the lowest out-of-bag error estimation (Janitza & Hornung, 2018).

In Part III, the stakeholders' selection of the three most important skills for the future was analysed quantitatively. Clustering and random forest tests were performed on this data, in the same way as for responses in Part II.

In addition, we conducted specific analyses on the links between the age of the participants and their answers on skills (Part I) using R software's multiple component analysis (MCA). These analyses were done using answers as a unit of account (as one participant could provide several answers on skills and profiles). To have enough answers per age group for the MCA analysis, we merged age groups "under 30" and "30–40", and we dropped skill categories with low frequencies.

3 | RESULTS

3.1 | Participation and response rate

A total of 1386 invitations were distributed through LimeSurvey™. Additionally, the Spanish National Hub reported 70 invitations. It was not possible to track the distribution range from the German hub, because in addition to personal email invitations the survey was sent to two soil science associations as an open access survey.

The main survey managed through LimeSurvey™ registered 547 completed surveys, which represents a response rate of 39%.

Despite the efforts to balance out participation, some countries and stakeholder categories had greater weight. This was the case of members from teaching and research institutions, who had high participation (Figure 2). French responses were also more numerous than from other countries (Figure 3), which was particularly notable for farmers and members of farming organisations (Table SM2). The latter was due to having access to a wider database of potential participants. The survey closing date was extended twice to increase participation. A total of 669 questionnaires were analysed. These included 610 fully completed surveys (including Spain and Germany) and 59 partially completed surveys with the mandatory questions completed. Partially completed surveys which had not fulfilled the mandatory questions were excluded from the analysis.

3.2 | Participant characterisation

The stakeholders' professional self-categorisation slightly differed from the national stakeholder's classification. The highest proportion of participants indicated that they worked within teaching or research institutions (34%, $n = 228$, including partially completed surveys) and the fewest indicated they worked for local public bodies (6%, $n = 41$). The remaining stakeholder categories had similar participation (11%–14%, $n = 75–93$). Some indicated other professional fields (9%, $n = 58$), which corresponded to international organisations, insurance companies, freelance consultancy for the public sector or a combination of consultancy and farming, among others. The participants worked on an international (40%), national (66%), regional (51%) or local (39%) level ($n = 666$, 3 gave no answer). Approximately 39% of the participants were between 40 and 55 years old and 26% belonged to the 55 to 62 age group. Interestingly, 44% of the participants had a PhD and

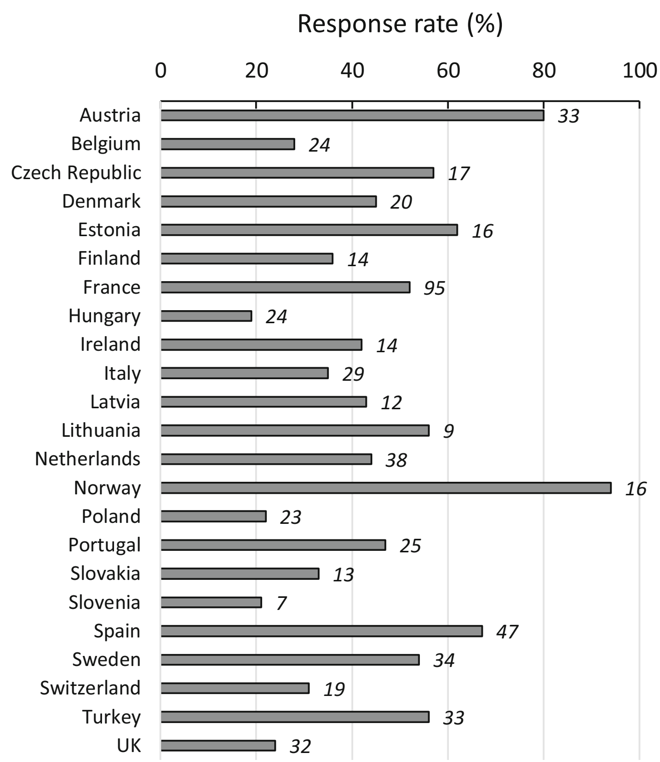

FIGURE 3 Response rates and number of complete surveys per country. Sixteen responses were received from Germany.

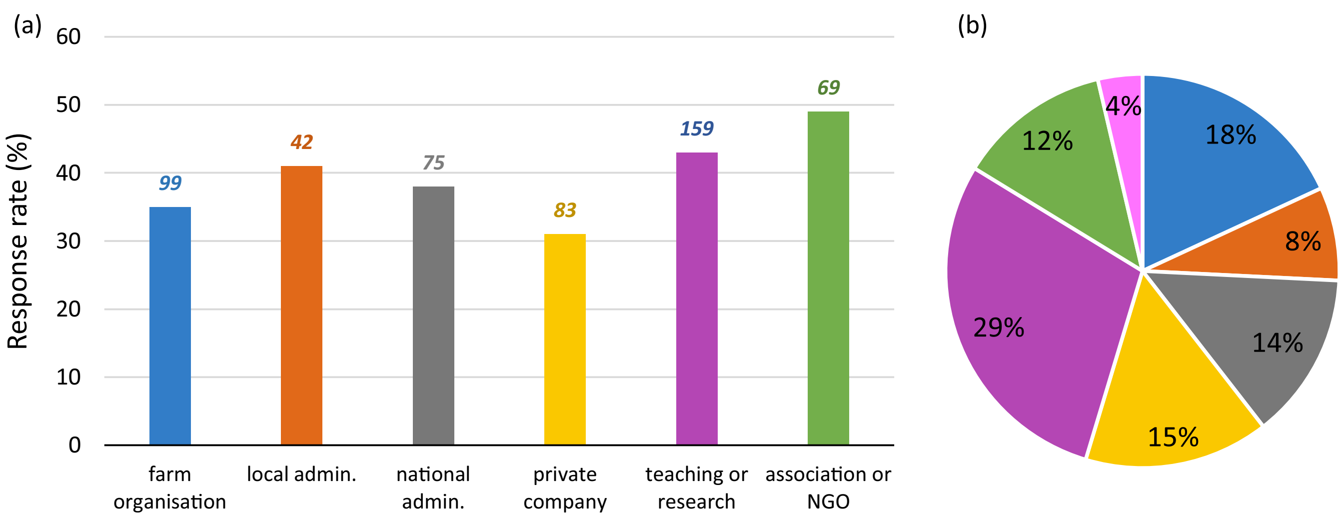

FIGURE 2 (a) Response rates and number of complete surveys according to stakeholder categories. (b) Proportion of each stakeholder category in the complete surveys. EJP SOIL National Hubs provided 20 additional responses (pink in [b]). Data does not include Germany nor Spain.

40% had a Master or equivalent diploma, showing a higher education level than in the general EU population: in 2022, 32% of people aged 25–74 years in the EU had a high (i.e., tertiary) educational attainment level (Eurostat Statistics Explained, 2023). Regarding stakeholders' knowledge on soils, 31% considered themselves experts and another 36% indicated an advanced knowledge on soils, while 30% indicated their knowledge on soils was basic and 2% considered themselves as novice on soils. Approximately 84% ($n = 561$) of the participants' job was directly related to soils. The stakeholders' soil-related jobs were linked to the fields of agriculture and farmland management (86%), environmental issues (64%) and water management (28%), whereas only a few related to urban planning (15.5%). Other jobs related to soils (8%) were in the fields of forestry, teaching, research, climate or soil mapping, among others. Conversely, 13% of the participants' jobs were indirectly linked to soils, and those participants worked in the fields of research, agricultural consultancy and farming, water management, policy, land use planning and lobbying, among others. Moreover, 93% of the stakeholders collaborated with people whose job was directly linked to soils. Approximately 15% (14.5%) collaborated with experts within their own organisation, while 19% collaborated with external professionals and 59% with both, establishing links with research and education institutions, public administrations, associations, farmers, international organisations, etc.

3.3 | What are the most important skills for the future (a priori)?

Responses in Part I to the open question "*In your opinion, what soil science skills will be important in the future?*" provided insights into the stakeholders' initial thoughts as an indicator of the a priori importance of skills and revealed detailed aspects of particular importance in relation to the skills that were presented in a more general manner in the other parts of the survey.

More than 2000 answers (2287) were given by the participants with an average of 3.4 answers per participant. Each answer was assigned to at least one code corresponding to a skill of the set initially anticipated for Part II in the survey (skill ranking). For instance, the response "*knowledge of soil water retention*" suggested by one participant was assigned to the '*Knowledge of soil physical functioning*' skill identified in Part II as part of the '*Having a scientific basis of knowledge on soils and their functioning*' group (Table 1). Some responses were assigned to two or (rarely) more coded skills. For instance, "*knowledge of the behaviour of water and nutrients in soil*" was assigned to both '*Knowledge of soil physical functioning*' and '*Knowledge of soil physicochemical functioning*'. This coding and reclassification ended up with 2997 skills suggested by the participants (4.5 per participant on average). Not all Part I answers could fit the set of skills as anticipated in Part II, therefore, additional skills had to be added. Sometimes, the suggested skill was very general, such as "*knowledge of soil processes*". In that case, a general skill was added to the corresponding group, such as '*General scientific knowledge on soils (characteristics, functioning)*' which was added to the group '*Having a scientific basis of knowledge on soils and their functioning*' for the given example. Twenty-two skills (of which six were of the general type) were added to the initial list of 66 skills and most of them could be placed in existing groups of skills (Table 1), such as '*Preventing nutrient leaching from agricultural fields*', which was added to the '*Proposing innovative strategies for the management of agricultural soils for other purposes*' group. However, an additional group of three skills was created on '*Assessing and preventing soil degradation*'. The majority of the skills corresponded to an ability or a know-how, while 30% related to knowledge and 20% to outcomes resulting from knowledge or abilities put into action (Table SM1).

The skill to which most of the stakeholders gave a related answer (28%, $n = 187$) was '***Knowledge on soils' ecological functioning***'. Other important skills were '***Reasoning cropping systems and plant cover to protect soils***' and '***Controlling crop fertilization***' (27% and 20%, $n = 178$ and 132, respectively). The most frequent skills which a priori responses were related to are listed in Table 3 while the complete list can be consulted in the Supplementary Material. Conversely, Figure 4 represents the dominance of each skill group defined in Table 1 (as a colour) and each skill (as a box) as a percentage of the total skills given a priori by stakeholders ($N = 2977$). Fifty-four skills had a frequency less or equal to 1% and were cited by less than 4.7% of the stakeholders (Table SM1). '***Knowing how to mobilise agronomic drivers to manage and protect soils***' and '***Having a scientific basis of knowledge on soils and their functioning***' were the groups which most of the responses were related to (respectively 27% and 19% of total skills). No particular skill type (i.e., knowledge, ability or outcome) emerged in the top skills listed in Table 3. Proportions of skill types were not different from the global skill list.

Stakeholders who addressed the importance of '*Knowledge on soils' ecological functioning*' emphasised the importance of soil biodiversity, plant–soil interactions and the role of soil in biogeochemical cycling. The ability to "*understand the interactions between living soil organisms (however small)*"[1] needs to be reinforced by "*continu*

[1]Quotations in inverted commas are taken from the verbatim of the Part 1 of the survey.

TABLE 3 Most mentioned skills in Part 1 (open question) of the survey.

	Number of responses	Frequency of the skill (% of total skills)	Stakeholder response rate (% of total stakeholders)
[KN]Knowing soils' ecological functioning (e.g., foodwebs)	187	6.2	28.0
[AB]Reasoning cropping systems and plant cover to protect soils	178	5.9	26.6
[AB]Controlling crop fertilisation	132	4.4	19.7
[KN]Knowing soils' biological functioning (e.g., microbial activity)	120	4.0	17.9
[AB]Agricultural soil management[a]	97	3.2	14.5
[OU/AB]Implementing soil quality indicators and knowing how to diagnose the state of a soil	93	3.1	13.9
[KN]General scientific knowledge on soils (characteristics, functioning)[a]	88	2.9	13.2
[AB]Knowing how to interpret soil analyses	85	2.8	12.7
[AB]Knowing how to interact with experts from other fields in the context of projects involving soils	82	2.7	12.3
[AB]Assessing the organic carbon storage capacity of a soil	80	2.7	12.0
[AB/OU]Evaluating the fertility of a soil and proposing solutions to improve it	77	2.6	11.5
[OU]Enhancing carbon sequestration in soils	77	2.6	11.5
Other 79 skills	1701	56.8	-
Total 91 skills	2997	100.0	-

Note: Skill classification: AB, ability or know-how; KN, knowledge; OU, outcome from KN or AB put into action.
[a]Skills added to the initial list of Part II.

[ing] to work on and disseminate the natural symbioses that soil microbiology teaches us". "*Knowledge on the soil microbiome and its relationship with the phytobiome*" appears as an important skill for the future, as well as "*in-depth knowledge and understanding of plant nutrient and carbon metabolism and its importance in food production and for the environment*".

In relation to '*Reasoning cropping systems and plant cover to protect soils*', stakeholders provided answers that ranged from conventional to alternative agronomic systems, including agroecological, conservation agriculture principles and practices and organic farming. Stakeholders considered those skills important for "*sustainable soil management*" and "*sustainable farming*" or to provide advice to farmers with those objectives. Stakeholders highlighted the importance of being competent in adapting farming practices to local soils and agri-environmental conditions. This is illustrated for instance by the response of an English association/NGO stakeholder involved in policy advocacy for agroecology: "*Knowledge of beneficial agroecological practices specific to soil type and context, to provide advice for farmers*". References to the ability to assess the impact of agricultural practices on soils and modify farming management were also included in this category.

'*Controlling crop fertilization*', from the point of view of the surveyed stakeholders, included both "*knowledge of plant nutrition*" and "*knowledge of nutrients availability in soils*", which were integrated in more global concepts such as "*nutrient management*". Stakeholders also focused on the ability to calculate nutrient balances. The role of organic inputs in crop fertilisation was often mentioned as well as the objective of minimum fertilisation. Crop fertilisation control was also viewed in an integrated manner as "*practical soil fertility management with the dual aim of sustainable crop production and minimised environmental side-effects*" or a "*competence in managing the carbon, nutrient and water stocks of soils*".

3.4 | Ranking the importance of suggested skills

In Part II of the survey, most of the 66 suggested skills were ranked essential, very important or important (8, 7 or 6, respectively) by the participants. Only '*Designing functional artificial soils (Anthroposols)*', and, among the '*Generic skills*' group, '*Accounting*', '*Drawing*' and '*Other languages (than English)*' were ranked less than 6 by the majority of the participants. Among the 12 skills that were ranked essential by the majority of the participants (Table 4), the most valued ones were '*Knowing soils' biological functioning*', '*Evaluating the*

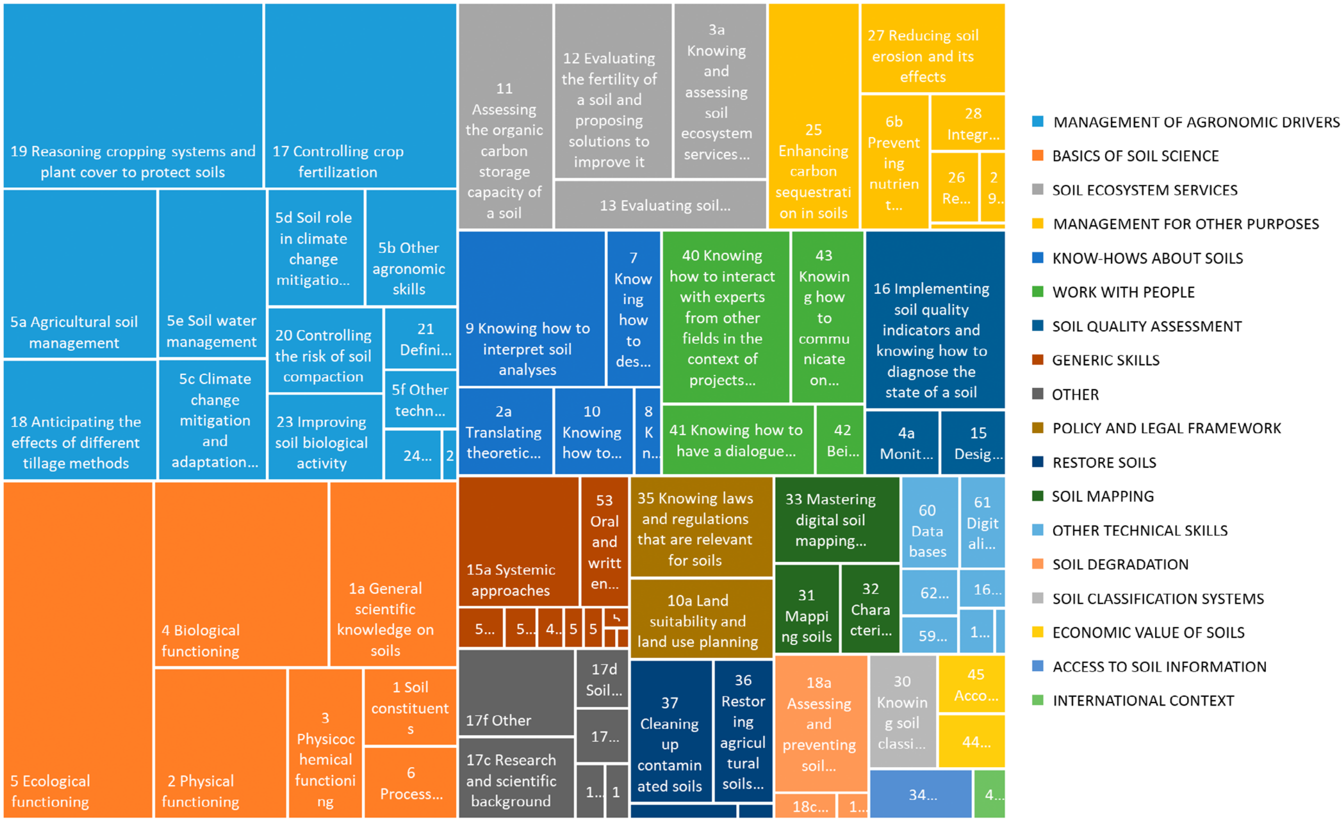

FIGURE 4 Frequency of skills (size of boxes) among total of stakeholders' responses to the Part I of the survey, per group of skills (colours; see Table 1 for the list of skill groups). Numbers before skill names refer to Table SM1 in the Supplementary Material. The complete skill names are available in Table SM1.

fertility of a soil and proposing solutions to improve it' and '*Knowing how to have a dialogue with farmers about their soils*'. The most valued group of skills was '*Having a scientific basis of knowledge on soils and their functioning*' (Table 5) consistently with the results in Part I. Skills related to outcomes resulting from knowledge and abilities put into action were more frequent in the most valued skills than in the global list of skills.

In Part I, stakeholders gave '***Knowing soils' biological functioning***' related answers, such as soil biology, soil microbiology, soil life, etc. Moreover, some of the answers referred to a shift from underestimating soil as dirt, to increasingly valuing soil due to soil life as is indicated in the following suggested skill: "*The ability to understand that soils are not just nutrients in the dirt. Soil is also made up of many micro-organisms*". The answers related to '***Evaluating the fertility of a soil and proposing solutions to improve it***' included references to soil fertility, measuring and assessing soil fertility or maintaining and improving soil fertility. For example, one stakeholder mentioned the "*ability to diagnose soil fertility issues and bring an answer by a strong integrated knowledge of agricultural soil systems*". Whereas the stakeholders' responses categorised in '***Knowing how to have a dialogue with farmers about their soils***' mainly referred to a traditional knowledge transfer or an advisory service from technicians to farmers, in the line of "*to be able to accompany farmers financially and technically towards a transition from conventional farming to soil conservation*".

Stakeholders considered it essential '*Having a scientific basis of knowledge on soils and their functioning*'. Figure 5 shows that 'essential' was the dominant ranking for all skills except for '*Knowing processes of soil formation*', which was ranked 'important'. '*Knowing how to interpret soil analyses*' was the most valued skill from the group '*Know-hows about soils*' (Table 4). '*Assessing soil quality*' skills were also considered dominantly 'essential' (Table 5). Indeed, in Part I many stakeholders suggested that skills related to soil quality or soil health assessment would be important in the future. The "*ability to make a rapid diagnosis of the condition of an agricultural soil*" on-site and by farmers themselves was also mentioned, as well as the need to monitor soil quality. The skills grouped under '*Valuing the ecosystem services provided by soils*' were mostly assessed as 'essential' except for '*Taking into account the importance of soils in terms of cultural services*'

TABLE 4 Most valued skills according to ranking (Part II of the survey).

	Proportion of participants who ranked essential (8)	Proportion of participants who ranked important to essential (6–8)
[KN] Biological functioning	65%	95%
[AB/OU] Evaluating the fertility of a soil and proposing solutions to improve it	62%	96%
[AB] Knowing how to have a dialogue with farmers about their soils	62%	96%
[KN] Physical functioning	58%	92%
[OU] Reducing soil erosion and its effects	56%	94%
[KN] Physicochemical functioning	56%	94%
[OU] Limiting the urbanisation of cultivated land	55%	85%
[AB] Knowing how to interpret soil analyses	55%	92%
[OU] Improving soil biological activity	53%	92%
[AB] Reasoning cropping systems and plant cover to protect soils	52%	94%
[OU] Restoring agricultural soils to a state of good health	51%	92%
[AB] Evaluating soil regulation services with regard to water, air and biodiversity	51%	94%

Note: Skill classification: AB, ability or know-how; KN, knowledge; OU, outcome from KN or AB put into action.

TABLE 5 Most valued groups of skills according to ranking (Part II of the survey).

	Proportion of participants who ranked essential (8)	Proportion of participants who ranked important to essential (6–8)
Having a scientific basis of knowledge on soils and their functioning	48%	86%
Proposing innovative strategies for the management of agricultural soils for other purposes than production	45%	85%
Assessing soil quality	44%	90%
Knowing how to work with people with different backgrounds	44%	90%
Valuing the ecosystem services provided by soils	44%	85%
Accessing soil information	43%	90%
Knowing how to mobilise agronomic drivers to manage and protect soils	41%	86%

Note: Average value for each group of skills (see Table 1).

(Figure 6). In the open question in Part I, there were no responses related to this skill.

From the skills grouped under '*Knowing how to mobilise agronomic drivers to manage and protect soils*' (Table 5), '*Improving soil biological activity*' was most often ranked as 'essential', followed by '*Reasoning cropping systems and plant cover to protect soils*' (Table 4). In Part I most of the stakeholders gave answers that related

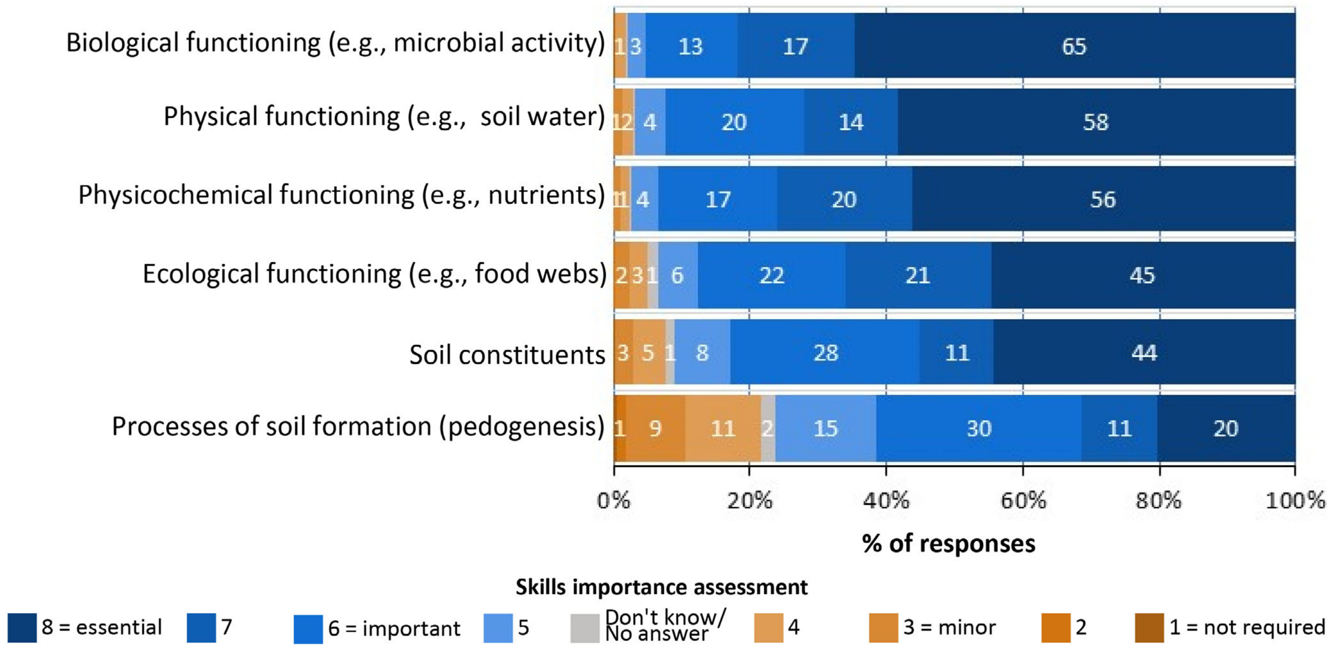

FIGURE 5 Importance assessment of skill group '*Having a scientific basis of knowledge on soils and their functioning*' per frequency of responses ($n = 669$).

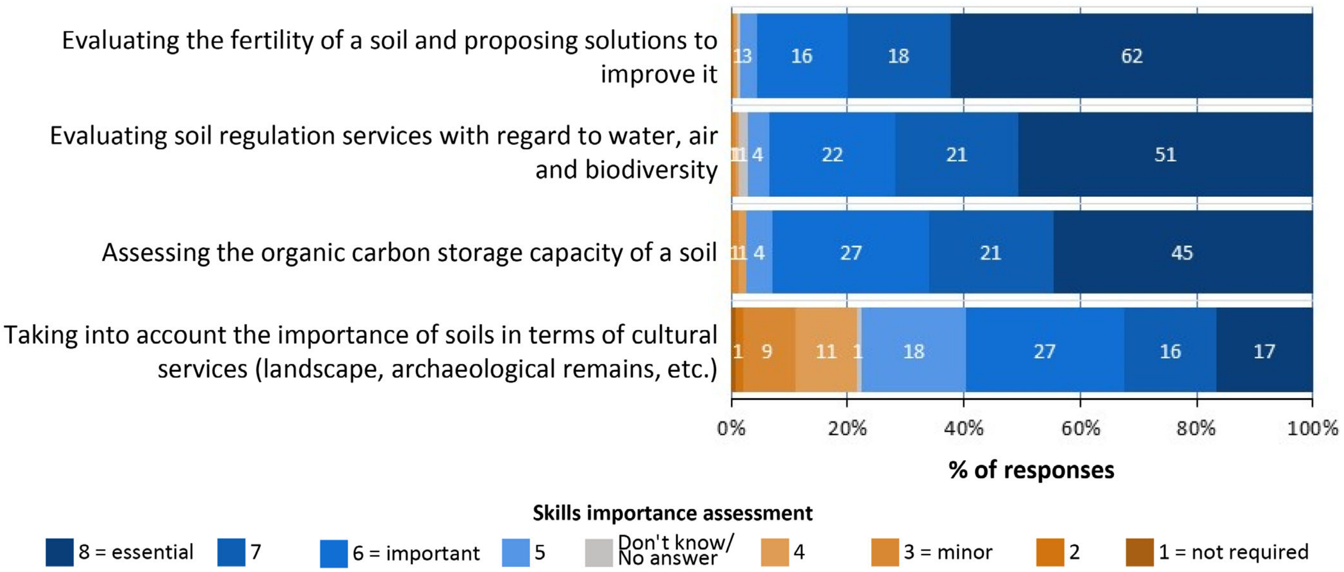

FIGURE 6 Importance assessment of skill group '*Valuing the ecosystem services provided by soils*' per frequency of responses ($n = 669$).

to the cropping systems' management for soil protection (Table 3, Figure 4), while suggested skills that related to the soils' biological activity addressed the theoretical knowledge rather than the practical skills to increase its activity in agricultural fields. Nonetheless, both assessments stress the importance of an increased knowledge of soil biological and ecological properties for managing agricultural soils in the future. All the skills grouped under '*Proposing innovative strategies for the management of agricultural soils for other purposes (than agricultural production)*' (Table 5) were ranked dominantly as 'essential', except for '*Recycling waste through soils*' which was more frequently ranked as 'important'. Nonetheless, in Part I some stakeholders suggested skills related to the recycling of urban organic waste such as "*Establish the feasibility of using organic waste from residual fraction after bio-stabilisation*". It is important to acknowledge that the suggested skills in Part I, which were assigned to '*Enhancing carbon sequestration in soils*', included increasing organic matter and humus in agricultural

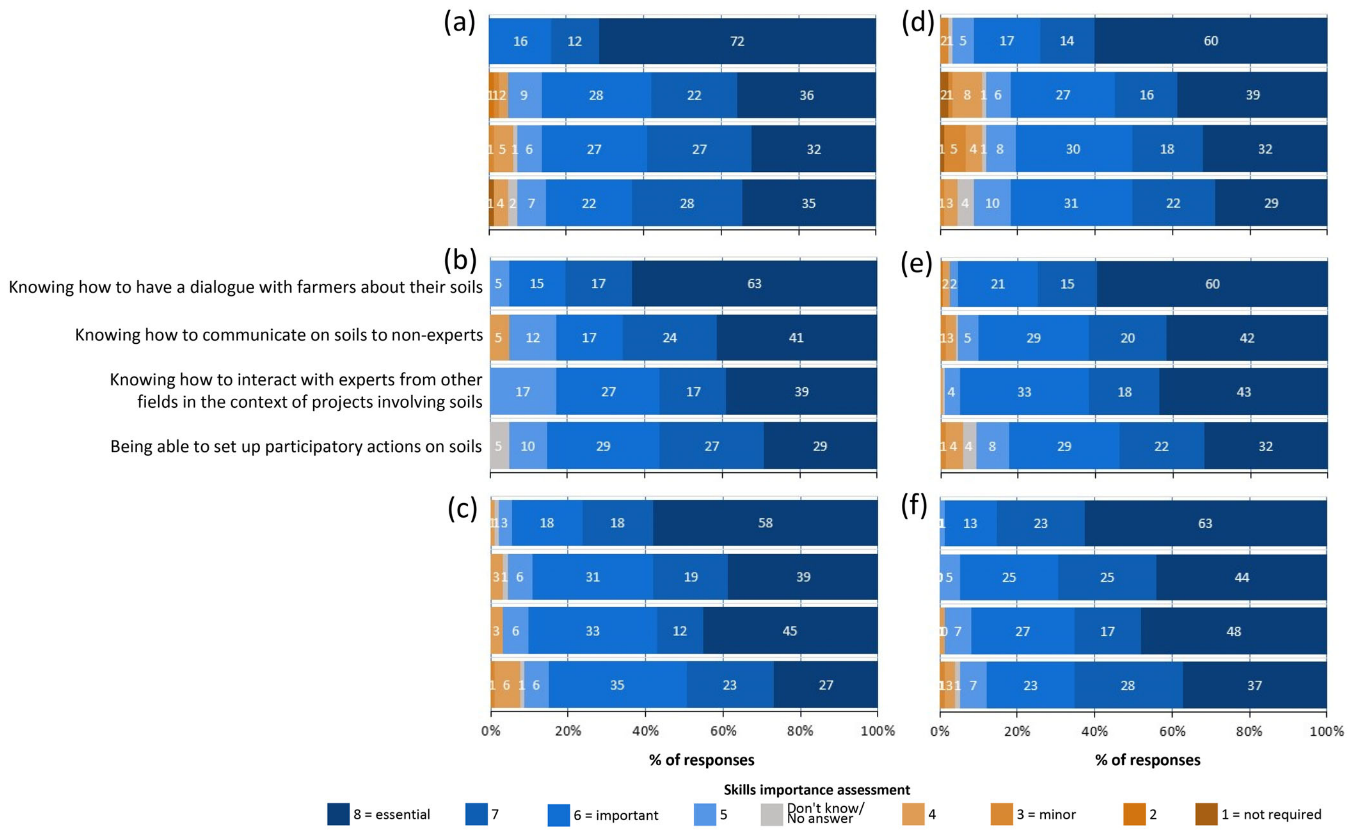

FIGURE 7 Importance assessment of skill group '*Knowing how to work with people with different backgrounds*' per frequency of responses per stakeholder category: (a) farmers or farmer organisations ($n = 81$), (b) local and regional public organisations ($n = 41$), (c) national administrations ($n = 93$), (d) private companies and consultancies ($n = 93$), (e) teaching and research institutions ($n = 228$), (f) associations and NGOs ($n = 75$).

fields for multiple purposes and general soil health. At the same time, a few responses in Part I related to the issue of '*Limiting the urbanisation of cultivated land*' (Table 4) stressing the "*consumption of natural, agricultural and forest areas due to urbanisation*" and "*farmers fighting for their production surfaces*".

Figure 7 shows the assessment for the skills grouped under '*Knowing how to work with people with different backgrounds*'. '*Knowing how to have a dialogue with farmers about their soils*' was ranked most frequently as essential. No significant differences were found between the different categories of stakeholders, except for the skill '*Knowing how to interact with experts from other fields in the context of projects involving soils*' (chi squared level between 1% and 2.5%), which stakeholders from private companies and consultancies tended to value less than the stakeholders from other categories. However, this skill was among the top ones which the stakeholders' answers related to in Part I. These responses mentioned abilities to work with scientists from other disciplines and "*skills that improve consultation and cooperation between researchers, agricultural advisers and farmers*" as well as policymakers at regional and local levels.

3.5 | Underlying drivers for stakeholders' importance assessment of soil-related skills

The results of the clustering and random forest analysis of the responses in Part II showed five clusters that consistently assessed all the skills with a similar level of importance. The largest cluster, representing 58.2% of the participants, used dominantly rank 8 ("essential") in the classification of skills, while the other clusters used dominantly rank 6 ("important", 18.5% of the participants), rank 7 ("very important", 17.9%) and ranks lower than 6 (3.6%). The last cluster (1.7%) used "Don't know/No answer" more frequently. No significant difference in the ranking of particular skills could be detected between countries or between stakeholder categories. The random forest model built from the variables describing stakeholders' characteristics (first section of the survey) to predict the cluster membership misclassified many cases allocating them into the largest cluster.

However, the results of the MCA suggest a relationship between age groups and skill categories

(Table 1). The youngest (groups 1 and 2) and the oldest age groups (groups 3 and 4) could be differentiated according to their answers on selected skills, especially with regard to the first axis (*x*-axis) of the graph (opposition between the left and right part of the graph) (Figure 8). In particular, group 1 (under 40 years old) was more oriented to skills dedicated to action (legal framework, ability to work with people from different backgrounds, other technical skills) and innovation (innovations in agriculture, reconstructing soils). By contrast, group 3 (55–62 years old) was associated with answers having an academic focus (scientific basis of soil knowledge, ecosystem services). This suggests that younger age groups are more sensitive to diversified, nonacademic skills on soils.

3.6 | The three most important skills

The results of the clustering and random forest analysis of the responses in Part III, the selection of the three most important skills, showed four clusters (Figure 9).

Cluster 1 grouped 12.7% of the participants. In this cluster, participants gave more focus to the assessment of soil fertility, especially its physical aspect, and less to improvement of soil biological activity, compared to the other participants. Cluster 3 (23% of the participants) gave more importance to soil biological functioning and less to physicochemical functioning than the other clusters. Cluster 3's stakeholders also selected more frequently '*Knowing how to have a dialogue with farmers about their soils*', '*Integrating soils into biodiversity conservation measures*' and '*Being able to set up participatory actions on soils*' as the most important skills. On the contrary, '*Implementing precision agriculture technologies*' was less considered. Cluster 4 (11.5%)'s most frequently selected skill was '*Restoring agricultural soils to a state of good health*', while '*Implementing precision agriculture technologies*' was selected more often. On the contrary, skills like '*Knowing how to have a dialogue with farmers about their soils*' or '*Reducing soil erosion and its effects*' were selected less frequently. Cluster 2 included the majority of the participants (52.8%) and was therefore close to the average behaviour.

4 | DISCUSSION

4.1 | Methodological aspects

A global number of 1500 invitations to answer the survey was calculated initially from a targeted number of responses of 500 and an expected response rate of 33%. With 669 exploitable surveys, the global response rate (including partially completed surveys) was 45%. This response rate could be considered as very good, but it should be kept in mind that it was an "expert survey", based on the opinions

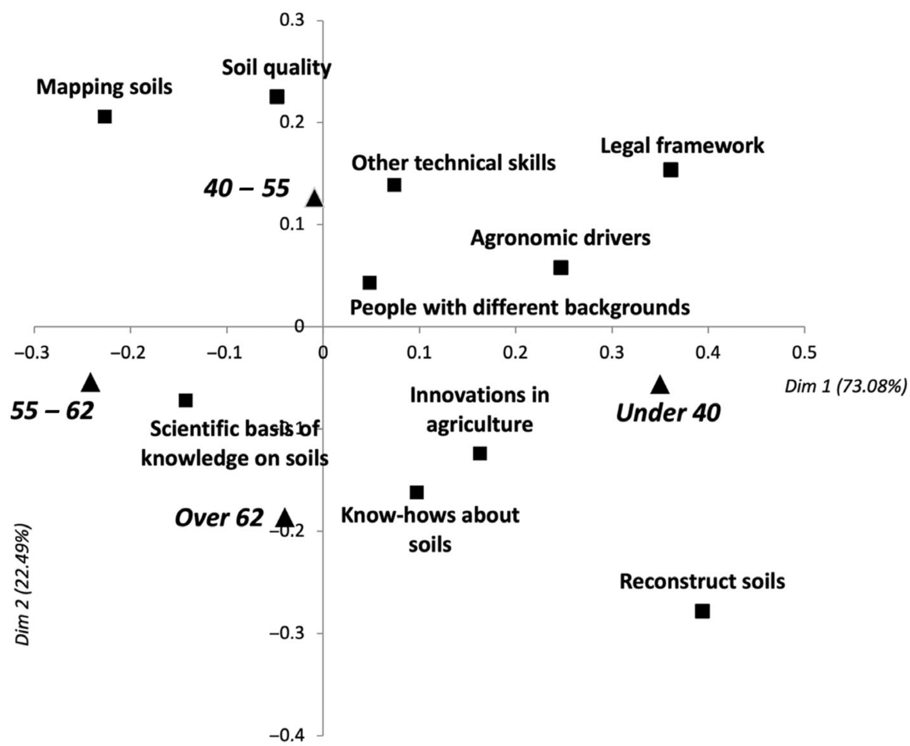

FIGURE 8 Correspondence analysis on links between age groups (triangles) and selected skill categories (squares).

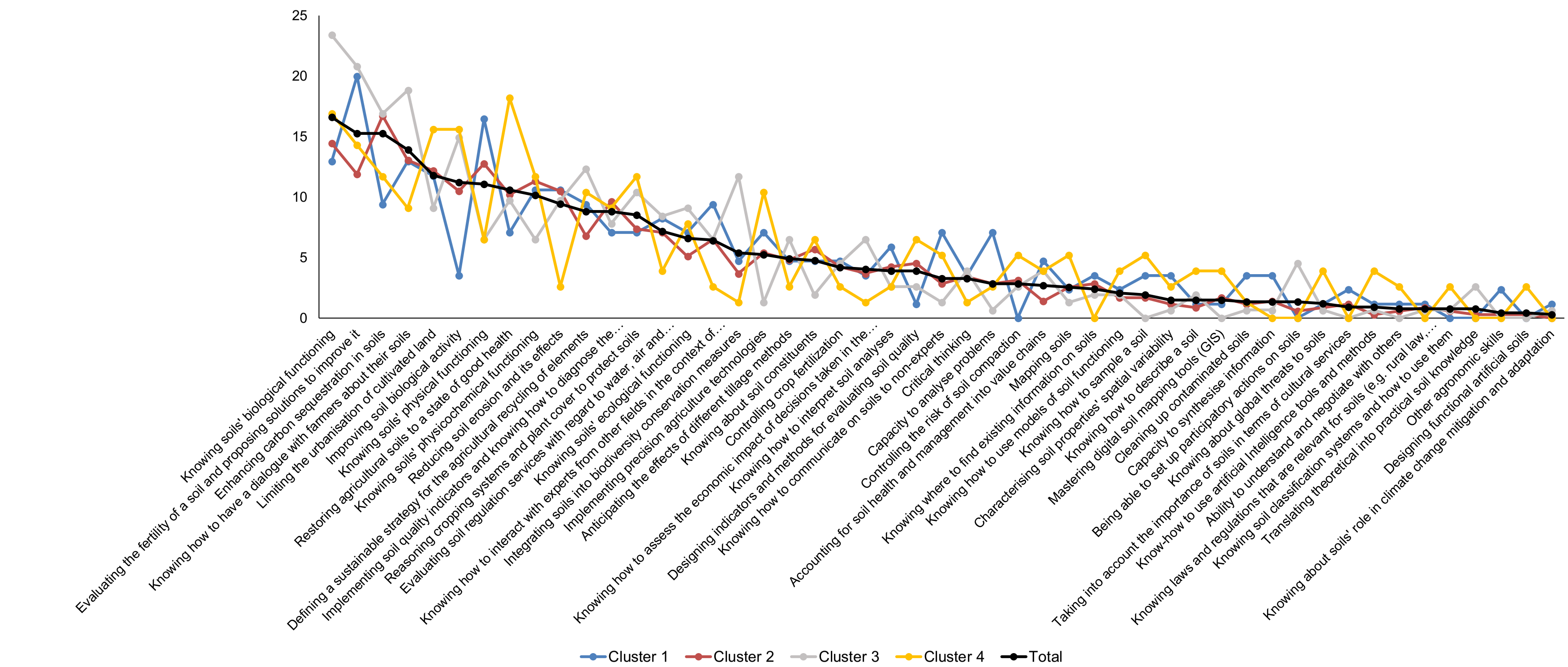

FIGURE 9 Selection of most important skills among 'essential' skills per cluster and average trend.

of experts (Steenbergen & Marks, 2007), the majority of whom had engaged to be involved in various research activities of EJP SOIL. Further, pre-recruitment of participants has shown to increase web-based survey participation (Manfreda et al., 2008). A more traditional survey, such as those used in sociological studies, would have meant having the capacity to randomly sample stakeholder populations (in general population or in a specific category of stakeholders, as farmers for example) at the scale of each country (Groves et al., 2009). It was clearly beyond the means of the current study.

The variability of the response rate was large among countries, from 19% to 94%, but was less marked among stakeholder categories, from 31% to 49%. Not all stakeholder categories could be reached in all countries (Table SM2). Members of research and education institutions were the only stakeholder category that was reached in every one of the 24 surveyed countries. Occasionally, in some countries, only one or two completed surveys were obtained from some stakeholder categories. The participant recruitment strategy restrained to closed panels and the response rate variability could explain the limited statistical power of the survey and the relatively poor performance of the random forest analyses used to identify the drivers of stakeholder's responses. Further, no real outlier could be identified. This, in turn, could indicate the relative homogeneity of opinions across European stakeholders regarding the soil-related skills needed in the future.

This study relied on expert opinion, as done in previous research about soil knowledge and soil science educational needs (Bampa et al., 2019; Cimpoiasu et al., 2021; Key et al., 2016; Masse et al., 2019). The majority (80%) of the participants were aged 40 or older, and 40% aged 55 or over. This might be seen as somehow problematic given the purpose of the survey, which was to forecast a situation 20 years from now. This could be explained by the fact that the experts and representatives of institutions contacted for the survey were not early career people, but it also reflects the current structure of the European population. The majority of the participants (67%) had advanced or expert knowledge on soil, with only 2% ingenuous, and 84% of the participants had their main activity centred on soils. All these characteristics made this panel quite well suited for delivering sound information on which could be the most important soil science skills in the future.

4.2 | Soil science skills for the future: Main findings

Two groups of skills were at the top of stakeholders' rankings: '*Having a scientific basis of knowledge on soils and their functioning*', and '*Knowing how to mobilise agronomic drivers to manage and protect soils*'. This means that there is a need to maintain **experts with a deep knowledge of soil science**, but also **soil scientists with integrated knowledge of agronomy and crop production**, or that future agronomists will need to strengthen their mastering of soil science. The fact that many single skills were ranked "essential" can also be interpreted as the need for specialised profiles in the future (see Walter et al., 2024). The soil science skills for the future belong to all three types that were identified: knowledge, abilities (or know-hows) and outcomes delivered from knowledge and abilities put into operation in real life. This argues in favour of equilibrated education programmes where all types of skills are mobilised. Charatsari and Lioutas (2019) underline that the adaptation of complex kinds of knowledges for agricultural development may need new kinds of skills to deal with transdisciplinary approaches and local knowledges produced by farmers. They identified various competences for this adaptation, among them coordination and problem-solving competences, but also knowledge creation competences. Currently, 'traditional lecture-based' teaching still dominates soil science teaching and learning activities (Villa Solis et al., 2021). Combinations of some of the most important skills identified in this study could help to design new education programmes giving a larger place to the construction of abilities and their testing in real situations. Three important findings of this survey relate to the knowledge of soil science itself: (i) there is a clear need to develop knowledge of soil biological and ecological functioning; (ii) it should not happen at the expense of a strong general knowledge of the fundamentals of soil science; (iii) future soil scientists should be trained to have a more holistic apprehension of soil rather than be trained as specialists of specific aspects of soil science only.

Several important skills for the future link soil science and agronomy, including the exchange of knowledge with farmers (Table 4). Knowing how to assess soil fertility, and more generally soil quality, and how to improve it is viewed as an essential skill for the future. This concurs with the importance given by agricultural stakeholders to soil health and quality as found by Cimpoiasu et al. (2021). This relates also to the highly valued outcome-oriented skill '*improving soil biological activity*'. The most valued skill of all (placed as the most important by more than 30% of the stakeholders) was the capacity of '*reasoning cropping systems and plant cover to protect soils*'. This means that future soil scientists should also have a good knowledge of cropping systems and their impact on soils, and how to adapt them for better soil protection. In the same way, the ability to adapt agricultural management to site-specific soils and environmental conditions is highly valued. Another skill that came very high (ranked "essential" by 62% of the stakeholders) was the '*ability to have a dialogue with farmers about their soils*'. This goes beyond communication skills and pleads for more interaction of soil scientists with farmers on the field. Although such a skill should be largely learned by practice, it could also benefit from elements of knowledge in psychology, rural economics, etc. The exchange of knowledge could include transdisciplinary approaches like co-designing innovative soil management practices. Finally, it is also worth noting that skills that can be specified as outcomes from particular knowledge and abilities related to soil, such as '*reducing soil erosion and its effects*', tend to be overrepresented in the top essential skills (Table 4) compared to skills related to knowledge or know-hows or abilities. As a matter of fact, the first open question of the survey asking for assumed most important skills for the future revealed a vast array of responses, which represents a very interesting corpus that could deserve further study.

No major differences in ranking the importance of soil-science related skills appeared among countries or stakeholder categories. Participants of some countries tended to rank skills higher than the others. This cultural bias is well known but affected the results only marginally. All countries and stakeholders ranked most of the skills as important, very important or essential. These results contrast with previous research that found clear differences between categories of stakeholders. In a study regarding knowledge of soil functions in Europe, Bampa et al. (2019) found that farmers were more focused on practice-oriented knowledge rather than on IT tools, while regional and national stakeholders were less interested in practice-oriented knowledge. In our study, skills formulated as outcomes tended to rank higher than other skills, but no difference between stakeholder categories could be found. Vanino et al. (2023) identified soil challenges for Europe and barriers and opportunities of soil knowledge to tackle them. They found "*highly diversified types of barriers*" and opportunities, which call for multi- or transdisciplinary research. Such a finding is consistent with the fact that most of the skills were ranked important or essential in our survey. Vanino et al. (2023) stressed the importance of capacity building to overcome soil challenges in Europe. The results of our study could help in the elaboration of future education programmes delivering the skills needed to address European soil challenges.

5 | CONCLUSIONS AND RECOMMENDATIONS FOR FURTHER ACTION

In the survey presented in this report, 669 stakeholders from 24 different countries gave their opinion on which would be the most important soil-related skills needed in the future (ca. 20 years from now). Participants were asked to rank each skill from a suggested list, from 1 (not required) to 8 (essential). Prior to that, they were asked to provide three to 10 soil-related skills that they assumed essential for the future. All stakeholders from all countries ranked the majority of soil-related skills as important, very important or essential for the future. Some key results were found:

- There is a strong need to strengthen soil biological and ecological functioning knowledge in the future. This is congruent with the fact that the skill "improving soil biological activity" appeared highly valued by stakeholders.
- There is also a strong need to maintain a high-level of knowledge of all soil science fundamentals. This means that improving knowledge of soil biology and ecology should not come at the expense of other fundamental knowledge of soil.
- Future soil scientists should have a holistic approach of soils, rather than be trained as specialists in one particular aspect of soil. They should have a clear vision of all the functions or services that soils provide to mankind.
- The ability to assess and improve soil fertility or quality is seen as essential for the future.
- Reasoning cropping systems and plant cover to protect soils is also one of the most desired skills for the future, as well as more generally the capacity to mobilise agronomic drivers to manage and protect soils.
- The ability to exchange with farmers about their soils was another skill that came out as one of the most valued ones. This underlines the importance of establishing two-way interactions between future soil scientists and farmers, not only communicating but also learning from one another. This could lead to co-design approaches in addressing innovative soil management practices.

No differences among countries or stakeholder categories could be identified, therefore, the survey results highlight major trends across Europe. These trends can be summarised as a need for professionals with fundamental knowledge of soil functioning, nurtured by research advances in soil biology and soil ecology, which can be put into practice in supporting the transition to a more ecology-based management of agricultural soils. However, these major trends should not mask the large number and variety of skills that shall be valued in the future as assessed by the rankings provided by the stakeholders.

These findings allow to offer a clear path for the development of soil science education curricula across Europe:

- A large component of soil science education should be devoted to the state-of-the-art fundamentals in soil biology and soil ecology, but without sacrificing the other fundamentals of soil science.
- A holistic approach to soil should be given priority over a reductionist approach (i.e., teaching soil physics, soil chemistry, soil biology, soil ecology, etc. separately).
- There is a need for greater integration of soil science with agronomy: dual profiles should be developed.
- Dialogue with local stakeholders (such as co-design with farmers) goes beyond the need for interdisciplinary approaches within the academic domain, but also implies transdisciplinary knowledge exchanges (Meynard et al., 2012).

Here again, this main path for evolution should not be seen as exclusive. In fact, as will be presented in another article resulting from the survey (Walter et al., 2024), there is a need for different professional profiles, such as soil data scientists or soil communicators, that should also be considered in the future. Also, more effort should be put in offering continuous learning and short education programmes for professionals whose jobs are not directly centred on soils but who need to enhance their soil-related skills. The data collected through this EJP SOIL Foresight study for soil science professional needs could help to design such training developments in Europe. It should also be regularly updated as our world is changing so rapidly.

AUTHOR CONTRIBUTIONS

Yves Coquet: Writing – original draft; conceptualization; methodology; data curation; investigation; validation; supervision; formal analysis; visualization; project administration; resources; software; funding acquisition. **Jennifer Veenstra:** Writing – original draft; methodology; software; data curation; formal analysis; visualization; investigation. **Romain Melot:** Conceptualization; methodology; software; data curation; investigation; validation; formal analysis; visualization; supervision; writing – review and editing. **Christian Walter:** Conceptualization; methodology; software; data curation; investigation; validation; formal analysis; supervision; visualization; project administration; writing – review and editing.

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CONFLICT OF INTEREST STATEMENT

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

DATA AVAILABILITY STATEMENT

The data collected from the survey is accessible at https://doi.org/10.57745/CRQMWA as part of the EJP SOIL dataverse.

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SUPPORTING INFORMATION

Additional supporting information can be found online in the Supporting Information section at the end of this article.

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