European Journal of Soil Science

WILEY

European Journal of Soil Science

SURVEY ARTICLE OPEN ACCESS

Assessment of Soil Science in European Higher Education to Meet Growing Soil Awareness Needs

Ana Villa[1,2] | Erik Fahlbeck[1,3] | Jennie Barron[4]

[1]Formerly Swedish University of Agricultural Sciences (SLU), Uppsala, Sweden | [2]Länsstyrelsen Uppsala/County Board of Uppsala, Uppsala, Sweden | [3]KTH Royal Institute of Technology, Stockholm, Sweden | [4]Department of Soil and Environment, Swedish University of Agricultural Sciences (SLU), Uppsala, Sweden

Correspondence: Jennie Barron (jennie.barron@slu.se)

Received: 30 June 2024 | **Revised:** 31 March 2025 | **Accepted:** 7 April 2025

Funding: This work was supported by European Union's Horizon 2020 research and innovation programme (grant agreement No. 862695).

Keywords: capacity building | internationalisation | soil knowledge | teaching and learning approaches | teaching collaboration

ABSTRACT

Humanity is facing a number of global challenges coupling soils and essential ecosystems, biodiversity, food production, and climate change. Hence, knowledge and expertise in soil science and soil management are increasingly needed to address these issues for sustainability and development. Soil science in higher education (HE) will be one essential vehicle to provide a new generation with skills and expertise. The aim of this study was to assess the current state of soil science in European higher education by assessing the existing degrees offered, teaching and learning approaches (TLAs) used, and exploring collaborations in internationalisation among higher education institutions (HEIs) in Europe. A survey was conducted in 2020–2021 and 94 responses were received from HEIs teaching soil science in 25 European countries. Results showed that only 16% of HEIs hosted a dedicated soil science department. In most cases, soil science was embedded in departments with other academic topics, mainly environmental sciences and agronomy. Full degree programs in soil science were offered in 28% (BSc), 37% (MSc) and 37% (PhD) of the HEIs ($N = 75$). Regarding internationalisation of HEIs, only 6% responded that they had international joint programs in place at all levels of education. Twenty-five HEIs (37%) expressed aspirations to establish international programs while 24 (35%) saw no need for joint programs. The top three priorities among the HEIs were to attract students from abroad, develop strategic research partnerships, and provide more opportunities to send students abroad. Traditional lectures dominated TLAs in most soil science courses, especially at BSc level, where 40% of the HEIs responded that more than half of a soil course is delivered as lectures. Several respondents claimed curricula had not changed significantly in the last 5 years. Computer/modelling was either not included or included as a small share in teaching according to 96% (BSc) and 98% (MSc) of the HEIs. We conclude based on the sample, soil science at European HEIs appears conservative, but with scope to strengthen to deliver better soil science expertise for the future. More diverse TLAs and updated teaching materials are needed to provide the next generation of experts with the skills needed to address local and global sustainability challenges related to soils.

1 | Introduction

Soils underpin multiple essential ecosystem services, societal and livelihood benefits. Healthy and productive soils are fundamental in provisioning ecosystem services, and the source of 95% of all food plus forests and fibre (FAO 2021). Soils provide regulating and supporting functions, including water storage, water quality and supply regulation (Powlson et al. 2011), climate regulation and erosion control (Haygarth and Ritz 2009; IPCC 2019; Silver et al. 2021). Soils also store a large share of

Summary

- Soil science as an academic topic was surveyed in 94 higher education institutions (HEIs) in 25 European countries in 2020–2021.
- Most soil science was taught in academic subjects of environmental sciences or agronomy, and less than 16% of respondents hosted a dedicated soil science department.
- More international collaboration through capacity building and research partnerships was considered an option to strengthen European HE soil science in the future.
- HEIs need to consider developing teaching and learning approaches beyond the current dominant lecture format to equip future soil expertise with the needed skills in communication, data, and digital skills for societal benefit.

global carbon (Tifafi et al. 2018), host a significant amount of global biota (FAO et al. 2020) and have the potential to store more through sequestration measures to mitigate climate change (Bossio et al. 2020; Paustian et al. 2016). The health and management of soil resources are therefore critical to provide these ecosystem services. Soil quality and the ecosystem services provided by soils do however face two immediate growing challenges, in terms of soil degradation and climate change (FAO 2021). Both challenges interact as a problem through the release of CO_2 and CH_4 from soils and as a potential solution through the sequestration of carbon in soils (Amelung et al. 2020). We therefore witness an increasing complexity of soil management with implications for society and human well-being, environmental sustainability and climate mitigation. As a result, soil science and soil and land management expertise generate more interest and action, from policy to practice and from local to global scale.

Since 2015 soil and land management has been addressed in the global AGENDA2030 and UNFCC climate agreement, and in Europe with the EU Soil Strategy for 2030 (European Commission 2021) and EU Mission "A Soil Deal for Europe" (European Commission 2022). These are built on different EU policies and initiatives such as the European Green Deal (European Commission 2020a), Water Framework Directive 2000/60/EC (WFD), Farm to Fork Strategy (European Commission 2020b), the development of the Directive on soil monitoring and resilience (European Commission, last accessed 2024) and the Common Agricultural Policy (CAP) (European Commission 2017). The main aim of the mentioned European soil strategy and mission is that all soil ecosystems are in a healthy condition and become more resilient to provide their key services. For the implementation of the EU Soil Strategy and EU Mission, the European Commission has defined different principles and objectives, and explicitly recognised the need for "Increase soil literacy in society across Member States" (objective 8). Various actions are taken, for example under Horizon Europe Research and Innovation Actions such as "Foster soil education across society" (HORIZON-MISS-2022-SOIL-01-07) and by linking Mission Soil research calls to the objectives of the European Education Area, the Education for Climate Coalition and improve the European sustainability competence framework (GreenComp, Bianchi et al. 2022).

Complementing efforts are in place to support a more proactive development of meeting the growing demand for soil science competences. The 2020 EU Skills Agenda (European Commission 2020c) provides a framework to strengthen sustainable competitiveness under the Green Deal. Soil science will be one contributing area of expertise needed, and higher education (HE) is one essential vehicle to provide students with the new skills and expertise for the future. Some of the specific types of skills that the EU Skills Agenda focuses on are digital skills, STEM skills (Science, Technology, Engineering and Mathematics) and transversal skills (e.g., working together, critical thinking, and creative problem solving).

In addition, international cooperation in research and innovation is a strategic priority for the EU, as one way to tackle global challenges also related to soilst to meet the Sustainable Development Goals (SDGs). In terms of HE, internationalisation can be addressed through the implementation of international and comparative perspectives, intercultural competences, solve real problems and provide solutions to critical problems (Beelen and Jones 2015). As defined by Knight (2004), internationalisation is "the process of integrating an international, intercultural, or global dimension into the purpose, functions or delivery of post-secondary education". Cooperation and internationalisation of HE at EU level have been promoted by development of different processes and programmes. From the Bologna Process to mobility programmes such as Erasmus, Erasmus +, Erasmus Mundus and Marie Curie, and homogenising tools such as European Credit Transfer and Accumulation System (ECTS) and the European Qualifications Framework (EQF). The Horizon Europe and the efforts under Mission "A soil deal for Europe" are key for funding research and innovation collaborations to tackle global challenges related to soils and facilitate action. These mechanisms have facilitated collaboration, cooperation and intra-European internationalisation of HE, especially student mobility.

However, to date there are few comprehensive studies of HE soil science in Europe that can provide the next generation of soil expertise in tune with societal demands. Soil science in HE studies has mainly focused on enrolment rates and less on HE qualitative and institutional aspects such as collaboration and learning methods, especially within studies of European HE. Some examples include Jelinski et al. (2019) who focused on the curricula content of introductory soil science courses, but few other studies (e.g., Brevik et al. 2022; Amador 2019; Hartemink et al. 2014) have focused on issues related to how soil science is taught and learned. As far as we know, there exist no wide studies of higher education in soil science in Europe. More recent studies on soil skills and expertise needs for future generations have been assessed by for example, Veenstra et al. (2024), and used to inform a proposal for new professional profiles in soil expertise (Walter et al. 2024).

Given the rapid growth in demand for expertise in soil science in research, policy and practice, it is urgent to understand how

TABLE 1 | Soil science in European Higher Education survey components.

Section number	Survey section	Number of questions	Comments
1	Respondent and Institutional information	6	Background reference information from the HEI
2	Teaching and research capacity	4	Composition and characteristics of the department (e.g., academic staff categories)
3	Academic topics and degrees offered	10	Academic fields and degrees offered (e.g., soil science as full degrees/courses, joint national/international programmes)
4	Student enrolment	10	Number of students at BSc, MSc and PhD level
5	Courses; teaching and learning approaches (TLAs)	18	Courses offered, teaching and learning elements and content e.g., policy topics and SDGs
6	Internationalisation and diversity	7	International dimension contributing to the education at the department (e.g., foreign academic staff, internationalisation strategies)
7	Job market	7	Prospect of job opportunities for students

to deliver and equip the needed human capacity to address current and future challenges. The main objective of this study was therefore to assess the state of soil science in European HE. The specific questions of the study were to (i) assess the existing degree programmes that offered soil science components across HEIs in Europe, (ii) explore existing aspirations and international collaboration in soil science among HEIs in Europe, and (iii) study the teaching and learning methods and teaching capacity used in soil science in HE.

2 | Materials and Methods

The study was developed as a survey to provide a baseline on the current state of soil science in European HE. The survey explored the capacity in teaching and learning for the delivery of soil science in HE and elaborated the linkages of soil sciences HE programmes to national and international collaborative actions, as well as explored teaching content. This survey included quantitative, categorical questions (i.e., categories such as not important at all to very important, strongly disagree to strongly agree) and open-ended response questions. The survey consisted of seven different sections, including 62 questions (Table 1) using a range of questions, including multiple choice, ranking, and open-ended for respondents additional inputs. The complete survey can be found in Villa et al. (2021). The protocol and associated survey instrument were informed by existing studies (Table 2) to be comparable with existing literature related to soil science HE in several countries and continents.

The survey was undertaken during November of 2020 to March of 2021. We used a web-based survey tool Netigate. It was distributed by facilitating a personal link by email to the respondents and by publishing the link to the survey in various websites and social media. The respondents at the HEIs were selected in several steps. A first set of HEIs were provided through the European Joint Programme "Towards climate smart sustainable management of agricultural soils" (EJP SOIL project https://ejpsoil.eu/), with dedicated contact points for higher education and training in 26 European countries. Secondly, the national contacts representatives in EJP SOIL coordinator provided in-country contacts with key HE institutions in respective country, which were invited through email to take the survey. Thirdly, an open invitation to other HEI was made on EJP SOIL website and social media, in order to reach to as many HEIs as possible. For the countries not participating in the EJP SOIL project, HEIs with display of substantial soil science elements in higher education courses and programs were selected through a desk study search. Two reminders were sent by email. The survey was distributed to 248 departments at HEIs in Europe. We received 94 survey responses from 83 different HEIs in 25 European countries. The number of responses received through personal email was 69 and responses through the general open web link were 25 (Figure 1).

In this study, we will focus on three different aspects of survey responses: existing degree programmes offered in soil science in HEIs, internationalisation/collaboration between European HE, and teaching and learning methods used in soil science in HE. The indicators from the survey informing these aspects and that were used in this study are presented in Table 3. In addition, results from student enrolment rates (questions 4.1–4.4) and main academic topic of the HE teaching soil science (questions 3.1–3.3) were also presented.

2.1 | Data Analysis

The survey responses were downloaded from Netigate as an Excel data file. All questions were optional, and statistical analysis was performed on the available responses for each question. Statistical analysis was performed with JMP software. Additionally, SigmaPlot was used for visualisation.

TABLE 2 | Main references considered in the elaboration of the survey.

Type of publication	Authors	Publication year	Geographic and educational scope	Methodology	Core element informing this study
Peer reviewed scientific	(Diochon et al. 2017)	2017	Canada	Survey, review	Student enrolment rates
Peer reviewed scientific	(Hartemink et al. 2008)	2008	North America, Europe and Oceania	Survey, review	Student enrolment rates
Peer reviewed scientific	(Havlin et al. 2010)	2010	United States and Canada	Survey, review, interview	Trends in soil science education
Report	(UNESCO-UIS 2012)	2012	International	International Standard Classification of Education (ISCED 2011)	Terminology for levels of education (i.e., Bachelor's level, Master's level, Doctoral level)
Report	(UNESCO-UIS 2015)	2015	International	International Standard Classification of Education. Fields of education and training 2013	Terminology for fields of education (question 3.2 in survey)
Report	(UNESCO 2017)	2017	International		SDGs learning objectives (question 5.17 in survey)
Database	(EUROSTAT 2020a, 2020b)	2020	Europe		

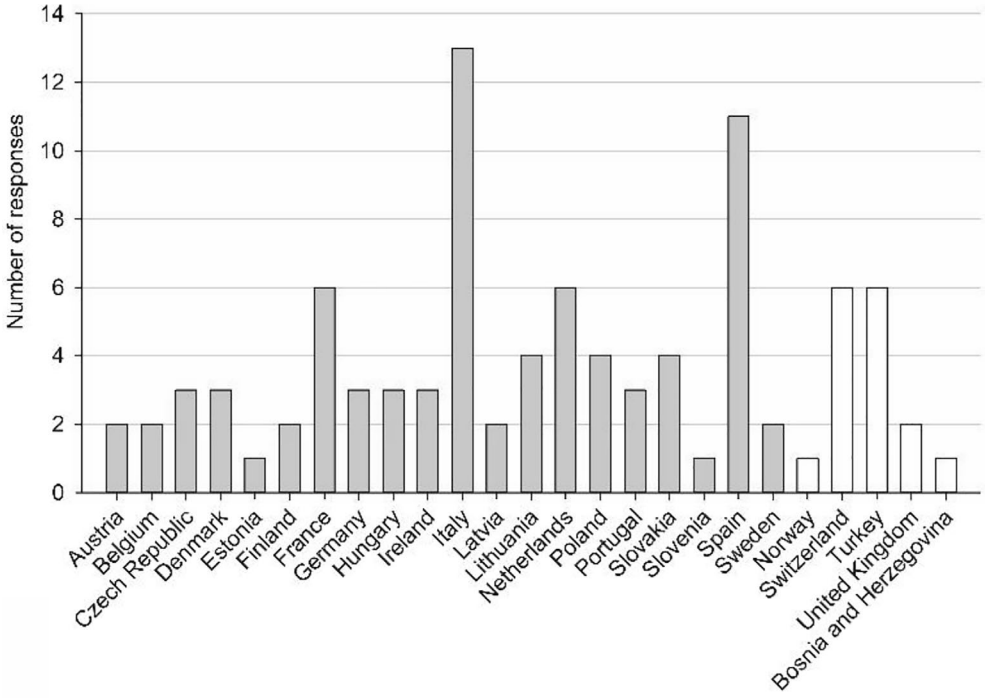

FIGURE 1 | Number of responses to survey in "Soil science in European higher Education" per country. Bars in grey correspond to EU countries and bars in white correspond to non-EU countries.

3 | Results

3.1 | Description of HEIs and Soil Science Degrees Offered

Both size and number of staff of respondent HEI varied considerably across respondents of the survey on "Soil science in European HE". The size of the HEIs in terms of number of staff varied from five to 350 persons. The distribution of the size of the departments showed that there are a few big departments and many small ones (Figure 2). Of the 94 survey responses from 25 countries, only 16% stated the HEI hosted a dedicated soil science department. These departments were mainly smaller. The most common size (median) of them were 15 persons (see Figure 2). On the other hand, 84% respondents stated that soil science was embedded in a department with other academic subject, such as environmental science/engineering, agronomy or earth science. Correspondingly, soil science was offered as a full degree programme at BSc level in 28% of respondent HEIs, and at 37% of respondents ($N = 75$) at MSc and/or PhD level.

Regarding the student enrolment rates, a majority of responding HEIs reported a weak tendency of increased enrolment for BSc programmes with soil science components, and mixed trends for MSc degree programmes. The results showed that students entering a BSc have increased in a greater number of HEIs (43%) of respondents reported increases while 28% of HEIs reported decreases. The number of HEIs that reported the same number of students entering a BSc degree was also 28%. The percentage of HEIs that reported increases and decreases in the number of students that entered an MSc degree was similar, 35% and 31%, respectively. Another 33% of the HEIs reported that the number of students remained about the same.

3.2 | Internationalisation and International Collaboration in European HEIs

As a measure of the internationalisation, we asked for the share of foreign staff and foreign undergraduate students. Results showed a similar distribution with a median percentage of 3% and 8%, irrespective of category PhD, MSc, BSc students or staff members, with large variations between HEIs. The share of foreign students increased at the PhD level, with a median of 50% and showing even higher variation (Figure 3). Regarding the number of international recruitments of academic staff over the last 5 years, it ranged from 0 to 15 ($N = 61$), where zero was the most common answer and the 75th percentile was 3.

Only 4 (6%) HEIs responded that they had international joint programs in place at all graduate levels (BSc, MSc and PhD), whereas double the amount of HEIs stated they hosted national collaborative programmes in HE. It was more common to be engaged in international programmes at MSc and/or PhD level (Figure 4). There was almost an equal number of responses stating aspiration for establishing international joint programmes ($N = 25$, 37%) in soil science HE, as the statement of no need for joint programmes ($N = 24$, 35%) (Figure 3).

As an additional indicator of accessibility for internationalisation and especially opportunity for student and staff exchange, the survey explored the language of teaching at different levels of education. In 38% of the responding HEIs (total $N = 67$), there was involvement in a research school for doctoral students. Soil courses were taught mainly in the local/national language at undergraduate level (83% at BSc and 63% at MSc). However, the use of English in soil courses increased to 47% of responding HEIs at the PhD level (Table 4). English was the main language at BSc level in only four countries, and in two of those, English

TABLE 3 | Key indicators related to internationalisation/collaboration and active teaching and learning approaches (TLAs) selected from full survey of Villa et al. (2021).

	Topic	Indicator	Type of question/answer		Question
Collaboration & internationalisation	Student characteristics	Number of international BSc/MSc students	Open-ended	%	4.6
	Scholar characteristics	Number of foreign academic staff at department	Open-ended	%	6.1
		Number of international recruitment in the last 5 years	Open-ended	%	6.2
	Curricular content	Language used in courses	Multiple choice (Local/ National or English)	Local/English/Other local	5.11
		SDGs learning objectives in courses	Yes/No	6 learning objectives from SDGs 2, 6 and 15	5.17
		EU/international policy in courses	Multiple choice (more than one can be selected)	Different EU/National legislations	5.18
	Collaboration	Joint programs with soil topic with other institutions in another country	Multiple choice & open ended	Yes, there are examples in all cycles/BSc/MSc/PhD Not yet, but plans No, no need	3.6–3.7
		Research school for PhD students	Yes/No	If yes, name is provided	5.13
		MOOCs	Yes/No	If yes, name is provided	3.9
	Organisational	Internationalisation strategy	Multiple choice	5 options (yes/one is developing/no/...)	6.5
		How important is to develop different strategies	Interval scale	From Not important at all to Very important	6.6
		Top 3 priorities for internationalisation (qualitative)	Ordinal scale	11 choices	6.7

(Continues)

TABLE 3 | (Continued)

	Topic	Indicator	Type of question/answer		Question
Active teaching (student centred learning)	Courses and learning approaches	Different teaching-learning elements used at BSc/MSc	Multiple choice	% ranges	5.8–5.9
		New courses added past 5 years	Yes/No	If yes, name is provided	
		Courses incorporating problem-based learning/case study	Multiple choice (more than one could be selected)	Problem-based learning/case study/real service projects/other	5.12
		Desire to implement something in soil courses but not able to do it	Open ended	Text	5.14–5.15
		Main reason for not being able to implement something	Multiple choice	Lack of time/constraint by study plans/lack of resources/lack of support/Other	
		New developments in teaching and learning methodologies	Open-ended	Text	5.16
		Study programs over time should include more generic competences	Agreement scale	From strongly agree to disagree	3.10

was also the native and local language. At MSc level, English was the main language in HEIs in 13 different countries—a similar trend as seen in many academic topics across European HEIs. These were countries that adhered to the EU by 1995 and before the Bologna process was signed in 1999.

Most responding institutions (87%) had either an existing internationalisation strategy ($N=52$, 63%) or internationalisation was a part of other strategies ($N=20$, 24%). Only two HEIs responded that such a strategy was under development, whereas two HEIs responded that there was no strategy, and six responded that they were not sure/did not know.

The top three priorities listed to enhance internationalisation by the HEIs were to (i) "attract students from abroad" (43%, $N=79$), (ii) "develop strategic research partnerships with other institutions" (42%) and (iii) "providing students with more opportunities to have a learning experience abroad" (38%). The fourth most answered priority was "internationalisation of learning and teaching" (35%).

In terms of a more internationalised curriculum related to policy issues, the results showed that various learning objectives from the Agenda 2030, SDGs related to soil (SDGs 2, 6 and 15) (UNESCO 2017) were included in a majority of the courses (68%–78%). Learning objectives related to SDG 15 (Life on Land) was the most widely included in the courses offered and it ranged from 82% to 98% depending on the learning objective. National legislation and regulations of importance for soil was widely covered as confirmed by 81% of the HEIs. Other EU legislation such as Farm to Fork (31%), EU Green Deal (37%), Common Agricultural Policy (53%) and WFD (55%), was less covered in the soil courses, according to responses.

3.3 | Teaching and Learning Approaches in Current Curricula of Soil Science at BSc, MSc and PhD Levels

As a means to explore how HEIs prepare new graduates for the current and future demands in soil in academics as well as policy and practice, the survey focused on a set of questions regarding teaching and learning approaches (TLAs) applied at different degree program levels. More than 2/3rds of the respondents (69%, 57 out of 83) answered that the teaching staff at the department had achieved at least a basic course in higher teaching and learning. The 31% that had not achieved a basic course in pedagogy came from 8 countries. In those countries, there had been at least one respondent in the other sense (staff achieving a basic course in higher teaching and learning) so it does not indicate that it is a country-wise factor. More than 57% of respondents claimed teaching staff always held a PhD. In addition, respondents also provided comments that it was useful to connect to practice andreal-world conditions by inviting practitioners from the field or researchers/engineers with large experience to give lectures or teach in practical activities.

Traditional lectures still dominated in most of the HEIs soil courses (Figure 5). At BSc level, 40% of the HEIs responded that the major part of the courses consisted of lectures (more than 50% of the content). Another 47% of the HEIs responded that lectures

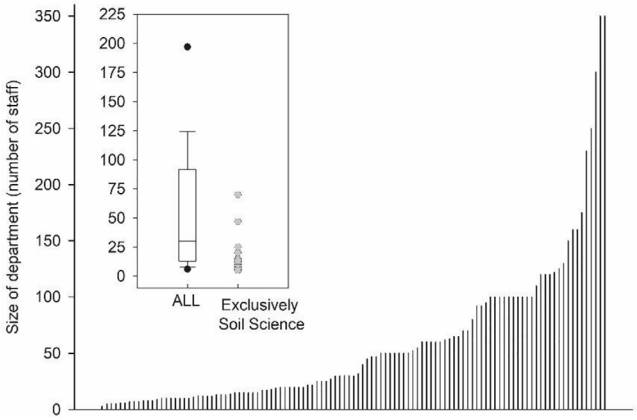

FIGURE 2 | Distribution of the size of the Higher Education Institutions (departments) teaching soil science, in terms of number of staff. In the smaller graph, the boxplot shows the distribution considering all types of HEIs while the grey dots indicate the HEIs that were exclusively soil science. The solid line within the boxplot is the median, the boundary of the box closest and farthest to zero indicates the 25th percentile and 75th percentile, respectively. Whiskers to the left and right indicate the 10th and 90th percentiles. The black dots indicate the 5th and 95th percentiles.

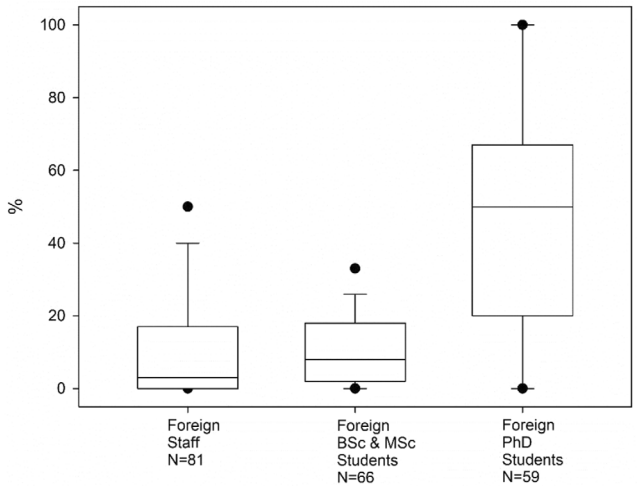

FIGURE 3 | Distribution of the foreign staff and students in the surveyed European Higher Education Institutions (HEIs). The solid line within the box is the median, the boundary of the box closest and farthest to zero indicates the 25th percentile and 75th percentile, respectively. Whiskers to the left and right indicate the 10th and 90th percentiles. The black dots indicate the 5th and 95th percentiles.

were a dominating part of the course delivery (26%–50% of the content). The fraction of lectures diminished at MSc level, but was still a large part (more than 26% of the courses) in 70% of the HEIs. Other teaching–learning elements such as computer/modelling were either not included or included as a small share of the courses in 96% (at BSc) and 98% (MSc) of the HEIs. Similarly, peer learning was also used only in a small fraction of the courses in the majority of the HEIs at both BSc and MSc levels. There were, on the other hand, elements of non-lecture-based teaching and learning methodologies reported such as problem-based learning (64% of responses), case study[1] (77% of responses) or real service projects[2] (21% of responses) or in one case, flipped classroom (Villa et al. 2021). When testing HEI characteristics such as departmental size of staff, number of PhD-level lecturers, or share of staff with basic teaching and learning training, no relation to the incidence of non-lecture TLAs could be identified.

In addition to the quantitative questions, respondents commented on teaching elements they would like to implement in the soil courses but were not able to do. Several respondents proposed including more practical activities, including field and laboratory work or case studies (12 respondents out of 29). Four respondents suggested strengthening elements for digital skill sets through modelling or computer activities and data management, inc., GIS applications. Another three respondents commented on the need for new teaching material in soil science, with updated contemporary issues applied to the local conditions and more online/computer-based tools as a complement to textbooks. Other responses included the incorporation of new topics and/or courses usually related to more contemporary topics (e.g., remote sensing, soil ecosystem services). When asked about the main reason(s) for not being able to implement such new topics or course material, more than half responded that the lack of resources was one of the reasons (54%, of total $N = 52$), followed by being constrained by the curriculum (45%) and by lack of time to plan and lack of support (21%), respectively. Other comments pointed towards the lack of students or qualified teachers and the difficulty of organising new courses. Suggestions came from institutions in 22 different countries with varying staff sizes.

In terms of course development within soil science and development of study options, a majority of respondents (61% out of 69 answers) stated that their courses in soil science have not changed over the last 5 years. Many HEIs (72% out of 64 answers) agreed or strongly agreed that programs over time should include more generic competences linked to communication skills, teamwork, digital skills, and learning to learn.

When asked about new methodologies in TLAs implemented by the departments, only a few responses were received. One respondent answered that a new graduate course will be "based on projects, blending frontal, participatory, and presentation teaching activities". Other new courses included a GIS based modelling and machine learning in soil science as well as new field soil courses. Other responded that they were developing videos showing processes, methods of field work, as well as technologies. In other cases, distance teaching and/or lectures recorded on video were being developed. The COVID-19 pandemic (2020–2021), also accelerated these developments when there was a need to transfer to virtual teaching.

4 | Discussion

4.1 | Soil Science in HE and Perceptions on Student Enrolment

Soil science and the need for soil expertise have been elevated in the European policy and research agenda. Over the last 5 years, soils feature both in response to environmental and climate concerns (e.g., Agenda 2030, IPCC 2019; FAO 2021), but also as a result of new policy and funding opportunities such as European Green Deal (European Commission 2020a),

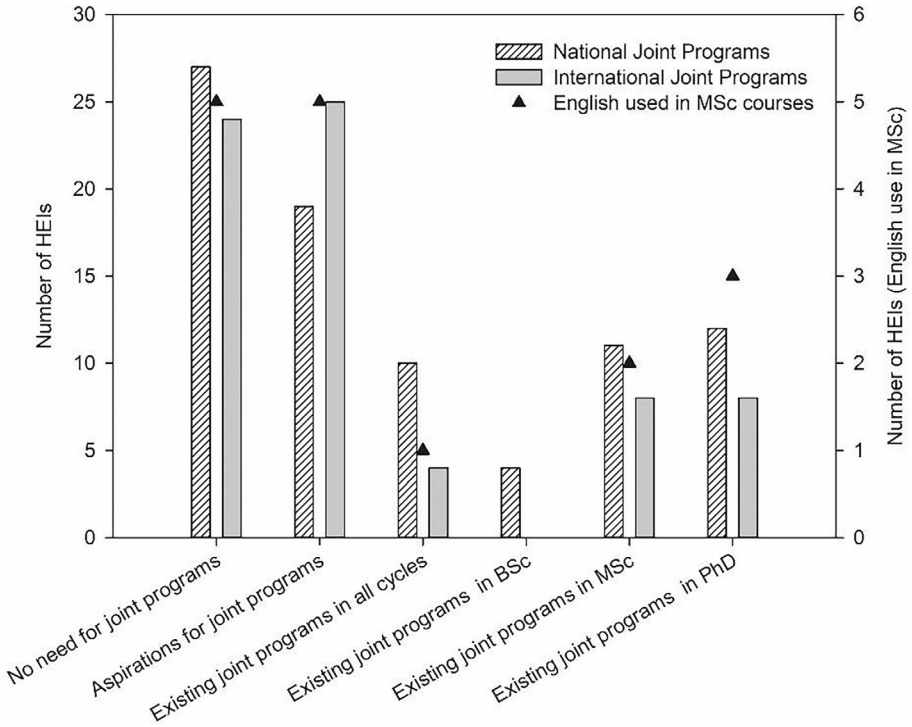

FIGURE 4 | Joint programs with soil science topics offered by the departments with other institutions in the same country and in another country.

TABLE 4 | Main language used in soil courses at different education levels.

	Bachelor's level (BSc)		Master's level (MSc)		Doctoral level (PhD)	
	N	%	*N*	%	*N*	%
English	7	11	22	35	28	47
Local/national	54	83	39	63	23	38
Not applicable (no courses offered)	4	6	1	2	9	15
N	65		62		34	

EU Mission "A Soil Deal for Europe" (European Commission 2022), and the development of the Directive on soil monitoring and resilience (European Commission, last accessed 2024). Our results provide a baseline on the current state of European Higher Education Institutions and give guidance on how to strengthen the next generation of soil expertise. The results showed that soil science was mainly embedded in departments with other main topics and taught in degree programs as part of other academic topics, rather than exclusive soil science (Section 3.1). Our findings are similar to earlier studies such as Diochon et al. (2017), Baveye et al. (2006), Hartemink et al. (2008) and Collins (2008), that found soil science was evolving to be taught as part of other science curricula and by other departments than dedicated soil science departments in Canada, Netherlands and USA. They also suggested that while soil science research is specialising into more sub-disciplines, soil science teaching at HEIs tend to be part of more general science curricula to keep student recruitment and ultimately build new generation of soil expertise. The incorporation of soil science into other degree programmes at European HEIs may therefore be an advantage, as these programmes deliver a greater number of graduates with soil science as part of their education.

4.2 | Collaboration Between European HEIs

Collaboration, partnership and internationalisation are important strategies to align and complement expertise at national and home institution. Joint programmes, as defined by the European Higher Education Area, are set up to enhance mobility of students and staff, to facilitate mutual learning and cooperation opportunities and to create programmes of excellence. Our study showed that partnerships in national and international soil science HE were either already implemented, or planned by two thirds of respondents. Yet, one third of the respondents did not have plans for joint programmes (Figure 4). One possible explanation that could hinder the collaboration between HEIs is language. Seeber and Lepori (2014) suggested language hinders the inward mobility in countries where less widely spoken languages are dominant and where the use of for example, English is not the major working language in academia. In our study, soil courses were taught mainly in the local/national language at undergraduate level but the use of English increased at MSc and PhD levels. In more populous countries with multiple HEIs related to soil science (e.g., Germany, Italy, Spain and France), foreign students are usually expected to speak the national language, which can serve as a barrier for inward mobility.

The large variation in departmental staff size (Figure 2) may also be a barrier for HEIs activities to enhance internationalisation.

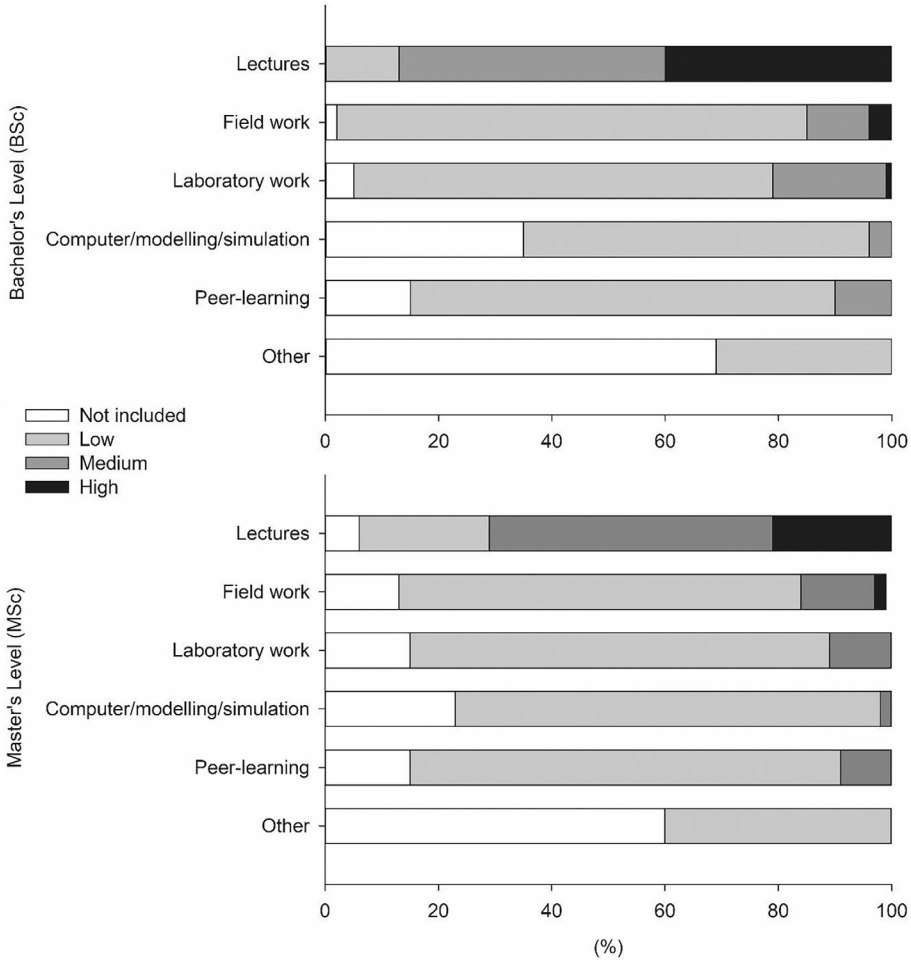

FIGURE 5 | The colours in the bars represent the fraction of the teaching elements used in the soil courses. Low represents share between 1% and 25%, medium is 26%–50%, and high is > 50%.

In our study, the top three priorities were to (i) attract students from abroad, (ii) develop research partnerships with other HEIs, and (iii) provide students with more opportunities to have a learning experience abroad. According to IAU (2010) for small HEIs, the priority is outgoing mobility of students, while medium-large ones prioritise research collaboration. In our case, results pointed towards a similar pattern, as a greater number of smaller institutions expressed a desire to provide students with opportunities to have a learning experience abroad. On the other hand, developing strategic research partnerships was selected as a top priority by a greater number of larger institutions. Internationalisation and staff-student exchanges will always be offered to a limited number, and therefore other measures for internationalisation at home should complement mobility, so that a greater number of students benefit from the international experience. MOOCs are one option that could be implemented, as they are still not being used extensively in soil science HE in Europe (EUA 2018).

4.3 | Active Teaching and Learning Approaches to Strengthen Transversal Skills

Increasingly, working in policy, practice, or academia requires more than solid and updated soil knowledge in order to be a skilled and knowledgeable employee for a dynamic job market. Students need to acquire certain skills in addition to soil knowledge and expertise to be prepared to solve complex problems after they graduate. These skills are often referred to as "generic skills", "transversal skills" or "key skills" and are expected to ensure graduates adapt to change and continue to engage in acquiring new expertise on soils as the science and demands develop. A previous study in Canada and the USA (Havlin et al. 2010) identified employers' dissatisfaction with the lack of soil science graduate field experience, poor communication, and critical-thinking skills as major gaps, reducing employability. The European Commission presented in 2020 a Skills Agenda (Commission 2020) that aims to strengthen sustainable competitiveness, ensure social fairness, and build resilience to react to crises. Walter et al. (2024) identified generic skills for a range of soil expert professional profiles, such as communication with non-soil actors, working together, digital skills, critical thinking, and creative problem solving being listed. It will be important to connect the need for strengthening transversal skills of soil expertise throughout the curriculum and the teaching and learning methodologies forward.

Hence, the results of this survey of soil science in European HE are concerning, in our view. Firstly, respondents stated teaching at BSc and MSc was, to a significant extent, dominated by

lectures. Secondly, a majority stated that courses in soil science had not evolved over the last 5 years, despite more than 70% of respondents recognising the importance of supporting transversal skills development. Thirdly, there was in general a low degree of digitalisation in the courses. According to the results, soil science courses are mainly taught by staff that hold a PhD degree and a majority have received a basic course in teaching and learning, yet the traditional lecture format is still predominant. The dominant use of lectures for soil science HE has been confirmed elsewhere. A study in Canada showed that traditional lecture (86%) and laboratory delivery (76%) were the most common formats in the surveyed soil science introductory courses, with a limited use of online teaching resources (36%) (Krzic et al. 2018). In the United States, Jelinski et al. (2019) showed that instructors were using more innovative approaches in soil introductory courses (e.g., flipped classroom, peer-learning, active learning environments) alongside the traditional lecture format accounting for 56% of the course hours. Yet, there is ample evidence that alternative methods in teaching and learning are more effective to prepare graduates both in terms of core knowledge and in developing generic skills (e.g., Amador 2019; Andrews and Frey 2015; Charzyński et al. 2022). For example, Field et al. (2011) showed that students rated field work as the most effective learning activity (43%) followed by laboratory work (36%) and tutorials/group discussions (11%). The motivation was that learning was related to real-life problems, learning-by-doing is more memorable, or that it was a complement to lecture material/related to theory. Virtanen and Tynjälä (2019) found that teaching practices involving collaboration and interaction, as well as features of a constructivist learning environment and integrative pedagogy, predicted the learning of generic skills (e.g., decision-making skills, creativity, and problem solving). Traditional forms of university teaching (e.g., reading, lectures, working alone) were negatively associated with learning transversal skills.

Another of the key skills identified in the European Skills Agenda is the acquisition of digital skills (European Commission 2020c). The proposed implementation of the Directive on soil monitoring and resilience (European Commission, last accessed 2024) will also require substantially more local, regional and national soil monitoring and analyses, alongside existing systems such as the Nitrate and Water Framework Directives and national climate reporting under the UNFCCC Paris Climate Agreement, that relies heavily on soil data. The Covid-19 pandemic put the spotlight on the need for digitalisation of HE in terms of online teaching, and many HEIs will continue to implement and develop online teaching and/or digital TLAs.

4.4 | Study Representativeness and Opportunities for Future Action

This survey was conducted during the COVID-19 outbreak and indeed implicated the European HEIs, which may have affected response rates. In addition, using the network of the EJP SOIL project could have limited the reach to HEIs, especially if teaching soil science as part of environmental and geotechnical courses and programs. Hence, this study is only in part representing the current European situation and with a likely bias of soil science related to agricultural HEIs. Whereas response rates were in the order of $< 30\%$, we would have expected more responses from HEIs in the UK, Germany, and also Spain, France, and Italy. Brevik et al. (2022) reported $n = 158$ and $n = 59$ HEIs delivering soil science in undergraduate programs in Germany and the UK, respectively, to be compared with the US with $n = 77$ (inc., Land Grant universities) and $n = 55$ in Canada. Even if not all European HEIs teaching soil science were included, we consider this as a first baseline to inform future studies.

In summary, to prepare a new generation of soil science graduates, there may be a need to give more attention to the design of teaching and learning approaches, in order to strengthen capacity both in generic (transversal) skill sets and in soil science knowledge. Additional studies are needed to address the role of HEIs to support more professional training and lifelong learning in soil science and expertise, to strengthen HEIs in the adaptation of curricula, the development of teaching and learning activities and internationalisation forward. This could further inform best investments in soil science education both in existing and new BSc, MSc and PhD programmes in soil science as well as other degrees to provide a next generation soil expertise.

5 | Conclusions

Soils and their management are fundamental to a range of essential ecosystems and societal and climate challenges facing humanity. Thus, soil science and expertise will be one contributing factor in higher education (HE) to build capacity, skills and expertise for the current and future sustainable development. This survey of 94 HEIs teaching in Europe show both strengths and limitations for building the human capacity in soil science expertise and can serve as a baseline for future work. Based on the survey findings we conclude HEIs is at advantage, with well-educated teaching capacity in several countries, in part connected through European collaborations, but could be strengthened further through strategic efforts. Firstly, HEIs need to better develop an teaching and learning activities (TLAs) aligned with latest evidence, for soil science that actively h strengthen transversal skills in communication, data management and digitalisation alongside soil science knowledge in for BSc, MSc and PhD curricula and teaching materials. Secondly, active support for soil science and knowledge networks among graduates, teachers and professionals may be valuable to strengthen European and regional cross learning and knowledge exchange. Internationalisation and opportunities for graduates and early career will be a first step for building these future 'communities of practise'. Thirdly, there is a need to consider how to develop and update learning materials at HEIs. There are still gaps in terms of how to mobilise more active and modernised curriculum. A major emerging knowledge gap outside of the scope of this survey are the needs, and opportunities for long term/lifelong/professional learning. HEIs in soil science can have a major and growing role in this field as the focus of soil health and management increase for food, environment and climate. We recognise that is a major gap that urgently needs to be addressed in EU context.

Author Contributions

Ana Villa: methodology, investigation, writing – original draft, formal analysis, data curation, visualization, software. **Erik Fahlbeck:** conceptualization, methodology, writing – review and editing, investigation, supervision. **Jennie Barron:** conceptualization, methodology, funding acquisition, writing – review and editing, project administration, supervision, investigation, formal analysis.

Acknowledgements

This work is part of the EJP SOIL project (Towards climate-smart sustainable management of agricultural soils) work package 5 "Education, training and capacity building". The study has received funding from the European Unions' Horizon 2020 research and innovation programme under grant agreement No. 862695 EJP SOIL and the Swedish University of Agricultural Sciences (SLU), which are gratefully acknowledged. We thank the contributors for the survey responses. We also thank colleagues Yves Coquet, Christian Walter, Jennifer Veenstra, and Bozena Smreczak, for continuous support during the work. The support of committed reviewers greatly helped the presentation of this study.

Data Availability Statement

The data that support the findings of this study are available on request from the corresponding author. The data are not publicly available due to privacy or ethical restrictions.

Endnotes

[1] A case study refers to a designed set of instructions to mimic a real world problem, provided as a TLA with a specific learning objective.

[2] A real service project refers to a case study that may be a real world problem, sometimes provided by an external client.

References

Amador, J. A. 2019. "Active Learning Approaches to Teaching Soil Science at the College Level." *Frontiers in Environmental Science* 7, no. 111: 111. https://doi.org/10.3389/fenvs.2019.00111.

Amelung, W., D. Bossio, W. De Vries, et al. 2020. "Towards a Global-Scale Soil Climate Mitigation Strategy." *Nature Communications* 11, no. 1: 5427. https://doi.org/10.1038/s41467-020-18887-7.

Andrews, S. E., and S. D. Frey. 2015. "Studio Structure Improves Student Performance in an Undergraduate Introductory Soil Science Course." *Natural Sciences Education* 44, no. 1: 60–68.

Baveye, P., A. R. Jacobson, S. E. Allaire, J. P. Tandarich, and R. B. Bryant. 2006. "Whither Goes Soil Science in the United States and Canada?" *Soil Science* 171, no. 7: 501–518.

Beelen, J., and E. Jones. 2015. "Redefining Internationalization at Home." In *The European Higher Education Area: Between Critical Reflections and Future Policies*, edited by A. Curaj, L. Matei, R. Pricopie, J. Salmi, and P. Scott, 59–72. Springer International Publishing.

Bianchi, G., U. Pisiotis, and M. Cabrera Giraldez. 2022. *GreenComp the European Sustainability Competence Framework*, edited by Y. Punie and M. Bacigalupo. Publications Office of the European Union. EUR 30955 EN.

Bossio, D. A., S. C. Cook-Patton, P. W. Ellis, et al. 2020. "The Role of Soil Carbon in Natural Climate Solutions." *Nature Sustainability* 3, no. 5: 391–398.

Brevik, E. C., M. Krzic, C. Muggler, D. Field, J. Hannam, and Y. Uchida. 2022. "Soil Science Education: A Multinational Look at Current Perspectives." *Natural Sciences Education* 51: e20077. https://doi.org/10.1002/nse2.20077.

Charzyński, P., M. Urbańska, G. Franco Capra, et al. 2022. "A Global Perspective on Soil Science Education at Third Educational Level; Knowledge, Practice, Skills and Challenges." *Geoderma* 425: 116053.

Collins, M. E. 2008. "Where Have All the Soils Students Gone?" *Journal of Natural Resources and Life Sciences Education* 37, no. 1: 117–124.

Commission, E. 2020. "European Skills Agenda for Sustainable Competitiveness, Social Fairness and Resilience."

Diochon, A., N. Basiliko, M. Krzic, et al. 2017. "Profiling Undergraduate Soil Science Education in Canada: Status and Projected Trends." *Canadian Journal of Soil Science* 97, no. 2: 122–132.

European Commission. 2020a. "A European Green Deal." Accessed 19 July 2022. https://ec.europa.eu/info/strategy/priorities-2019-2024/european-green-deal_en#actions.

European Commission. 2020b. *Farm to Fork Strategy for a Fair, Healthy and Environmentally-Friendly Food System*. European Commission Accessed July 19, 2022. https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:52020DC0381.

European Commission. 2020c. *European Skills Agenda*. European Commission Accessed July 19, 2022. https://ec.europa.eu/social/main.jsp?catId=1223&langId=en.

European Commission. 2021. "The European Pillar of Social Rights Action Plan." Accessed July 19, 2022. https://op.europa.eu/webpub/empl/european-pillar-of-social-rights/en/.

European Commission, Directorate- General for Environment. 2024. "Proposal for a Directive on Soil Monitoring and Resilience." Accessed June 30, 2024. https://environment.ec.europa.eu/publications/proposal-directive-soil-monitoring-and-resilience_en.

European Commission, Directorate-General for Communication. 2017. *Agriculture – A Partnership Between Europe and Farmers*, 2017. Publications Office. https://data.europa.eu/doi/10.2775/64508.

European Commission, Directorate-General for Research and Innovation. 2022. *EU Mission, Soil Deal for Europe, Publications Office of the European Union*. https://doi.org/10.2777/706627.

EUROSTAT. 2020a. "Learning Mobility Statistics."

EUROSTAT. 2020b. "Tertiary Education Statistics."

FAO. 2021. *The State of the World's Land and Water Resources for Food and Agriculture – Systems at Breaking Point*. Synthesis Report 2021. FAO.

FAO, ITPS, GSBI, SCBD, and EC. 2020. *State of Knowledge of Soil Biodiversity – Status, Challenges and Potentialities, Summary for Policymakers*. FAO.

Field, D. J., A. J. Koppi, L. E. Jarrett, et al. 2011. "Soil Science Teaching Principles." *Geoderma* 167-168: 9–14. https://doi.org/10.1016/j.geoderma.2011.09.017.

Hartemink, A., M. Balks, Z. Chen, et al. 2014. "The Joy of Teaching Soil Science." *Geoderma* 217: 1–9.

Hartemink, A. E., A. McBratney, and B. Minasny. 2008. "Trends in Soil Science Education: Looking Beyond the Number of Students." *Journal of Soil and Water Conservation* 63, no. 3: 76A–83A.

Havlin, J., N. Balster, S. Chapman, D. Ferris, T. Thompson, and T. Smith. 2010. "Trends in Soil Science Education and Employment." *Soil Science Society of America Journal* 74, no. 5: 1429–1432.

Haygarth, P. M., and K. Ritz. 2009. "The Future of Soils and Land Use in the UK: Soil Systems for the Provision of Land-Based Ecosystem Services." *Land Use Policy* 26, no. Suppl 1: S187–S197. https://doi.org/10.1016/j.landusepol.2009.09.016.

IPCC. 2019. "Summary for Policymakers. In: Climate Change and Land: An IPCC Special Report on Climate Change, Desertification, Land Degradation, Sustainable Land Management, Food Security, and Greenhouse Gas Fluxes in Terrestrial Ecosystems."

Jelinski, N. A., C. J. Moorberg, M. D. Ransom, and J. C. Bell. 2019. "A Survey of Introductory Soil Science Courses and Curricula in the United States." *Natural Sciences Education* 48: 1–13.

Knight, J. 2004. "Internationalization Remodeled: Definition, Approaches, and Rationales." *Journal of Studies in International Education* 8, no. 1: 5–31.

Krzic, M., T. T. Yates, N. Basiliko, et al. 2018. "Introductory Soil Courses: A Frontier of Soil Science Education in Canada." *Canadian Journal of Soil Science* 98, no. 2: 343–356.

Paustian, K., J. Lehmann, S. Ogle, D. Reay, G. P. Robertson, and P. Smith. 2016. "Climate-Smart Soils." *Nature* 532, no. 7597: 49–57.

Powlson, D. S., P. J. Gregory, W. R. Whalley, et al. 2011. "Soil Management in Relation to Sustainable Agriculture and Ecosystem Services." *Food Policy* 36: S72–S87.

Seeber, M., and B. Lepori. 2014. *Knowledge, Diversity and Performance in European Higher Education, the Internationalization of European Higher Education Institutions*. Edward Elgar Publishing.

Silver, W. L., T. Perez, A. Mayer, and A. R. Jones. 2021. "The Role of Soil in the Contribution of Food and Feed." *Philosophical Transactions of the Royal Society, B: Biological Sciences* 376, no. 1834: 20200181.

Tifafi, M., B. Guenet, and C. Hatté. 2018. "Large Differences in Global and Regional Total Soil Carbon Stock Estimates Based on SoilGrids, HWSD, and NCSCD: Intercomparison and Evaluation Based on Field Data From USA, England, Wales, and France." *Global Biogeochemical Cycles* 32, no. 1: 42–56.

UNESCO. 2017. *Education for Sustainable Development Goals: Learning Objectives*. United Nations Educational, Scientific and Cultural Organization.

UNESCO-UIS. 2012. *International Standard Classification of Education ISCED 2011*. UNESCO Institute for Statistics.

UNESCO-UIS. 2015. *International Standard Classification of Education: Fields of Education and Training 2013 (ISCED-F 2013) – Detailed Field Descriptions*. UNESCO Institute for Statistics.

Veenstra, J., Y. Coquet, R. Melot, and C. Walter. 2024. "A European Stakeholder Survey on Soil Science Skills for Sustainable Agriculture." *European Journal of Soil Science* 75, no. 2: e13449.

Villa, A., E. Fahlbeck, and J. Barron. 2021. *Synthesis Report on Soil Science in European Higher Education*. Department of Soil and Environment, Swedish University of Agricultural Sciences.

Virtanen, A., and P. Tynjälä. 2019. "Factors Explaining the Learning of Generic Skills: A Study of University Students' Experiences." *Teaching in Higher Education* 24, no. 7: 880–894.

Walter, C., J. Veenstra, R. Melot, and Y. Coquet. 2024. "Identification of Soil-Related Professional Profiles for the Future From a Survey of European Stakeholders." *European Journal of Soil Science* 75, no. 2: e1346.