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Soil literacy

Scoping document

Outlook on the knowledge gaps related to soil literacy

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Introduction

Soil is often overlooked despite being a crucial component of the terrestrial environment. People often see it just as ‘dirt’ and as an exploitable natural resource (European Commission, Directorate-General for Environment 2021b). Moreover, the soil was, and still is, not considered as relevant as other key environmental components although is one of the three fundamentals that ensure life on land: air, water and soil. What is hidden is the significance of soils to people's daily lives and its key role in sustaining all life on dry land of the Earth. The ‘dirt’ and ‘no value’ perception of soil may contribute to the lack of public discussion and appreciation of soils in public life, and, consequently, a political

reluctance to pass laws to preserve and enhance soil health (EU Soil Observatory (EUSO) 2024). There is also little emphasis on soils in education, highlighting the need to increase public awareness and societal engagement in sustainable soil management and soil protection, which has an impact on soil literacy.

The Soil Mission Implementation plan understands soil literacy as *both a popular awareness about the importance of soil, and specialised and practice-oriented knowledge related to achieving soil health.* A more detailed definition of what soil literacy entails is provided by Johnson et al. (2020), *a combination of Attitudes, Behaviours and Competencies required to make sound decisions that promote soil health and ultimately contribute to the maintenance and enhancement of the natural environment*.

The EU Mission 'A Soil Deal for Europe' (Mission Soil) is one of five Missions funded under the EU Research and Innovation (R&I) Programme Horizon Europe. Its goal is to create 100 Living Labs and Lighthouses by 2030 to promote sustainable land and soil management in urban and rural areas. **The success of the Soil Mission depends on response and action being taken by society.** However, the current low level of soil literacy is a major barrier to achieve significant soil health improvements. Therefore, **valuing soils as part of all aspects of the environment and daily life is key**. This can be strongly supported by enabling the general public to have access to both general education on soil and targeted training for specialised needs (European Commission, Directorate-General for Environment 2021b). However, purely scientific information about soils in itself will not trigger citizen action and involvement. Rather, increased **soil literacy has to connect to people's existing values, interests, and concerns**. While some messages may be widely attractive (e.g., healthy soils underpinning achievement of physical and mental health, beautiful and healthy landscapes, good quality food), soil literacy should also be linked with specific and locally relevant concerns and should empower citizens to make a change (European Commission, Directorate-General for Environment 2021a).

Despite its importance, little prior work considers the conceptualisation and measurement of soil literacy, as well as its components, which could potentially lead to more informed and conscious decision-making by citizens towards healthier soils. Understanding the individual and community drivers that motivate people to interact with soil is crucial for informing policies aimed at facilitating initiatives that promote human-soil interaction, such as those within farming communities (Johnson et al. 2023).

Based on the importance of the development of soil literacy for the achievement of soil health, the Think Tank (a body of experts providing advice and ideas on specific issues) focuses its work in the identification of knowledge gaps in research and development around this topic. This document starts by highlighting the relevance of soil literacy for the achievement of the Soil Mission and the relation of the topic among the Think Tanks. In addition, the methodology followed by the Think Tank for the identification of members and the analysis of the knowledge gaps is described, together with the current state of the art of soil literacy.

Soil literacy in the context of the Soil Mission

The Mission's goal is underpinned by eight specific objectives, and each of those have various policy targets. The policy targets for the "Increasing soil literacy in society across Member States" objective are:

- T. 8.1: Awareness of the societal role and value of soil is increased amongst EU citizens, including in key stakeholder groups, and policymakers.
- T. 8.2: Soil health is firmly embedded in schools and educational curricula, to enable citizens' behavioural change towards the adoption of sustainable practices both individually and collectively.
- T 8.3: Citizen involvement in soil and land-related issues is improved at all levels
- T 8.4: Practitioners and stakeholders have access to appropriate information and training to improve skills and to support the adoption of sustainable land management practices.

Soil literacy is also heavily linked to one of the four Soil Mission transversal-operational objectives: "Engage with the soil user community and society at large". The activities included in this operational objective are:

- Activity 4.1: Foster soil education across society
- Activity 4.2: Engage with and activate municipalities and regions to design their own strategies and actions for the protection of soil health
- Activity 4.3: Engage with the private sector and consumers to embed soil health in business practices
- Activity 4.4: Strengthen soil health advice and improve access to training for practitioners in line with Agricultural Knowledge and Innovation Systems (AKIS)
- Activity 4.5: Create citizen-led soil stewardship
- Activity 4.6: Bring soil closer to citizens' values

Considering the importance of the soil literacy topic within the Soil Mission, the Think Tank focuses its work in the definition of the soil literacy term, identification of existing frameworks and assessment of knowledge gaps related to the topic. Additionally, it is important to consider that, since soil literacy encompasses both the understanding of soil science and the engagement of the soil community and society at large, the Think Tank's activities intersect with those of the other eight Think Tanks. This interconnection between Soil Literacy and the other Think Tanks is depicted in Fig. 1.

Scoping methodology for knowledge gaps on soil literacy

The Soil Literacy Think Tank started its work with the identification of the relevant stakeholders, followed by their engagement and discussions for the identification of knowledge gaps. In May 2023, a screening process was started by ICLEI European Secretariat to identify potential stakeholders working on the topic of soil literacy at EU level. The stakeholders identified belong to the four target group areas defined in the

quadruple helix model: research, governance, civil society and businesses. By October 2023, nine stakeholders had agreed to become members of the soil literacy Think Tank (a group of experts on the topic). The soil literacy Think Tank now comprises members covering a broad range of backgrounds, from soil researchers and university teachers to environmental social scientists, soil consultants, and communications experts. All the groups are represented except for business/industry. The Think Tank is designed to be dynamic and to grow and change over the lifetime of the SOLO project, therefore the screening process is ongoing and recruitment to the Think Tank will remain open.

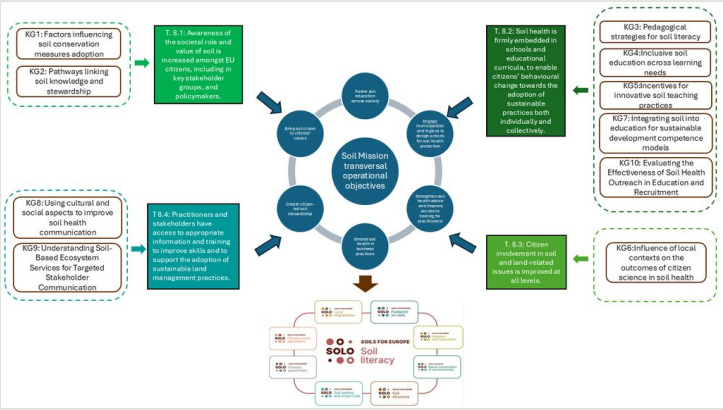

Figure 1. doi

Soil Literacy and the Soil Mission

The first official online meeting of the soil literacy Think Tank took place in October 2023, during which Think Tank members and goals were introduced. During this meeting the members agreed that soil literacy is not well defined under the Soil Mission, generating a challenge to identify gaps, bottlenecks, and activities to address it. Based on this, the members decided to meet again to have a brainstorming session around the concept of soil literacy. This took place in November 2023 and was structured around the content of several scientific papers suggested by the Think Tank members. This information together with the main discussion points is synthesised in the present paper. Future steps might include discussions around the educational part of soil literacy, based on the collected resources and the feedback received during the review process.

Additionally, during the SOLO project conference in Barcelona in November 2023, the soil literacy Think Tank leaders had the opportunity to interact and discuss the preliminary results in a round table format with members from the other SOLO Think Tanks. The inputs collected during this session have also been included in this scoping document.

In 2024, desk research of several papers took place. The main objective of this desk research was the identification of research and innovation knowledge gaps related to soil literacy. As a secondary objective, this review also collected information on the actions and bottlenecks mentioned in the records related to the research and innovation knowledge gaps.

The process began on the 22nd of May of 2024 with a comprehensive search for relevant literature using **Publish or Perish** software, which facilitated the retrieval of academic papers from **Google Scholar**. The removal of duplicates was performed automatically by the software. The search was performed using a predefined search string (based on the concept of soil literacy):

- "soil" AND ("literacy" OR "capacity building" OR "training" OR "perception" OR "values" OR "awareness" OR "engagement" OR "education" OR "citizen science")

and inclusion criteria:

- English language (the language ICLEI team members can understand)
- Open access
- Papers from 2010 ongoing
- Specifically related to the topic of soil literacy, based on the search string terms ensuring the relevance of the selected studies to the research objectives.

The screening process was divided into four stages:

1. **Identification**: A total of **898** records were identified from the Google Scholar database using Publish or Perish software.
2. **Screening**: **252** of the records, roughly the 30%, were screened based on title and abstract relevance. The remaining **646** records will be screened in 2025.
3. **Eligibility**: Following the initial screening, **64** full-text articles were assessed for eligibility against the inclusion/exclusion criteria.
4. **Included**: Finally, **23** studies were included in the analysis forming the basis for the findings in terms of research and innovation knowledge gaps, actions and bottlenecks.

This analysis was supplemented with online meetings with the Think Tank members to cross-check the relevance of the found research knowledge gaps. For Think Tank members who could not attend the online meeting in July 2024, a Google survey was shared with a list of the identified knowledge gaps so they could also share their impressions. This feedback was considered to cluster or rename several of the knowledge gaps. Together with the in-person meeting in Sofia, Bulgaria, all the conversations provided highly relevant suggestions to the initial list, ending up with a total of **18 knowledge gaps**, methodology presented in **Fig. 2.**

2. State-of-the-Art

2.1 Current state of the knowledge on soil literacy

Defining the meaning of soil is a ‘complex matter’. As it is complex to define “soil health” and “soil literacy”.

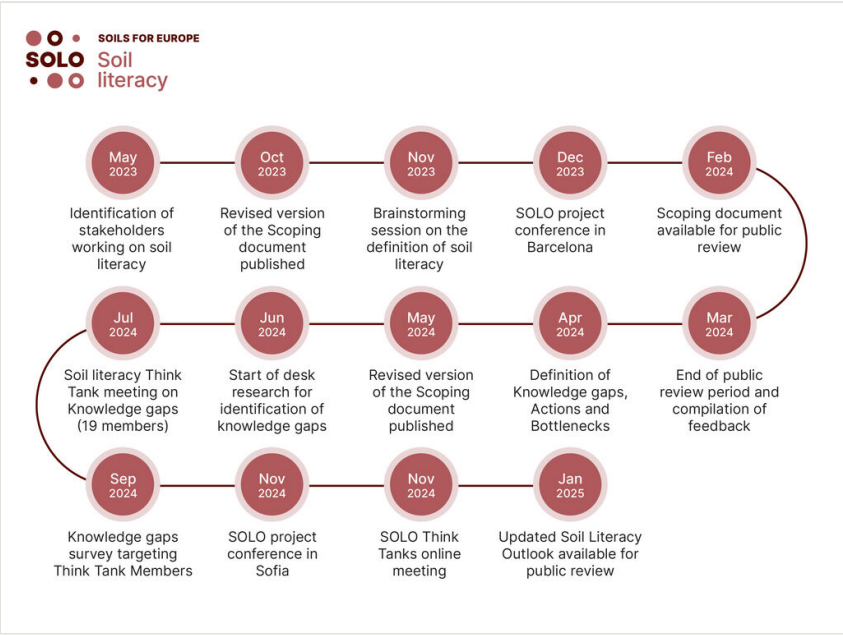

Figure 2. doi

Soil Literacy Think Tank work-flow

Within soil science, the definition of the above terms have changed over time. Beyond the field of soil scientists, different groups have different understandings of what soils are. The way in which soils are known, represented, and understood is diverse. In different regions, farmers, foresters, government officials, soil researchers, or environmental NGOs know soil in different ways, and attach different meanings to them (Granjou and Meulemans 2023).

There is also the historic context of how soil science has emerged and developed as a topic seeking relevance within the scientific community and governance spheres over the past one hundred years, which adds another level of complexity to the discussion. Accounts of the history of soil science usually locate the origins of the discipline in the late 1800 with Vasiliy Dokuchaev (*Rusakova et al. 2022)*, then first international soil science congresses and conferences in 1909, 1924, and 1927 (KEEN 1927). Based on Dokuchaev's work, Hans Jenny developed in the 1940's a conceptual model of soil formation factors. In the early 1900's soil related concepts started developing and being published, such as Soil Fertility, Soil Productivity and Soil Conservation. Before the 1970's soil knowledge was mainly related to agricultural practices, as technologies started developing (e.g., mechanization, chemicals, modified plant crops, namely the "first green revolution" Melillo 2012), there was a shift in this concept. This shift can also be reflected in the appearance of concepts like soil quality and soil protection in the 1970's (Mizuta et al. 2021). As a result, soil science entered a period of legitimation crisis, which extended until around 2010 in connection with the discourse on soil carbon and climate

change. Soil science has re-articulated its relevance in 5 different epistemic commitments along the years (*Sigl et al. 2023*):

1. Communicating to policymakers, to find new ways to convey existing soil science knowledge to policymakers.
2. Internationalising soil science knowledge, to create international bodies of soil science knowledge with a broad geographical scope.
3. Rethinking soil science research by using boundary concepts, soil scientists started using concepts like ecosystem services, policy cycle, or soil health to improve communication, interaction, and collaboration beyond traditional and agrocentric soil science (creation of soil ecology).
4. The ecosystem approach in soil-related research, an approach that studies soils as part of broader ecosystems with the aim to understand interactions within and beyond soils.
5. Developing regional scenarios for (agricultural and rarely forest and urban) soil management, the goal is to use soil management as a mean to tackle societal and environmental problems without losing sight of other soil functions and ecosystem services, such as local food production or regional economic functions.

In accordance with these epistemic commitments, it can be observed that in the 1990's new concepts like soil sustainability, resilience and health were introduced. While the concept of soil security did not appear until 2013 (Mizuta et al. 2021).

The following figure summarizes the evolution of soil science, soil concepts and the epistemic commitments in a timeline Fig. 3.

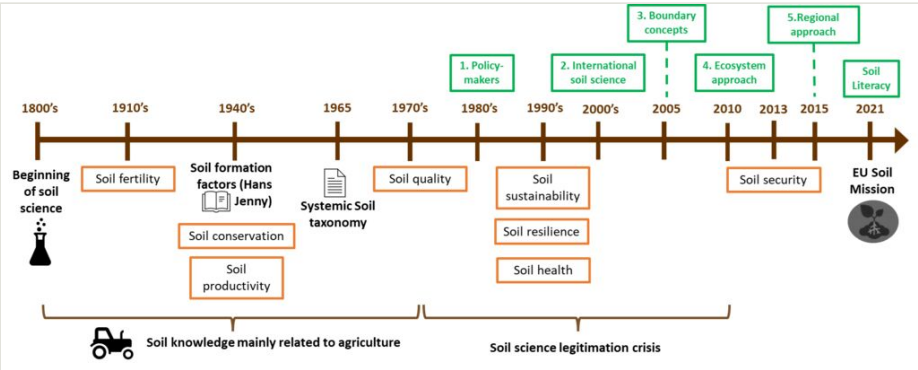

Figure 3. doi

Soil sceince evolution timeline

As mentioned before, by "soil literacy" the EU Soil Mission recognises both a popular awareness about the importance of soil, as well as specialised and practice-oriented knowledge related to achieving soil health (European Commission, Directorate-General for Environment 2021a). By doing so, the Soil Mission seeks to establish a strong link

between soil literacy and soil health. However, the main problem is that the lack of a consistent understanding of what soil is leads to complexities in defining soil health, which in turn influences the development of a concept for soil literacy.

The term “soil health” has a broader meaning and should be considered as an ‘umbrella’ term incorporating many different dimensions beyond ecosystem services and human health. According to the proposal for a Soil Monitoring and Resilience directive, soil health means the physical, chemical, and biological condition of the soil, determining its capacity to function as a vital living system and to provide ecosystem services (European Commission, Directorate-General for Environment 2023). This definition only relates to the functional part of the soils and obscures the different understandings and contexts that offer the great diversity of what soil health may be. The definition needs to consider how it relates to different Sustainable Development Goals (SDGs) and other environmental and socio-economic factors. In that sense, the soil literacy Think Tank agrees on the need to expand the soil health concept beyond the anthropocentric idea related to ecosystem services. It advocates for recognizing soil as a living community from which humans benefit and which they nourish. For example, ‘Soil health means the physical, chemical and biological condition of the soil determining its capacity to function as a vital living system and to provide ecosystem services under different environmental and socio-economic driving forces…’ . This paradigm shift would involve moving from a purely anthropocentric utilitarian approach to one that is ecocentric and deontological, attributing inherent value to all soils.

As mentioned before, soil science has moved from a very local and regional perspective in which the main target of soil literacy were farmers, foresters and landowners, to a more global perspective that tries to tackle several environmental and societal challenges, and where it deals with different target audiences. Until relatively recently, there has been a linear process between researchers/policymakers/public, in which the sciences are seen as the source of knowledge about the soil which needs to be acted on by others, such as policymakers or farmers. The linear model assumes that the main group with knowledge on how soils should be managed are the scientists. However, awareness of the value or importance of soil already exists amongst other different target audiences who observe soil and land degradation taking place. For instance, community-led initiatives (CLIs) challenge this linear model by integrating traditional ecological knowledge, local practices, and experiential learning. Through grassroots networks, CLIs expand soil literacy beyond academic and agricultural contexts, offering diverse, place-based perspectives that enrich both formal education and policy development (Penha-Lopes 2019).

From all of this, we can conclude that there is not a singular soil health idea to transfer in soil literacy. But rather, due to the different viewpoints and management priorities of the target audience, there needs to be an adaptive approach to soil literacy, respectful of multiple perspectives and sources of knowledge. For instance, soil literacy for a farmer might be more practical with strong relational values, for people living in metropolitan areas, soil literacy might be linked to urban sustainability practices.

The lack of soil literacy might not only be limited to citizens, youth, students or farmers, but also extend to policymakers or planners for example. The Think Tank's preliminary desk research did not yield many results related to studies on the current status of soil literacy, or linked topics such as soil awareness raising, in Europe. This can already indicate that further research in the field is needed. Nevertheless, it is worth mentioning the work already done by soil networks like the Global, European and subregional Soil Partnerships on soil awareness and capacity building, including their collection and production of soil awareness raising and educational materials and the events they organise. Similarly, European projects such as LOESS, HuMUS, PREPSOIL, CURIOSOIL, ECHO, Links4Soils and NBSOIL work to collect the best policies and practices around soil health, and soil-related training and courses that are relevant for building the basis of knowledge around soil literacy. As relevant are the outcomes of over 18f projects under the EU LIFE programme between 2012 and 2019, see LIFE Soil Ex-Post Study - Final Report (Giandrini 2023).

Case studies outside of Europe may also serve as examples of soil literacy assessment.

For example, a soil literacy survey was conducted (Johnson et al. 2023) among a population of 3661 school children aged between 13-15 years in three African countries, Ghana, South Africa and Zimbabwe to measure their 'Attitudes, Behaviours and Competencies' to soil, which they termed 'ABC'. The survey showed that although students were generally equipped with a good attitude to (overall 52% positive) and behaviour towards soil (overall 60% engagement), they had little competency as to how to improve soil health (overall 23% knowledge). For example, less than 35% of respondents across all countries knew that soil is living. And less than 13% of students were aware of the important role of soil in climate change mitigation.

The study is supported by The ABC of Soil Literacy Report from the University of Durham (Johnson et al. 2020), which, as mentioned at the beginning of this document, provides a first definition of what "soil literacy" entails: *a combination of Attitudes (Heart), Behaviours (Hands) and Competencies (Head) required to make sound decisions that promote soil health and ultimately contribute to the maintenance and enhancement of the natural environment* (Fig. 4). Through acquired knowledge, people can develop the right attitudes, behaviours and competencies, improving soil management practices and interactions, thus increasing soil health. Additionally, the report offers approaches to measure soil literacy levels targeting school children in three African countries. This is done through a soil literacy toolkit including a survey questionnaire, guidance on how to select samples of the target population, and advice on preparing fieldwork teams.

2.2 Recommendations for soil literacy

Soil literacy should seek to contribute to the creation of a new form of moral agency (concern for soil or soil stewardship) which would foster voluntary action (care for soil) and the implementation of mandatory and clear measures to secure soils (soil protection). A promising pathway for this is through linking responsibility for soils with already articulated governance objectives, such as reducing carbon emissions, ensuring

food security, securing a functional environment, and/or land take limitation (Krzywoszynska 2023). A systemic and holistic approach to soils ensures a robust soil literacy by acknowledging the interrelation between soil and other crucial areas such as water management, circular economy, biodiversity, land use, and human and environmental health. As such, healthy soils are capable of providing a number of ecosystem services that support the achievement of the SDGs, and enhancing health. For instance, the One Health concept defined by the World Health Organisation (an integrated, unifying approach that aims to sustainably balance and optimize the health of people, animals and ecosystems) can be instrumental in establishing a connection between human health, biodiversity, and environmental health, encompassing soil.

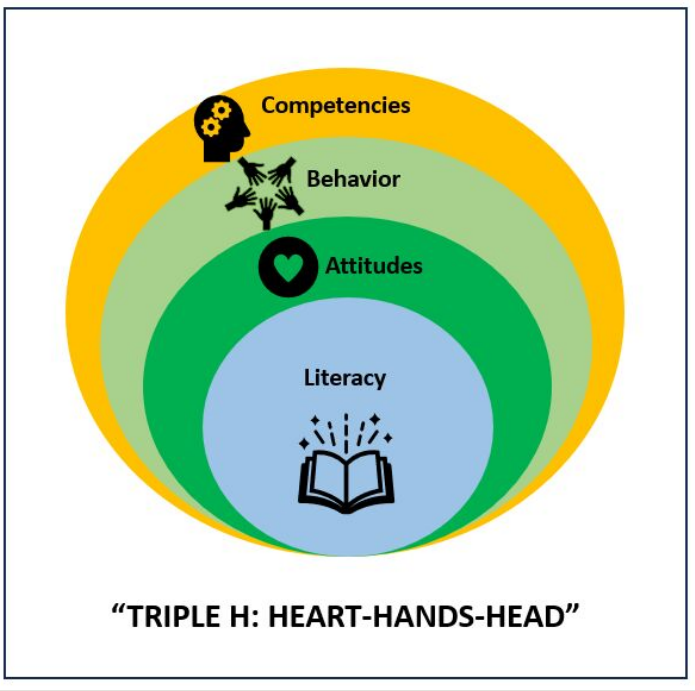

Figure 4. doi

Components of soil literacy emphasizing the ABC (Attitudes, Behavior, Competencies; (Johnson et al . 2020)). Heart in relation to feelings-values, Hands in relation to action-management and Head in relation to abilities-capacities

We need to understand that most people already have knowledge of soils and about soils, although this knowledge may be different to scientific understanding. We also need to acknowledge that different forms of soil knowledge, and different levels of soil knowledge, exist unequally among the different groups and decision makers whose actions have direct or indirect impacts on soil health. Soil literacy should build upon this pre-existing knowledge and values around soils and find ways to build on actions which can lead to "healthy soils" in a just and equitable manner. In this sense, a care network model can play a key role, in which an initial attentiveness to one aspect of soils leads to

a further attentiveness to other interconnected aspects. For example, farmers' attentiveness to soil structure can lead to an attentiveness to soil biota, and result in changes to land management practices so that the needs of soil biota are respected. Attentiveness can thus have a transformative effect on human-soil relations, leading, for example, to a questioning of models of land use which neglect the needs of soil organisms (Krzywoszynska 2023). In terms of engagement, when developing effective soil literacy programs, it is recommended to integrate lessons from sustainability-focused communities as well as locally/regionally relevant knowledge on soils, landscape, land use, etc. Embedding such practical, community-based learning models into soil literacy initiatives can foster a deeper, hands-on understanding of soil health.

In this sense, the Fifth National Climate Assessment - the US Government's pre-eminent report on climate change impacts, risks, and responses - indicates a series of processes and actions to improve the effectiveness of engagement efforts and accessibility to climate information (Marino 2023). These can also be applied to soil literacy:

1. Co-produced or co-created research is a promising approach for soil literacy. This type of research defines non-scientific individuals as experts within their specific context, integrating community-based and scientific insights and solutions. However, integration can fail if power dynamics, goals, trust, and compensation within research teams and epistemologies are not equitable.
2. Establishing clear, measurable objectives with well-defined benchmarks or desired outcomes leads to more effective communication products and processes; bringing key stakeholders into the process at this early stage can improve effectiveness.
3. To inform real-world decision-making, information needs to be calibrated to the needs of target audiences; importantly, communicating relevant information sometimes involves translating science into understandable, accessible and actionable language, whereas in other cases it involves incorporating diverse forms of knowledge into communications products and efforts.
4. Efforts that have been successful in engaging people on climate change across existing ideological and cultural divides generally do so by addressing the things people care about most (this links to the care network model mentioned in previous paragraph).
5. Including intended target audiences throughout the process of developing communication products both promotes procedural justice and increases the likelihood that such efforts meet shared goals.
6. Engagement outcomes also strongly reflect the relationships and levels of trust between intended audiences and messengers. The use of trusted messengers increases acceptance and use of climate change risk information.
7. Pervasive uncertainty surrounding climate change continues to be a major challenge to communication (in our case soil health).

Finally, soil literacy should be addressed/considered at multiple scales and differentiate between sectors, disciplines, priorities, and age groups. One example of how this could be accomplished comes from the concept of 'Learning for Sustainability (LfS)' education

or Education for Sustainability (ESD). The work is based on the green competence framework from the JRC's GreenComp document (Bianchi et al. 2022). The JRC defines 12 broad competence areas clustered on different knowledge, skills and attitude levels. Merging both competence frameworks with the European Green Deal (e.g., Farm to fork strategies), different competence areas were developed, starting from a primitive level of knowledge, skills, and attitudes to more advanced concepts. The Horizon Europe projects GreenSCENT and EC4Clim have contributed to the further refinement, expansion, and enhancement of the Green Competence Framework (GreenComp). GreenSCENT broadened the framework by aligning all competencies with the pillars of the EU Green Deal, ensuring a comprehensive approach to sustainability. Meanwhile, EC4Clim employed a multidisciplinary, transdisciplinary, and participatory process to develop and validate a European Competence Framework (ECF) for transformative change. These efforts have strengthened the applicability and relevance of GreenComp, supporting its role in fostering sustainability competencies across sectors like soil.

If some competence areas can be delineated, a target audience could then be segmented by age, interest, educational background, roles and values e.g., kindergarten, schools, youth (university, experts) or public officers. The focus would be on creating competence-based and not just content-based curricula and training programmes following a progressive multi-level approach which can be presented in a way to highlight the multidisciplinary nature of the issue and the multidimensional nature of solutions.

In summary, achieving soil health depends on the context and needs of the actors involved. There is not "one state" of soil health knowledge that we can achieve, but there is a common basic knowledge that can be shared. Additionally, the definition of soil care is necessary to achieve a societal shift in attitudes, behaviour and competencies, which should include all actors coming from different backgrounds. Fostering soil care can begin with sparking curiosity and raising awareness among all actors, encouraging them to seek knowledge and enhance soil literacy. This, in turn, supports landowners and managers in implementing and justifying sustainable practices that improve soil health (Fig. 5).

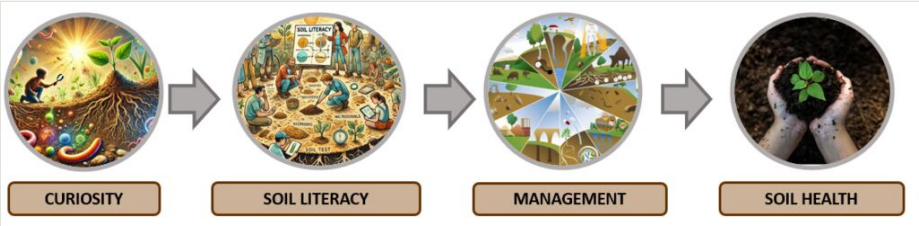

Figure 5. doi

Awareness-to-action continuum for soil health

3.1 Prioritization of knowledge gaps

Table 1

Table 1.

Ranking of the top 10 knowledge gaps identified (a full list of all identified knowledge gaps is given in section 3.3)

Rank	Knowledge gap	Type of knowledge gap
1	Further research is required to develop and validate frameworks that integrate soil as core component into Education for Sustainable Development (ESD) competence models.	Knowledge Application Gap
2	More research is needed in understanding the ecosystem services delivered by different soil types for key actor groups to improve targeted communication.	Knowledge Development Gap
3	More research is needed in evaluating the effectiveness of outreach efforts aimed at engaging primary and secondary school students, as well as the general public, in soil health topics and their impact on attracting new students to university-level soil health programs.	Knowledge Development Gap
4	More research is needed to promote understanding of the key factors that enable and/or prevent foresters, farmers, urban planners, civil engineers and other actors to consider soil health and to adopt soil conservation practices.	Knowledge Development Gap
5	More research is needed on the development of effective pedagogical strategies to foster a deeper understanding of soil's importance. These strategies should promote critical thinking and be state-of-the-art, hands-on and experiential.	Knowledge Development Gap
6	More research is needed in fostering the connection between soil science knowledge and soil stewardship. Instead of focusing on why the gap exists (soil stewardship paradox), studies should explore how, where, and when soil knowledge contributes to responsible soil care.	Knowledge Development Gap
7	More research is needed in assessing how local conditions affect the long-term success of citizen science initiatives in soil health, in terms of scientific data collection and public education goals and other outcomes.	Knowledge Development Gap
8	More research is needed in improving soil health communication strategies that prioritise cultural and social aspects of soils significant to diverse actors.	Knowledge Application Gap
9	More research is needed to identify the key factors that stimulate instructors to adopt new and inspiring teaching methods with regard to soil education.	Knowledge Development Gap
10	More research is needed in creating educational materials tailored to different educational levels and neurodivergent people to encourage student interest, curiosity and engagement.	Knowledge Application Gap

4. Roadmap for Soil Literacy Think Tank

4.1 Key knowledge gaps

1. Further research is required to develop and validate frameworks that integrate soil as core component into Education for Sustainable Development (ESD) competence models.

Living soil can be used as an entry point to the five principles of sustainability education. The first principle, related to the valuing of biocultural diversity, draws a parallel between the vast biodiversity within soil and cultural and social diversity among human communities. By respecting and protecting soil, we can better appreciate the balance necessary to sustain biocultural diversity, fostering a deeper connection to the interdependence of life. The second one is related to the sensitising of all the senses. This emphasises the importance of engaging all the senses in the learning process. It uses soil as a metaphor of the value of ancestral knowledge and the understanding of soil through direct interaction and experimentation. The third principle, “Recognising place”, highlights the need for contextualized learning in sustainability education. Soil provides an ideal lens to explore place-based factors, including geographical, historical, ecological, and cultural dimensions. These considerations help ground sustainability education in the unique characteristics of each environment, promoting a localized understanding of global challenges. The fourth one is “cultivating interconnectedness”, in which soil reveals the intricate relationships between microorganisms, plants, animals, and abiotic elements, demonstrating the interconnectivity that underpins ecological balance. By studying soil, learners can develop a holistic perspective on the interconnected systems that sustain life on Earth. Finally, the fifth principle is the embracing of practical experience. The use of hands-on approaches in education can foster positive environmental behaviors and help the creation of meaningful bonds and values in relation to soil and other related environmental factors (Williams and Brown 2011).

Additionally, soil plays a key role in sustainable development and education. Soil health is an integral factor to address a wide range of topics, including public health, poverty, displacement, inequality, biodiversity loss, water retention capacity, carbon sequestration and climate change. To tackle these interconnected challenges, sustainability education must adopt an interdisciplinary and innovative approach that emphasizes soil's essential role in ecosystem services. As a fundamental resource, soil is also key to achieving the Sustainable Development Goals (SDGs) (Reyes-Sánchez 2024).

Despite the importance of soils, knowledge on different soil processes remains disconnected across various disciplines. This lack of integration hampers the development of comprehensive strategies for sustainable soil management. Research must prioritize the multifunctionality of soil health, examining its connections to major global challenges such as agricultural production, land use management, biodiversity conservation and climate change. Addressing soil degradation requires understanding

the human and natural factors driving soil degradation in terms of erosion, salinization, deforestation, industrial pollution, and unsustainable farming practices.

Advancing soil literacy requires interdisciplinary and innovative educational practices that emphasise the critical role of soil in sustainability. It is essential to train scientists and educators to effectively communicate the importance of soil across all levels of education, fostering a broader understanding of its value. Moreover it is necessary to recognize the complexity of soil science and the need to integrate it with other disciplines to create more comprehensive and cohesive educational frameworks. This will foster a more holistic understanding of soil's role in sustainability (Johnson et al. 2020).

Related Questions:

- How can soil as a core component be effectively integrated into interdisciplinary educational frameworks to teach sustainability concepts across diverse educational settings?

2. More research is needed in understanding the ecosystem services delivered by soils for key actor groups to improve targeted communication.

Soils are essential for maintaining ecosystem functions critical to human well-being, such as nutrient cycling, water filtration and carbon sequestration. However, despite their importance, there is a significant lack of knowledge among key social actors regarding the services provided by soils. Brevik et al. (2022) highlight that understanding the link between soil health and human life is critical to promoting sustainable soil management practices. They suggest that effective soil education programmes tailored to specific groups can help bridge this gap by demonstrating the tangible benefits of healthy soils. Increasing public and policy-maker awareness of the vital role that soils play is fundamental to the implementation of effective soil management strategies.

Psychological barriers often prevent individuals from adopting pro-environmental behaviours. According to Kollmuss and Agyeman (2002), factors such as lack of environmental awareness, social norms and a sense of alienation from nature contribute to this gap between knowledge and action. These barriers can be particularly challenging when communicating the importance of soil health, as people may not recognise the direct impact of soil degradation on their daily lives. Krasny and Tidball (2012) highlight the potential of community-based education and participatory approaches, such as urban gardening and soil restoration projects, to overcome these barriers. These initiatives not only educate participants, but also foster a deeper connection to the environment, which is essential for promoting long-term sustainable behaviours. Additionally, Hallett et al. (2017) emphasise the importance of using innovative tools such as social media, storytelling and interactive apps to engage diverse audiences and effectively communicate the value of soils.

With the increasing focus on the United Nations Sustainable Development Goals (UNSDGs), soils are becoming a key topic. Understanding the functions of soil is important for addressing global challenges and promoting sustainability Keesstra et al.

(2016). However, research is still needed to further explore the knowledge gaps related to soil services supplied to different societal groups. As indicated by Brevik et al. (2022), there is an opportunity to reevaluate and redesign soil curricula by focusing on soil functions instead of the conventional emphasis on soil properties. This approach would prioritise the practical roles soil plays in ecosystems and human systems, fostering a deeper understanding of its applications and value. However, this needs to be acompanied by an analysis of the current level of soil literacy in different sectors, such as agriculture and urban planning, for developing targeted education programmes and communication campaings.

Related Questions:

- How do soils contribute to ecosystem services relevant to key actor groups, and how can these benefits be effectively communicated to enhance awareness and decision-making?

3. More research is needed in evaluating the effectiveness of outreach efforts aimed at engaging primary and secondary school students, as well as the general public, in soil health topics and their impact on attracting new students to university-level soil health programs.

The need for research to evaluate the effectiveness of outreach efforts aimed at engaging primary and secondary school students, as well as the general public, in soil health topics is becoming increasingly urgent. Soil health is fundamental to agricultural productivity, ecosystem services, and climate change resilience, yet it remains poorly understood by the general public and is often underrepresented in formal education systems. This disconnect is especially concerning as soil degradation continues to accelerate in many parts of the globe, with significant social and environmental consequences. Outreach programs offer a potential remedy, but their impact on raising awareness, changing attitudes, and influencing academic and career aspirations in soil science has not been comprehensively assessed.

In broader science education, outreach initiatives have demonstrated measurable success in enhancing engagement and academic interest among students. For instance, programs like "Shadow a Scientist" and "Present Your PhD Thesis to a 12-Year-Old" have been shown to boost students' enthusiasm for science, enhance their understanding of complex concepts, and foster interest in pursuing related academic pathways. Such initiatives also provide a two-fold benefit by improving the communication skills of participating scientists (Clark et al. 2016).

However, despite these proven models in other fields, soil science has not fully leveraged or evaluated similar outreach strategies. Research into the specific outcomes of these programs could offer valuable insights into best practices for enhancing soil literacy and engagement.

The importance of addressing this gap is highlighted by the declining enrolment in soil-related university programs globally. Sources such as Havlin et al. (2010) and Collins

(2008) discuss the systemic challenges facing soil science education, including outdated curricula, insufficient public engagement, and the low visibility of soil-related careers in primary and secondary education. For example, Havlin et al. emphasize the importance of curricular revisions and targeted outreach in reversing enrolment declines, citing successful initiatives at institutions like California Polytechnic State University, where program updates led to a notable increase in student enrolment. Collins highlights the broader, national, and international scale of this issue, highlighting how declining undergraduate numbers weaken graduate programs and reduce the influx of professionals into soil science careers.

In conclusion, targeted research addressing this knowledge gap is essential for advancing soil literacy. Such studies would provide evidence-based guidance for designing outreach programs that effectively engage young learners and the general public while inspiring interest in soil-related careers.

Related Questions:

- What is the long-term impact of soil health outreach programs on primary and secondary school students' interest in pursuing soil science or related university-level education?

4.2 Prioritized knowledge gaps

- **More research is needed to find suitable means to promote understanding of the key factors that enable and/or prevent foresters, farmers, urban planners, civil engineers and other actors to consider soil health and to adopt soil conservation practices.**

A better understanding of the factors that lead soil actors to adopt soil, land and water conservation practices is critical for the development of successful interventions to promote sustainable soil management practices. Mango et al. (2017) provide a comprehensive analysis of such factors in the Chinyanja Triangle region of Africa. The study shows that factors such as the age and education level of the household head, agricultural extension and membership of farmer groups are critical to awareness and adoption of conservation practices. These findings suggest that social inclusion and knowledge transfer play a central role in motivating soil actors to adopt soil conservation practices. In Europe, Fantappiè et al. (2020) emphasise that economic and operational benefits - such as productivity increases and cost reductions - are key drivers for the adoption of soil conservation practices. In Sicily, farmers who perceived management benefits were more likely to perceive positive environmental benefits, suggesting a close link between economic efficiency and environmental awareness. Lavergne et al. (2024) draw attention to another important issue: the under-representation of studies on the global South, particularly on environmental issues. This knowledge gap could affect the development of global solutions to soil degradation if certain regions are not sufficiently included. Furthermore, Charzyński et al. (2022) highlight the need for educational programmes to focus more on concrete solutions to soil degradation problems in order to

create a deeper awareness and commitment to sustainable practices among farmers. This suggests that both cultural and practice-based approaches are needed to promote the adoption of sustainable soil conservation measures.

Nonetheless, soil degradation is a multifaceted problem, influenced by activities in many sectors, including urban development, forestry, infrastructure construction and industrial activities. For example, urban expansion is a growing threat. Research by Barbero-Sierra et al. (2013) highlights that "urban sprawl in peri-urban areas leads to the fragmentation of fertile soils, reducing their productivity and ecological functions". This is of particular concern, as urban settlements often expand into areas of high soil fertility, making "urban sprawl the most active agent of desertification in Spain". Soil sealing - covering soil with impermeable materials for roads, buildings and other infrastructure - is one of the most devastating threats to soil ecosystem services, effectively halting critical functions such as water filtration, carbon sequestration and nutrient cycling.

Unsustainable forestry practices, such as clear-cutting, contribute to soil erosion, loss of organic matter and disruption of soil structure, increasing the risk of landslides and reducing biodiversity. According to Pimentel and Kounang (1998), "deforestation and poor land management practices accelerate soil erosion rates, often beyond the natural regeneration capacity of the soil".

The effects of industrial pollution are also critical. Research by Nagajyoti et al. (2010) shows that "heavy metal contamination from industrial activities leads to deterioration of soil microbial activity, nutrient cycling and plant productivity, resulting in long-term soil degradation".

Given these multiple threats, it is essential to adopt a holistic approach to soil protection that addresses the drivers of soil degradation across all sectors. This includes not only promoting sustainable agricultural practices, but also promoting sustainable urban planning, responsible forest management and the development of green infrastructure to mitigate soil sealing, erosion and pollution. By broadening the focus of key factors that enable and/or prevent soil protection efforts, we can more effectively safeguard soil health as a critical resource for environmental resilience, climate regulation and human well-being.

Related Questions:

1. What socio-economic and cultural factors influence and prevent the adoption of soil conservation practices by farmers and other stakeholder groups?
2. How can education be adapted to promote and enable the adoption of sustainable practices?

- **More research is needed on the development of effective pedagogical strategies to foster a deeper understanding of soil's importance, promoting critical thinking and be state-of-the-art, hands-on and experiential.**

In addition to the lack of integration of soil science and management practices within the educational curricula, traditional teaching approaches are often relying on passive learning methods that primarily involve receiving information without active participation and are only able to provide basic knowledge. These approaches fail to develop critical thinking and problem solving skills in students, which are required to understand and address the complexity of soil related issues and processes (Amador 2019). The complexity of soil science derives from the need to understand the interaction of the different components like atmosphere, biosphere, hydrosphere, lithosphere, ecosphere and anthroposphere, requiring students and practitioners to have the knowledge to understand these interactions, while also possessing the skills to collaborate across the various disciplines (Al-Ismaily et al. 2023). Therefore, the study of soil science requires contextualised, holistic, practical and experiential learning approaches centred around living soil as a way to foster a deeper ecological understanding and improvement of sustainability literacy (Williams and Brown 2011).

Practical and hands-on experience in soil science teaching can be understood in two ways: The first one refers to more practical approaches in the learning process of students, focusing on innovative pedagogical techniques like Problem Based Learning (PBL), Soil Skills (SSK) or Soil Judging Contest (SJC). The second approach focuses on more experience based and hands-on methods, in which students get the opportunity to directly observe and interact with soil.

As well, inquiry-based learning approaches, such as Soil Skills (SSK) and Soil Judging Contest (SJC) can enhance the engagement of students, creating dynamic learning environments. SJCs are a program based on competition, teams will evaluate soil properties and features (e.g. soil texture, structure, color) and make informed judgements based on their knowledge and observations. While, in the case of SSK, students have to address real case studies by applying interdisciplinary approaches, considering the relations between soil, water, landscape and community to solve problems (Al-Ismaily et al. 2023).

Moreover, the use of hands-on and interactive activities with soil has an advantage, as experiences associated with unstructured activity in a natural setting can positively influence environmental behaviour and can produce meaningful relationships with nature and the environment, especially for children (Williams and Brown 2011).

This can also be implemented through project based learning approaches like fieldwork or field trips, including soil sampling and measuring of parameters, which generates higher levels of student engagement and a better understanding of soils as an ecosystem component and how it can be related to other disciplines (Aran 2024). The use of practical and interactive experience approaches can further foster awareness and understanding of the value of soil, increasing soil stewardship (Williams and Brown 2011). Studies indicated that early interaction with natural environments plays a crucial role in shaping social engagement, well-being, and lifelong connections with nature. Children who regularly experience nature tend to be more active, engage more with their communities, and develop higher self-esteem and resilience to stress. These benefits

extend into adulthood, fostering continued participation in social and environmental initiatives (Hartig et al. 2014).

Related Questions:

1. What pedagogical strategies can be integrated to improve the understanding of soils in different age group students?
2. How can pedagogical strategies be adapted depending on students/ schools location (students from urban or rural areas, living near mountains or plains, agricultural practices around them..?
3. What is the place of soil in the holistic approach of environmental (and socio-economic) undertanding?

- **More research is needed in fostering the connection between soil science knowledge and soil stewardship. Instead of focusing on why the gap exists (soil stewardship paradox), studies should explore how, where, and when soil knowledge contributes to responsible soil care.**

There is a growing need for research that bridges the gap between soil science knowledge and soil stewardship. The idea of "stewardship" involves the conscientious and responsible management of resources entrusted to one's care. In this sense, a mix of factors such as socio-economic conditions, policy frameworks, cultural perceptions, and education systems play significant roles in determining whether knowledge is translated into action (Prager and Posthumus 2011).

The study by Neaman et al. (2024) points out that agricultural professionals, particularly those with academic or urban backgrounds, may possess extensive technical soil knowledge without a corresponding level of care for soil health. This disconnect calls for further research to clarify the relationship between knowledge acquisition and stewardship behaviours. As well, studies on environmental knowledge and behaviour, such as those by Kollmuss and Agyeman (2002), illustrate this "knowledge-action gap" across environmental fields. They suggest that psychological, social, and contextual factors heavily influence whether knowledge translates to stewardship behaviours. However, while much focus has been placed on the reasons behind the soil stewardship paradox— a disparity between knowledge without a corresponding sense of care and care without a corresponding level of knowledge (Neaman et al. 2024) —less attention has been given to understanding how, where, and when soil knowledge can be effectively applied to promote sustainable soil management practices.

Identifying the specific contexts and conditions in which different forms of soil knowledge (e.g., scientific, traditional, or experiential) leads to responsible soil care would contribute significantly to fostering a culture of stewardship and ensuring that soil management practices are both effective and sustainable. Furthermore, understanding the pathways that link soil knowledge to action could uncover mechanisms for improving the adoption of sustainable soil practices.

Related Questions:

1. How can different forms of soil knowledge (scientific, historical traditional, experiential) contribute to responsible soil care?

2. What are the specific contexts and conditions in which soil knowledge leads to effective stewardship practices?

- **More research is needed in assessing how local conditions affect the long-term success of citizen science initiatives in soil health, in terms of scientific data collection and public education goals and other outcomes.**

In terms of soil health, there is a lack of targets and indicators for its monitoring in the global context as well as a lack of a common method, or a unified protocol that can be applied. Additionally, soil monitoring presents another degree of complexity as soil quality presents a high variability in cities across short distances, making regulation difficult (Price et al. 2024). An extra challenge is the lack of recognition from both policy makers and the general public of the importance of healthy soils as an environmental asset of equal importance as clean air and water. Participatory approaches can play a key role to engage the general public in scientific inquiries about soils and soil health, which can cultivate awareness and soil values (Price et al. 2024).

It is important to keep in mind that integrating citizen science into soil health initiatives presents both opportunities and challenges, particularly in ensuring the scientific validity of data collection and the effectiveness of proposed remediation methods. While citizen engagement can enhance data collection and public awareness, there is a risk that misinterpretations of scientific facts and the promotion of unproven soil management practices may undermine long-term outcomes. For example, certain remediation techniques, despite being scientifically discredited, continue to gain traction among non-experts. Addressing this challenge requires structured collaboration between soil experts and citizen initiatives, fostering mutual understanding through capacity-building efforts, transparent communication, and scientifically sound methodologies. Further research is needed to assess how local conditions influence the success of such collaborations and to develop strategies that align citizen-driven efforts with evidence-based soil health management.

Participatory approaches can be classified into three categories based on the phase of involvement of participants or the general public: contributory, collaborative or co-created. Contributory approaches are designed by scientists, and participants are used to contribute to data. In collaborative approaches, participants can also help refine the project design or analyse the data. In co-created approaches, participants are involved from the initial design and conceptualization of the research question (Wadoux and Mcbratney 2023).

A study highlighted by the European Joint Programme SOIL emphasizes the underutilized role of participatory citizen science in advancing soil health. The research showcases how engaging the public not only enhances data collection but also fosters a

broader commitment to sustainable soil management (Mason et al. 2024). In addition, Hou et al. (2020) highlight the potential of emerging technologies, including 5G telecommunications, big data, and machine learning, to revolutionize soil data collection and analysis.

In general, further research is needed to assess how local conditions influence the success of such collaborations and to develop strategies that align citizen-driven efforts with evidence-based soil health management and how they can effectively contribute to data collection and public education goals.

Related Questions:

1. How do local environmental, social, and policy conditions influence the long-term success of citizen science initiatives in soil health, particularly in ensuring scientifically valid data collection and effective public education?

2. What strategies can enhance the integration of robust citizen science into soil health monitoring while ensuring scientific rigor, preventing misinformation, and fostering productive collaboration between soil experts and the public?

- **More research is needed in improving soil health communication strategies that prioritise cultural and social aspects of soils significant to diverse actors.**

Understanding effective strategies for soil science communication and outreach is essential for fostering meaningful engagement with diverse social actors. Brevik et al. (2022) highlight the importance of integrating cultural and social dimensions in soil education to enhance public connectivity to soil, suggesting that storytelling and social media engagement can resonate with non-experts by linking soil to quality of life and cultural heritage. This finding highlights the need to align communication strategies with the cultural and social contexts of different audiences, using concepts like soil health and terroir, which make soil science more accessible and meaningful.

Research indicates that individuals who are dissatisfied with their financial situation are more likely to express skepticism toward eco-social policies and prioritize welfare-related concerns over environmental challenges. This suggests that lower-income groups may perceive climate and environmental action as a less immediate necessity compared to economic security. Conversely, as financial stability improves, individuals are more inclined toward environmental advocacy, as they can afford to prioritize post-materialistic values. However, financial satisfaction alone does not necessarily lead to stronger eco-social engagement (Otto and Gugushvili 2020).

Additionally, trust in public institutions and egalitarian values appear to be more decisive in shaping environmental attitudes than factors such as income, education, or place of residence. This highlights the importance of addressing ideological and perceptual divides when fostering broad-based environmental engagement and communication strategies (Otto and Gugushvili 2020).

Furthermore, socioeconomic disadvantage—characterized by lower education and income levels—as well as spatial marginalization, such as living in rural or economically declining areas, should be better recognized in the design and implementation of climate and environmental policies in the EU. Ensuring equitable access to knowledge and opportunities is crucial to fostering inclusive participation across all societal groups (Schüle et al. 2019).

Effective communication on soil health requires strategies that resonate with diverse audiences and foster meaningful connections to the environment. Evidence from the GEN Ecovillage Impact Assessment highlights the importance of participatory, narrative and experiential communication methods (Kovasna and Mattos 2017). Ecovillages, traditional or intentional communities that aim to become more environmentally sustainable, show that soil health messages are most effective when embedded in personal stories, cultural practices and community experiences. The study notes that "76% of ecovillages regularly engage in educational activities related to environmental sustainability, using both formal and informal channels". One key strategy is to use storytelling as a tool for environmental communication. By sharing stories about local food systems, land regeneration and community resilience, complex ecological concepts become more accessible. These approaches can be researched and adapted to soil literacy campaigns to foster emotional connections and lasting awareness.

However, current approaches are often limited in addressing how empirical and scientific knowledge can be communicated and integrated in ways that foster genuine engagement. As Krzywoszynska (2019) explains, soil science communication frequently overlooks the knowledge and meaning-making practices within local communities. Her work on sustainable soil management in England reveals that a focus on scientific knowledge alone can isolate local, experiential understandings of soil and calls for strategies that consider these community-rooted insights.

Furthermore, Krasny and Tidball (2012) explore how civic ecology practices provide a model for community-centred stewardship, illustrating the importance of grounding environmental communication within local, culturally relevant practices. In this context, soil communication must not only inform but also foster connections that enable diverse stakeholders to see their roles in soil stewardship. These insights point to a significant knowledge gap in soil science outreach: few studies have explored how communication strategies might effectively initiate step-by-step dialogues that bridge scientific and local knowledge frameworks.

Addressing this gap may aid in developing inclusive, context-sensitive communication strategies that better support sustainable soil management practices across diverse regions and communities.

Related Questions:

1. What strategies can create dialogue between empirical, practical, and scientific knowledge about soils to engage diverse social actors?

2. How can local knowledge be integrated into soil science communication to foster connections between different social actors and produce stewardship?

- **More research is needed to identify the key factors that stimulate instructors to adopt new and inspiring teaching methods with regard to soil education.**

Soil science education faces the challenge of developing innovative teaching methods that both convey specialised knowledge and engage a broader audience from various disciplines. While Brevik et al. (2022) highlight the need to organise content in ways that combine in-depth knowledge with interdisciplinary perspectives, studies investigating how educators can be motivated to implement these methods remain sparse. The integration of practice-oriented approaches, such as experiential learning emphasised by Williams and Brown (2011), offers an opportunity to make complex soil topics tangible and to underscore their significance for issues such as climate adaptation, biodiversity, and human health.

Particularly, the idea of presenting soil not solely as a scientific subject but as a nexus between ecological and social systems underscores the relevance of interdisciplinary approaches. Brevik et al. (2022) stress that making soil knowledge accessible to students from other disciplines is crucial for raising awareness of soil's importance in global sustainability challenges. However, educators often face practical challenges such as time and resource constraints, which make it difficult to integrate innovative methods into their teaching practices. Krzic et al. (2024) demonstrate how incorporating the concept of "Soil Health" into curricula in Canada can strengthen the connection between soil science and sustainability education, yet also reveal the practical barriers that hinder educators from broadly implementing these concepts.

Furthermore, there is insufficient clarity on which resources and incentives would most effectively support educators. While practical, hands-on approaches such as field studies and the use of soil biocrusts de Lima and Rojas (2022) demonstrate significant potential, questions remain about how to embed these methods into interdisciplinary frameworks. Field (2017) proposes deepening soil understanding through concepts such as "knowing soil, knowing about soil, being aware of soil" across different levels of education. This could not only achieve specialised learning objectives but also enhance the broader relevance and acceptance of soil topics. Combining practice-oriented and interdisciplinary approaches thus represents a promising avenue for advancing soil science education. However, there is a lack of systematic studies exploring how these approaches can be effectively implemented, the factors influencing educators' acceptance of such methods, and ways to overcome practical barriers.

Related Questions:

1. What factors influence the willingness of educators to adopt practice-oriented and interdisciplinary teaching methods in soil science education?

2. What educational resources or incentives are most effective in promoting the adoption of innovative teaching methods?

3. How can practical barriers, such as time and resource constraints, be overcome to support the implementation of these approaches?

- **More research is needed in creating educational materials tailored to different educational levels and neurodivergent people to encourage student interest, curiosity and engagement.**

Developing educational materials tailored to diverse educational levels and to individual needs (e.g. neurodivergent individuals) is essential for fostering student engagement. Neurodivergent students, including those with autism spectrum disorder (ASD) and attention-deficit/hyperactivity disorder (ADHD), often encounter systemic barriers in traditional educational settings, which can impede their learning experiences and engagement (Durgungoz and Durgungoz 2025).

Despite this, existing studies often lack comprehensive strategies for adapting curricula to accommodate diverse learning preferences and sensory sensitivities, which are crucial for effective engagement. Additionally, there is still a lack of understanding regarding how such efforts not only impact immediate learning processes but also influence academic success, well-being, successful transitions, and life outcomes beyond higher education (McDowall and Kiseleva 2024).

This research gap is especially relevant for all students at different education levels, from young learners in primary education, to adults with advanced knowledge. In early education, structured and concrete learning materials help build a strong foundation. As students move through secondary and higher education, learning becomes more abstract and complex to encourage critical thinking and independence.

When it comes to soil education, there is a lack of standardized and adaptable materials across these levels. While resources exist, such as the British Society of Soil Science's educational materials or the Soils 4 Teachers platform, they are not widely integrated into curricula and vary in content and accessibility. This inconsistency creates gaps in soil literacy, making it difficult to ensure that students at all levels gain a comprehensive understanding of soil's role in environmental and societal systems. Developing structured, adaptable, and standardized soil education materials tailored to different learner needs and levels is essential for improving engagement and learning outcomes.

Related Questions:

1. What strategies can be used to develop standardized and inclusive soil education materials that accommodate diverse learning needs and levels, including those of neurodivergent students?

4.3 Overview table

The Soil Literacy Think Tank has identified a total of 18 Knowledge gaps, which are presented in the following table along with the respective Actions and Bottlenecks. Additionally, these Knowledge Gaps have been classified in Figure 7 following the Attitudes (Heart), Behaviours (Hands) and Competencies (Head) framework referenced in previous sections from the ABC of Soil Literacy Report from the University of Durham (Johnson et al. 2020). These classifications allow a better understanding of the societal impact of the identified Knowledge Gaps. As it is presented in Fig. 6, the majority of the knowledge gaps are targeting Behaviours and Competencies, with a few that have relevance across the three ABC components. For future work, the Think Tank will take into consideration the identification of more Knowledge Gaps targeting the Attitudes component of the framework.

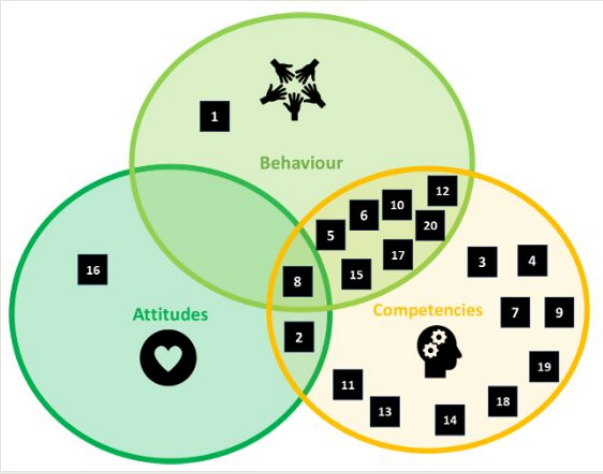

Figure 6. doi

Classification of the Soil Literacy Knowledge gaps within the Attitudes, Behaviour, Competencies framework (ABC)

Soil literacy knowledge gaps overview table

An overview of the soil literacy knowledge gaps and can be found under Suppl. material 1.

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Supplementary material

Suppl. material 1: Soil Literacy Knwoledge gaps overview 2025 doi

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