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Mapping soil knowledge: A qualitative comparison of laypeople's understanding of soil and expert-identified essentials in Germany

Johanna Schaal *, Nicolas Neef, Siegmar Otto

Department of Sustainable Development and Change, University of Hohenheim, Wollgrasweg 49, 70599 Stuttgart Hohenheim, Germany

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ABSTRACT

Soils play a critical role in mitigating climate change, conserving biodiversity, and supporting human well-being. To ensure a sustainable future for soil, raising the publićs awareness of soil conservation and enhancing their knowledge is crucial. This qualitative study captures and represents laypeople's soil knowledge through concept maps. These concept maps, along with the associated knowledge, were gathered through semi-structured interviews based on the approach of didactic reconstruction and are compared with expert-identified essentials for laypeople. These Laypeople demonstrate basic knowledge of certain aspects, such as the decomposition process, organisms and plant interactions with soil, and human impacts on degradation. However, notable gaps exist in soil genesis, its role in climate protection, and perception of soil texture, types, and processes, including misconceptions about erosion. This study underscores the importance of education and awareness-building in soil conservation efforts. The concept maps generated in this study can serve as a basis for this purpose.

1. Introduction

Healthy soils play a crucial role in supporting sustainable development and achieving the Sustainable Development Goals (SDGs), including zero hunger, water quality, climate mitigation, and sustainable land use (Lal et al., 2021). Soils are pivotal for conserving biodiversity, producing biomass, and providing ecosystem services (Löbmann et al., 2023). The European Commission's "Horizon Europe" project, which prioritizes soil health, reflects a multinational commitment to protecting and enhancing soil quality (Com, 2021; Lal et al., 2021). On one hand, political measures are required for soil conservation, which establish agricultural and forestry standards and promote research institutions dedicated to soil protection. On the other, it is key to involve citizens in protective measures and to create general awareness of soil and soil conservation (Pino et al., 2022). Engaging citizens is addressed in the European strategy for soil protection, which, among other things, highlights the lack of soil knowledge in environmental education (Corrochano et al., 2023). Soil knowledge includes understanding soil properties, composition, functions, and its significance for ecosystems, conservation, human well-being, and the consequences of soil degradation (Löbmann et al., 2023). Educating people about soils and their environmental significance can shift public attitudes and behaviors toward prioritizing soil protection and conservation (Brevik et al., 2022b; Charzyński et al., 2022; Duoblienė et al., 2023; Durmaz & Fidanoğlu, 2023). Many everyday decisions, ranging from private gardening and food consumption to recreational habits and political engagement, can cumulatively affect soil health (Brevik et al., 2022a; Kastner-Wilcox et al., 2023). While laypeople may not interact with soil professionally their indirect influence through lifestyle choices and civic behavior makes them a key audience for educational efforts. Unlike experts who often possess systemic knowledge and engage in land stewardship, laypeople tend to underestimate soil's fragility and importance, leading to uninformed behaviors (Brevik et al., 2022a). When people value soil as a living system essential to life, they are more likely to support politicial measures for land-use protection, resist land sealing in their own garden, consume in soil friendly ways (regionally and organically), or engage in citizen science and local conservation initiatives (Charzyński et al., 2022). This bottom-up approach, promoting change in attitude and behavior through knowledge and awareness, can contribute to long-term soil protection complementing top-down strategies (Brevik et al., 2022a). Knowledge holds a significant role in shaping attitudes and behavior, as one cannot act appropriately without understanding the why and how (Levine & Strube, 2012). Knowledge, as an active construct that is utilized in specific contexts, forms the foundation for such changes (Greeno et al., 1996; Novak, 2010). It encompasses the entirety of cognizance and aptitudes that individuals employ in problem-solving endeavours, including theoretical insights and practical guidelines for everyday actions (Duerden & Witt, 2010; Gropengießer & Marohn, 2018; Heimlich & Ardoin, 2008; Levine & Strube, 2012; Thieroff et al., 2021). To enhance people's knowledge of

* Corresponding author.
E-mail addresses: j.schaal@uni-hohenheim.de (J. Schaal), nicolas.neef@uni-hohenheim.de (N. Neef), siegmar.otto@uni-hohenheim.de (S. Otto).

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soil, it is necessary to take stock at first. The everyday ideas and personal experiences of individuals are just as important as subjective knowledge, because they form the foundation for educational approaches and the enhancement of knowledge (Burnham et al., 2023; Kastner-Wilcox et al., 2023; Kattmann, 2022; Kelemen-Finan et al., 2018). Concept mapping (Novak, 2010), offers a unique approach to characterize knowledge. Concept maps visually represent the interrelationships between concepts and propositions, allowing for a comprehensive depiction of the structure of knowledge. This method provides valuable insights into laypeople's soil knowledge, including their perceptions, misconceptions, and focus areas (Novak, 2010).

Few studies exist on laypeople's soil knowledge, with the majority utilizing surveys to record the perceptions of pupils, students, and teachers regarding soil (Appendix A) (Charzyński et al., 2022; Dazzi & Lo Papa, 2022; Huynh et al., 2020; Kastner-Wilcox et al., 2023; Pino et al., 2022; Rossiter et al., 2015). Hardly any studies reflect the perspective of the non-expert adult population, and do not use concept mapping as visualization tool for soil knowledge characteristics. As an initial step, the aim of this qualitative study is to capture laypeople's knowledge of soil and illustrate it through concept maps. Additionally, experts were consulted and asked about fundamental soil knowledge that they consider central and important for laypeople, to contextualize the laypeople's understanding. The research questions guiding this study are as follows:

RQ1: What are the main characteristics of laypeoplés soil knowledge?

RQ2: How can the broad spectrum of expert knowledge be used to contextualize the knowledge of laypersons?

1.1. Theoretical framework

1.1.1. Characterizing knowledge

When it comes to knowledge, the study primarily refers to definitions of knowledge according to Novak (2010). In this context, knowledge arises through the linking of concepts into propositions. A "concept" refers to an abstract idea or a general understanding of a phenomenon. Concepts serve as the building blocks of knowledge. Propositions consist of two or more concepts that are connected to each other through relationships. They indicate how concepts are related or interact in a specific situation or context. Further, Kaiser and Fuhrer (2003) identified four forms of knowledge that must be acknowledged as significant factors in soil awareness and conservation efforts. *Declarative knowledge* involves the ability to articulate specific facts or concepts related to a topic, answering questions such as "what is" soil. *Procedural knowledge* addresses the question of "how to" and focuses on action-oriented abilities such as gardening techniques to enhance soil fertility. *Effectiveness knowledge* pertains to understanding "when" and "why" to implement different actions to protect soil, requiring the successful application of knowledge in various contexts guided by cost-benefit reasoning. *Social knowledge* influences soil protective behavior by drawing from socially shared norms and observations of others' behaviors, with individuals often conforming to social expectations to gain approval. Initially, acquiring declarative and procedural knowledge about soil is necessary before effectiveness knowledge becomes relevant, while social knowledge can still influence behavior patterns, even if the other forms of knowledge align. In summary, increasing soil knowledge is likely to be effective when different forms of knowledge align towards a shared goal of e.g. soil protection (Kaiser, 2021; Kaiser et al., 2007, 2010; Roczen et al., 2014). Therefore, this study aims to utilize Novak's definitions of concepts and propositions to depict what is commonly known about soil. Given his definition of knowledge, concept mapping is assumed to best characterize soil knowledge.

2. Materials and Methods

In the context of a qualitative semi-structured interview-based study, the knowledge of laypeople and what experts consider to be important for them about soil is captured according to the didactic reconstruction by Kattmann (2022). This study follows an exploratory research approach, as defined by Stebbins (2001), to generate new insights and understand the complex phenomena of soil knowledge among laypeople, making it particularly suited for this under-researched area. The subject clarification phase and capturing learning perspectives constitute essential steps in this study (Reinfried et al., 2009). However, the third step, involving content reduction and elementarization, is content for further investigation.

2.1. Participants

For the interviews, 15 laypeople varying in socio-demographic data were chosen, as outlined in Appendix B, with the sample size being deemed adequate for an exploratory study (Guest et al., 2006). To ensure a heterogeneous sample, we combined self-activation and snowball sampling (Duit et al., 2012). Initial recruitment took place via university and personal networks, followed by participant referrals targeting variation in socio-demographic data to avoid potential bias about lay soil knowledge due to homogeneity. Additionally, the study obtained written consent from all participants and received ethical approval (Ref. No. 2023/31_Neef). Moreover, five soil experts were interviewed to identify the fundamental concepts of soil knowledge they consider relevant for laypeople, aiming to determine whether these basics align with or differ from the concepts understood by laypeople.

2.2. Data collection

For the qualitative interviews, a semi-structured interview approach aligned with "The Quality of Qualitative Data – Manual for Conducting Qualitative Interviews" by (Helffrich, 2011) was used. The questionnaire was designed based on literature research focused on presenting soil knowledge in a way accessible to laypeople, and to explore the individual everyday conceptions and understandings of the participants without imposing scientifically established categories of soil science on them. The questions, see Appendix C, were divided into four question blocks: soil components, soil genesis and degradation, ecosystem services and soil protection (Beblek et al., 2019; Charzyński et al., 2022; Dazzi & Lo Papa, 2022; Drieling, 2015; Hartemink et al., 2014). The same guideline was formulated for the expert interviews but was treated as a flexible tool for the interviewer rather than a strict questionnaire. It served as a kickstart to initiate the conversation and as a reference point for the interviewer to ensure that the discussion covered topics relevant to the study (Appendix D). The interviews were pretested with a volunteer master's student from agricultural science who specialized in soil parameter modelling, and three laypeople volunteers. The pretests focused on assessing whether the questions were understandable and meaningful, specifically evaluating if the expert and laypeople began to speak freely or if the questions were too complex or inadequately formulated in a pedagogical sense, potentially overwhelming the lay participants. The interviews were audio recorded.

2.3. Data analysis

The laypeoplés audios of the interviews were transcribed by the first author, whereas the expert interviews were transcribed using transcription software (Digitalmeister GmbH, n.d).

As well as the experts, laypeoplés transcripts were reduced to essential content using Mayring's qualitative content analysis method (2015). To ensure reliability, validity and intersubjective traceability, three laypeoplés transcripts and one expertś transcript were analyzed by another scientist from our department. The results were compared, discussed and adjusted in the event of discrepancies (Kuckartz, 2014; Mayring, 2015). The paraphrases given by experts were aggregated. By combining their insights, which are considered broadly applicable and central to fundamental soil knowledge, the study was able to create a structured overview that effectively informs and enhances the contextualization of lay knowledge.

2.3.1. Concept mapping

We decided to map the responses and the results of qualitative content analysis using the concept map methodology after (Novak, 2010) and (Kinchin et al., 2010). A graphical concept map consists of concepts (nodes) and edges (relationships) between concepts that visualize the underlying proposition of a subject (Fig. 1) (Jünger & Gärtner, 2023). Concept maps serving both, as means for data collection and as an interpretive tool (Enders et al., 2020; Zak & Munson, 2008; Kinchin et al., 2010; Zartl, n.d).

Each layperson's concept map and the aggregated expert map were constructed from sentences that had been previously categorized into five predefined categories and were colored according to these categories as represented in Table 1.

Particular attention was paid to maintaining the linking words as close as possible to the original wording used by laypeople to avoid distorting their concepts and propositions about soil. Concept maps were built as non-hierarchical network structures using Neo4j, a native graph database which stores data as nodes and relationships (Eifrem, 2000a). Neo4j was further utilized to evaluate the betweenness centrality, fragmentation, and nodes, and relationships count of each network (Fahd & Venkatraman, 2021; Gricourt et al., 2024; Wang, 2024).

The betweenness centrality is a metric used to quantify the importance of a node within a network by calculating the number of shortest paths between all other nodes that pass through that particular node. The betweenness centrality is represented as a numerical value. A high score indicates that the node has a large number of shortest paths passing through it, thus playing a central role in connecting various propositions in the network (Jünger & Gärtner, 2023; Thurn, 2021). Visualization of the nodes was accomplished via Neo4j Bloom (Eifrem, 2000b). Consequently, node sizing served as an indicator of betweenness centrality; larger nodes correspond to higher betweenness centrality values. The length of the arrows connecting the nodes holds no significance.

The number of isolated units correspond to the level of fragmentation (Schaal, 2006).

2.3.2. Comparison between aggregated expert and laypeoplés concept maps

To answer the research questions, the concept maps are subjected to comparative analysis both amongst themselves and in relation to the aggregated expert map, focusing on aspects of nodes and relationships count, fragmentation, and betweenness centrality. To facilitate a meaningful comparison of betweenness scores across laypeople and between laypeople and the expert map, ranking and normalization of scores were conducted, restricting the analysis to concepts that are represented in at least 15 of the 16 expert and laypeoplés networks. Additionally, an in-depth examination of the propositions within each category was undertaken to discern discrepancies in terms of missing, inaccurate, and frequently employed concepts, propositions, and thus knowledge across the maps.

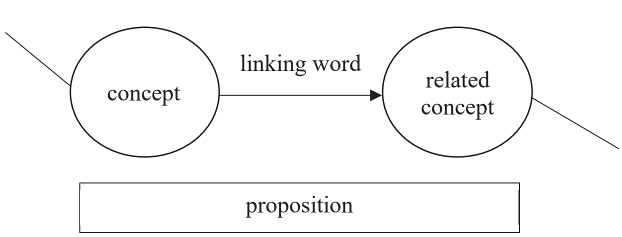

Fig. 1. Concept map format according to Novak 2010.

Table 1
Categories and their representative node coloring of the key concepts formulated by laypeople as well as the experts. For each category an example sentence is included.

Category	Node color	Example of laypeoplés sentences
Soil genesis	Green	*"Soil genesis needs thousands of years"*, ChSe
Soil components	Dark green	*"Soil consists of earth"*, JoDo
Soil degradation	Pink	*"Soil degrades through dryness which causes compaction"*, JuRe
Ecosystem services	Light blue	*"Soil provides food"*, GaEl
Soil protection	Dark blue	*"Crop rotation can protect soils*", LaBe

3. Results

3.1. Quantitative metrics of the concept maps

The observation in Table 2 reveals a relatively heterogeneous number of nodes and relationships present in laypeople's soil networks. This ranges from fewer than half of the nodes and less than a quarter of the relationships used by experts to almost as many nodes and relationships. Nevertheless, an increasing node count does not always lead to an increase in relationships and a more interconnected network, as is the case of participant gael compared to jodo, chst, phul, and tite (the participants were assigned an alibi; see Table 2). Approximately half of the laypeoplés networks are fractured into two, three, or four separate concept maps, lacking a unified understanding of soil. Fracturing is represented in concept maps with few nodes and relationships, as well as in larger networks, but the degree of fracturing decreases as the number of nodes and relationships increases.

3.1.1. Betweenness centrality

The betweenness centrality score is visualized via node size (Figs. 3, 4, and 5). Soil knowledge amongst all interview partners differs, as do the concept maps, and thus the central role of each node in connecting all other nodes or propositions. Therefore, only the normalized ranks of the 13 nodes that are listed in at least 15 of all 16 networks are compared. As the study focuses on soil knowledge, the node soil is consistently ranked as highly relevant in all concept maps when bridging all other soil-related propositions. Therefore, it is not included in the comparison of the betweenness centrality of similar nodes but can be observed as well as all other ranked values in Table 3.

Examining the laypeoplés ranks for nodes in Table 3, the ranks for each node are mostly unevenly distributed. However, for food, weathering, and degradation, most laypeople assign a medium, subordinate, or central role in linking different statements in the network. One person

Table 2
Soil knowledge concept map data of laypeople and aggregated expert map.

Participants	Nodes	Relationships	Fracturing
Pema	25	22	4
isso	26	25	3
chse	28	30	1
lubi	32	42	1
juba	33	45	3
lust	36	39	1
naev	36	41	3
jaan	37	50	1
gael	38	56	2
jodo	39	50	2
chst	40	50	1
phul	40	49	2
tite	41	50	1
jure	42	59	1
labe	63	80	1
experts	77	136	1

Table 3
Normalized ranks of betweenness centrality scores of analogous nodes in laypeople's concept maps and the aggregated expert map. Normalized scores range from zero to one, with one indicating high betweenness centrality, thus playing a central role in connecting various propositions in the network while numbers close to zero indicate low betweenness centrality.

Participants	compaction	degradation	decomposition/deposits	ecosystem-services	food	nutrients/minerals	organisms	plants	soil	soil genesis	water	weathering	(earth) worms
pema	0.86	0.98	0.40	0.92	0.40	0.40	0.40	0.00	0.98	0.80	0.40	0.40	0.40
isso	0.88	0.92	0.37	0.81	0.37	0.37	0.96	0.73	1.00	0.85	0.37	0.37	0.37
chse	0.34	1.00	0.34	0.88	0.34	0.34	0.34	0.34	0.96	0.71	0.79	0.00	0.34
lubi	0.75	0.94	0.72	0.81	0.25	0.50	0.97	0.63	1.00	0.88	0.25	0.56	0.00
juba	0.82	0.85	0.35	0.76	0.35	0.92	0.97	0.35	1.00	0.71	0.35	0.35	0.79
lust	0.36	0.85	0.36	0.75	0.36	0.97	0.89	0.81	1.00	0.75	0.94	0.36	0.36
naev	0.67	0.92	0.94	0.86	0.33	0.33	0.97	0.81	1.00	0.89	0.78	0.33	0.33
jaan	0.78	0.95	0.32	0.84	0.32	0.97	0.92	0.89	1.00	0.68	0.81	0.32	0.32
gael	0.58	0.28	079	0.74	0.28	0.95	0.84	1.00	0.92	0.66	0.97	0.28	0.28
jodo	0.31	0.95	0.82	0.90	0.31	0.31	0.31	0.92	1.00	0.74	0.31	0.31	0.31
chst	0.31	0.95	0.90	0.88	0.31	0.93	0.98	0.85	1.00	0.69	0.31	0.31	0.31
phul	0.70	0.90	0.35	0.76	0.35	0.85	0.95	0.98	1.00	0.76	0.73	0.35	0.35
tite	0.67	0.88	0.95	0.85	0.00	0.93	0.98	0.33	1.00	0.90	0.83	0.33	0.67
jure	0.32	0.98	0.93	0.85	0.32	0.81	0.90	0.95	1.00	0.85	0.32	0.32	0.32
labe	0.94	0.97	0.83	0.87	0.38	0.92	0.98	0.86	1.00	0.95	0.79	0.38	0.38
mean value	0.62	0.89	0.62	0.83	0.31	0.70	0.82	0.70	0.99	0.79	0.60	0.33	0.37
experts	0.69	0.90	0.68	0.88	0.20	0.73	1.00	0.99	0.97	0.64	0.20	0.55	0.20

does not mention food, and another is unfamiliar with the concept of weathering. Plants, organisms, degradation, and ecosystem services represent central bridging concepts for experts. For over half of laypeople, plants are similarly ranked as highly central as for experts. Less than half assign plants a minor or middle central role, and one person does not even include plants in his/hers understanding of soil. For most laypeople, organisms and degradation are considered as central as they are for experts. However, when considering other nodes, the ranking varies from moderately to highly central (such as for ecosystem services and soil genesis) or even from minimally to highly central (such as for nutrients, decomposition, compaction, water, and earthworms). Most laypeople assign a more central role to nodes such as soil genesis, food, water, and earthworms, whereas these nodes play a minor or less central role in the experts' network.

3.2. *Qualitative content of the concept maps*

To contextualize laypeoplés soil knowledge, the aggregated expert map is used as a reference (Fig. 2). Three laypeople concept maps of different scopes are presented in Figs. 3, 4, and 5.

3.2.1. *Soil components*

All laypeople in this study recognized soil as a living substance due to the presence of organisms. However, their understanding lacks the depth and specificity seen in experts' classifications. Experts distinguish between macro- and microorganisms, categorizing bacteria and fungi as microorganisms and grouping collembola, moles, and earthworms as macroorganisms (Fig. 2). In contrast, laypeople do not make such distinctions and instead mention a broader range of organisms, especially larger ones like mice, beetles, and rabbits, which were not emphasized by experts. Organisms are central to both laypeople's and experts' conceptualizations of soil, but with differing implications. For experts, organisms are crucial due to their roles in soil genesis, decomposition processes, humus formation, and the provision of ecosystem services.

However, laypeople's understanding tends to be more fragmented. Some of the laypeople describe their role in soil formation as involving the loosening of soil, becoming part of the earth upon death, and thus contributing to soil creation. Others describe their role in terms of decomposing or consuming other organisms and plants, or simply undergoing decomposition, which is associated with soil genesis. Figs. 3, 4, and 5 illustrate this exemplarily.

Some laypeople believe that only microorganisms or small organisms are involved in decomposition processes, while experts generally attribute this role to organisms more broadly. When it comes to soil fertility, the connection between organisms and soil fertility is recognized by half of the laypeople, though their explanations are sometimes vague or overly simplistic, just somehow impacting each other (Fig. 4). Soil fertility is not specifically stated as a node in the experts' map but indirectly mentioned in connecting organisms to humus, and humus being rich in nutrients that can be absorbed by plants. The role of plants in soil processes is another area where knowledge diverges. Experts consistently position plants as central, connecting them to various soil concepts such as humus, degradation, soil genesis and diverse ecosystem services such as affecting the microclimate. Laypeople, however, exhibit a more varied understanding, with some failing to mention plants at all (Fig. 3). Plants are primarily associated with water and nutrients/minerals, which they absorb, as well as being decomposed or metabolized by organisms, and impacting soil fertility (Figs. 4, 5). Some participants associate plants with being negatively affected by soil degrading factors (Fig. 5), while others connect them to affecting the climate. Gaps in knowledge are evident in laypeople's understanding of soil structure. Unlike experts, laypeople rarely conceptualize soil as having distinct horizons or understand the chemical and physical processes that influence soil properties (Fig. 4). For instance, there is a general lack of awareness about chemical processes, e.g. the impact of oxidation on soil color. Moreover, none of the laypeople recognize the importance of soil

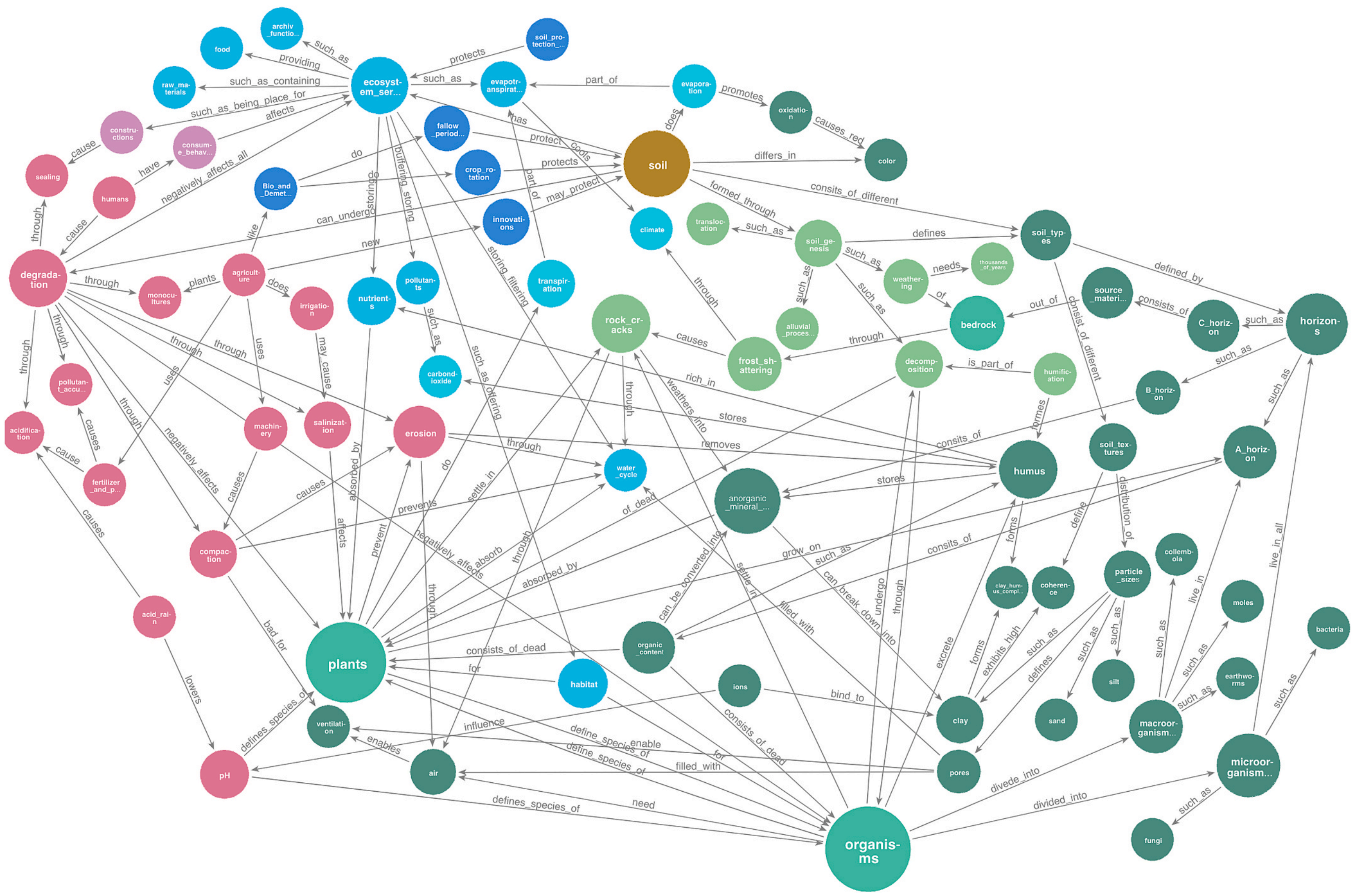

Fig. 2. Aggregated expert concept map of soil. Soil knowledge categories are represented by different colors: soil components (dark green), soil genesis (light green), ecosystem services (light blue), soil protection (dark blue), and soil degradation (pink). Mixed colors like purple and turquoise represent nodes, which could be assigned to more than one category. Nodes are sized according to the betweenness centrality score. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

porosity and its role in air and water retention, which are critical for plant growth and soil health (Baligar et al., 2004). Additionally, there is no consistent understanding of soil. Interpretations vary, including views of earth and soil as the same, soil as containing earth and other components such as clay, sand, and stones, and conceptualizations of differences of soils in thickness, wetness, color, and consistency.

3.2.2. Soil genesis

Soil genesis propositions in laypeoplés concept maps vary. All of the laypeoplés maps display that rotted materials, dead animals, and plants are being decomposed and somehow transferred into soil, and thus part of soil creation (Figs. 4, 5). However, their understanding of soil genesis varies widely. Some link soil formation to agriculture, permaculture, human activities, volcanic eruptions (Fig. 5), composting (Fig. 3), or general evolution. Weathering, a process recognized by experts as crucial to soil genesis, is not connected to soil formation by most laypeople. Instead, it is connected to various other concepts, such as producing humus, somehow related to rust, rotting, weather (Fig. 4), or just impacting soil (Fig. 5). Humification, experts related the process to decomposition and soil formation, is known to four laypeople, though interpretations differ: two equate it with decomposition (Fig. 5), one views it as the initial stage of soil formation, and another relates it to compost (Fig. 3). Overall, laypeople display gaps in their understanding of weathering, humification, and the broader processes of soil genesis.

3.2.3. Ecosystem services

Food is the most frequently connected concept to the ecosystem services of soil, appearing in 14 out of 15 cases. Two-thirds of laypeople also recognize soil's role in storing and filtering water, a view shared by experts. However, three laypeople do not directly link water to ecosystem services, instead considering it a soil component (Fig. 4). Most laypeople relate soil functions to human needs, such as providing resources, serving as building material, supporting agriculture, or simply as a stable ground. Six laypeople understand soil functions independently of human use, including providing habitat (Fig. 4), being essential for life on earth, and maintaining natural balance. Experts' views on soil ecosystem services include similar human-related and nature-related functions. Additionally, experts recognize soil as a historical archive and a factor in climate cooling through evapotranspiration. None of the laypeople's concept maps mention the historical archive function, and only one describes interaction with the atmosphere, while two mention the evaporation of water from soil. Soil's role in storing carbon dioxide to slow climate change is noted twice, and securing air quality is mentioned once in relation to plants growing on soil (Fig. 5). Laypeople mostly do not include evapotranspiration in their concept maps, indicating a gap in understanding this process and the historical archive function of soil.

3.2.4. Soil degradation and protection

Laypeople and experts are most similar in their understanding of soil degradation and protection. All laypeople recognize compaction and sealing as negatively affecting soil, with half linking these issues to restricted water flow, flooding, impacts on plants and organisms, or erosion. Experts define erosion as the removal of humus by air and water, with plants playing a role in preventing it. Four laypeople align with this definition, associating erosion with water and/or wind and

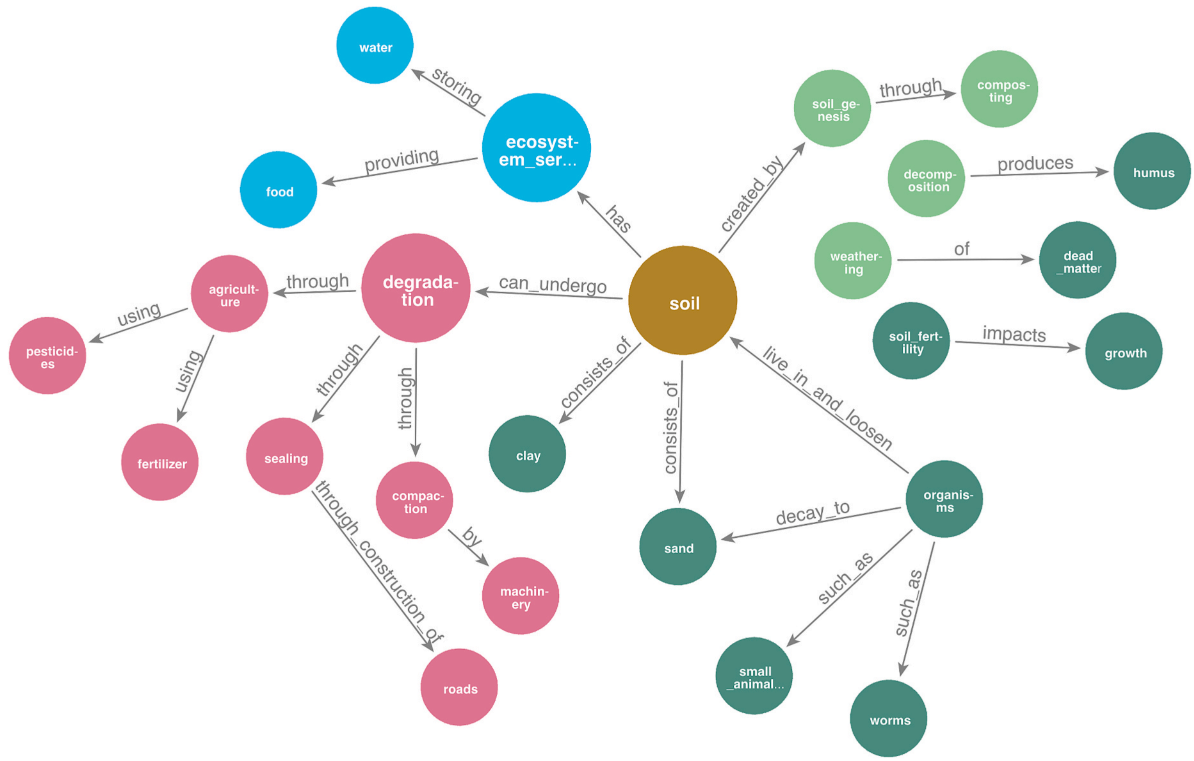

Fig. 3. Example of a simple, less complex soil concept map created by a layperson. Soil knowledge categories are represented by different colors: soil components (dark green), soil genesis (light green), ecosystem services (light blue), soil protection (dark blue), and soil degradation (pink). Nodes are sized according to the betweenness centrality score. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

recognizing its impact on soil fertility or humus. However, one third of laypeople are unfamiliar with the term erosion, while others interpret it in various ways, linking it to heat, general negativity, movement, or flooding (Figs. 3, 4, 5). Experts attribute soil acidification to the use of fertilizers and pesticides in agriculture, as well as acid rain, which impacts plants and organisms. Two laypeople also connect acidification to agriculture, but three do not make further connections. Additionally, two laypeople are unfamiliar with the term in relation to soil (Fig. 3), while the others relate it to changes in pH values and effects on plants (Fig. 4). Both laypeople and experts agree that human activities cause soil degradation. In terms of soil protection, nine laypeople share similar views with experts. Most protective measures discussed are agricultural in nature, including fallow periods, crop rotation, green fertilizer, and ecological agriculture. Similar to the experts, soil protection is viewed by two laypeople as enhancing biodiversity and by one as establishing natural reserves (Fig. 5). Four laypeople believe that responsible consumer behavior could also protect soil, while one individual does not mention any soil-protective actions (Fig. 3).

3.3. Sociodemographic data

Participants varied in sociodemographic data (see Appendix B). No systematic association was found between these characteristics and the quantitative metrics of the concept maps, such as number of nodes, relationships, degree of fragmentation, or betweenness centrality. The same applies to the qualitative comparison among the laypeople themselves, as well as in comparison with the expert map. No distinct groups could be identified that indicated any influence of gender, age, profession, education, garden ownership, or income on soil knowledge.

4. Discussion

4.1. Quantitative characteristics of laypeople's and experts' concept maps

Laypeople's concept maps in this study typically contain about half or fewer links and nodes compared to those of the experts, revealing that laypeople may not fully grasp or include many of the fundamental concepts and connections that experts consider essential to soil knowledge for them. Additionally, inconsistencies in soil knowledge among laypeople are evident from the discrepancies observed between the different concept maps (Kucharzyk, 2022; Thurn, 2021; Thurn et al., 2022; . Soil science is considered complex, as it covers interlinked physical, chemical, and biological disciplines (Corrochano et al., 2023; Roca & Ríos, 2019). This difficulty is reflected in the concept map metrics, where more nodes don't necessarily indicate a deeper understanding of soil, nor do they ensure a consistent and unfragmented network of knowledge. Thus, familiarity with soil concepts does not necessarily mean understanding the relationships and underlying propositions (Charzyński et al., 2022).

The heterogeneity of soil knowledge is further evidenced in the comparison of betweenness centrality, where only thirteen nodes were similar enough to be compared (Charzyński et al., 2022; Pino et al., 2022; Rossiter et al., 2015). The comparison of betweenness centrality scores shows a diversity of understanding among participants regarding the significance of nodes in the conceptual network. Laypeople often interpret concepts through their everyday experiences and perceptions, which are vital for constructing new knowledge in the context of didactic reconstruction, as explored in this study (Duerden & Witt, 2010; Gropengießer & Marohn, 2018; Heimlich & Ardoin, 2008; Schrenk et al., 2019). This subjective interpretation leads to varied node rankings; for example, concepts like decomposition and ecosystem services are valued differently. Laypersons often prioritize familiar concepts like

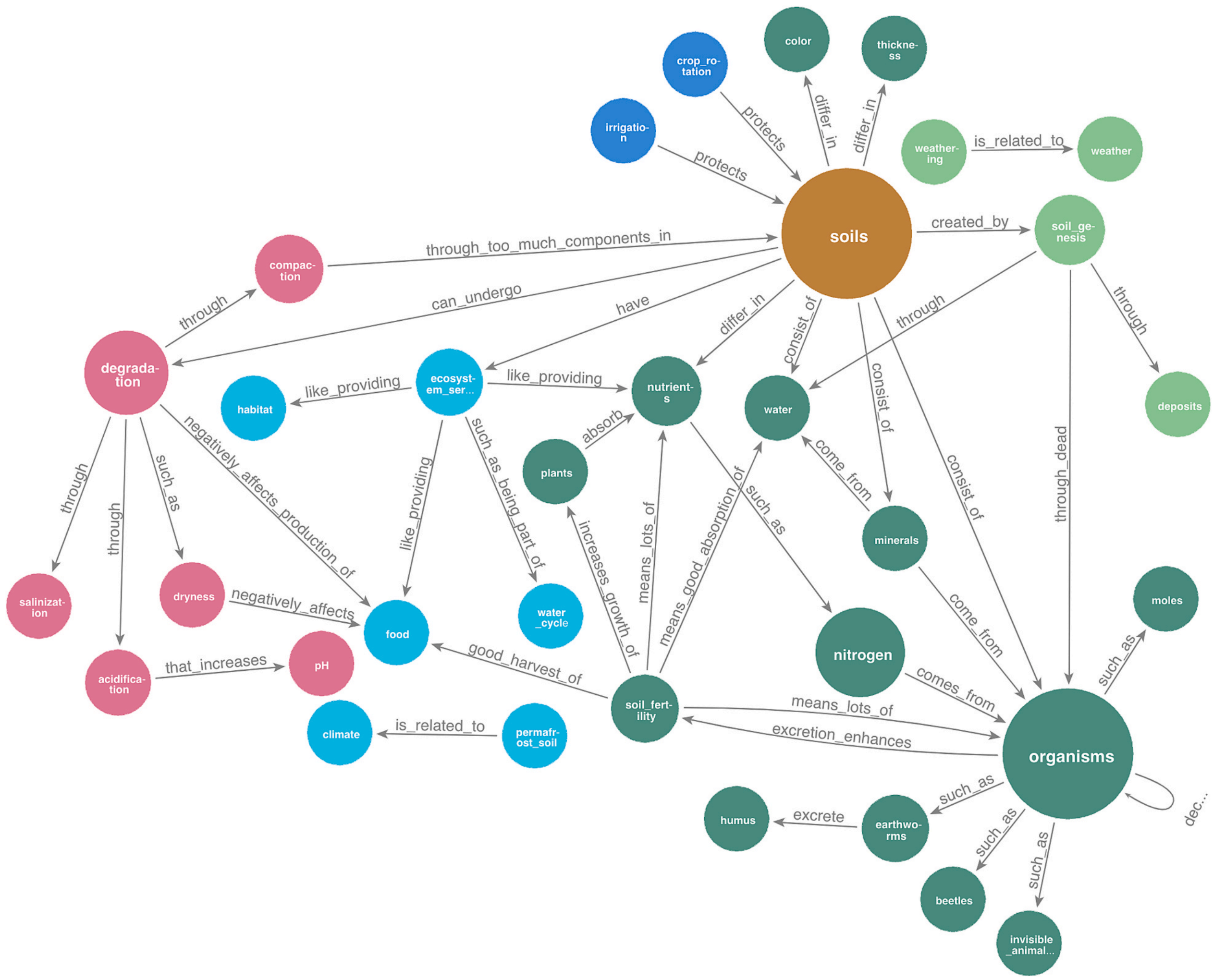

Fig. 4. Example of a medium-sized soil concept map created by a layperson. Soil knowledge categories are represented by different colors: soil components (dark green), soil genesis (light green), ecosystem services (light blue), soil protection (dark blue), and soil degradation (pink). Mixed colors like purple and turquoise represent nodes, which could be assigned to more than one category. Nodes are sized according to the betweenness centrality score. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

earthworms and water, reflecting their everyday experiences and limited exposure to soil science (Menzel & Bögeholz, 2009; Thieroff et al., 2021, Schrenk et al., 2019). However, degradation scored as a landmark concept for most laypeople and for experts. It should be noted that while a high score indicates that many paths in the network pass through this node, it must be considered in the overall context of the network (Jünger & Gärtner, 2023). Therefore, degradation scores high for some laypeople because the category of degradation encompasses one-third to half of all the concepts. This means that degradation, as a node, is primarily linked to degradation-causing concepts, making it central, but not because it connects various other soil knowledge categories (Leyesdorff, 2007).

4.2. *Qualitative characteristics of laypeople's soil knowledge*

4.2.1. *Soil components*

The findings revealed that the participants recognized soil as a living substance, due to the presence of organisms (Dazzi & Lo Papa, 2022; Drieling, 2015). As Drieling (2015) encountered in their study on pupils' perceptions of soil organisms, special emphasis is placed on organisms, mostly referring to mammals, hexapods, (earth)worms, and small or invisible animals. Laypeople named more organisms than experts, who focus on key aspects and may find listing all soil-related organisms less relevant (Dazzi & Lo Papa, 2022). Visible animals that evoke strong emotions, like disgust (hexapods, worms) or cuteness (moles, rabbits), are more memorable to laypeople and thus mentioned more often (Duerden & Witt, 2010; Kucharzyk, 2022). Nevertheless, the different propositions of organisms in the concept maps vary underscoring the disparity between their concept of soil organisms and their knowledge of their significance and interconnectedness with other soil-related topics (Baisch, 2009; Charzyński et al., 2022; Drieling, 2015). However, it seems that most laypeople in this study possess some knowledge of organisms' roles in decomposing processes and their impact on soil fertility. This knowledge likely stems from everyday experiences like composting or observing decay, which helps shape their understanding of these processes within soil ecosystems (Baisch, 2009; Kattmann, 2022; Wadoux & McBratney, 2023). Expert maps reference soil fertility indirectly through connections among organisms, plants, humus, and nutrient-rich environments. This indicates that understanding the interdependence between soil fertility and organisms is a logical inference rooted in soil science and ecology principles for them (Tiessen et al., 1994).

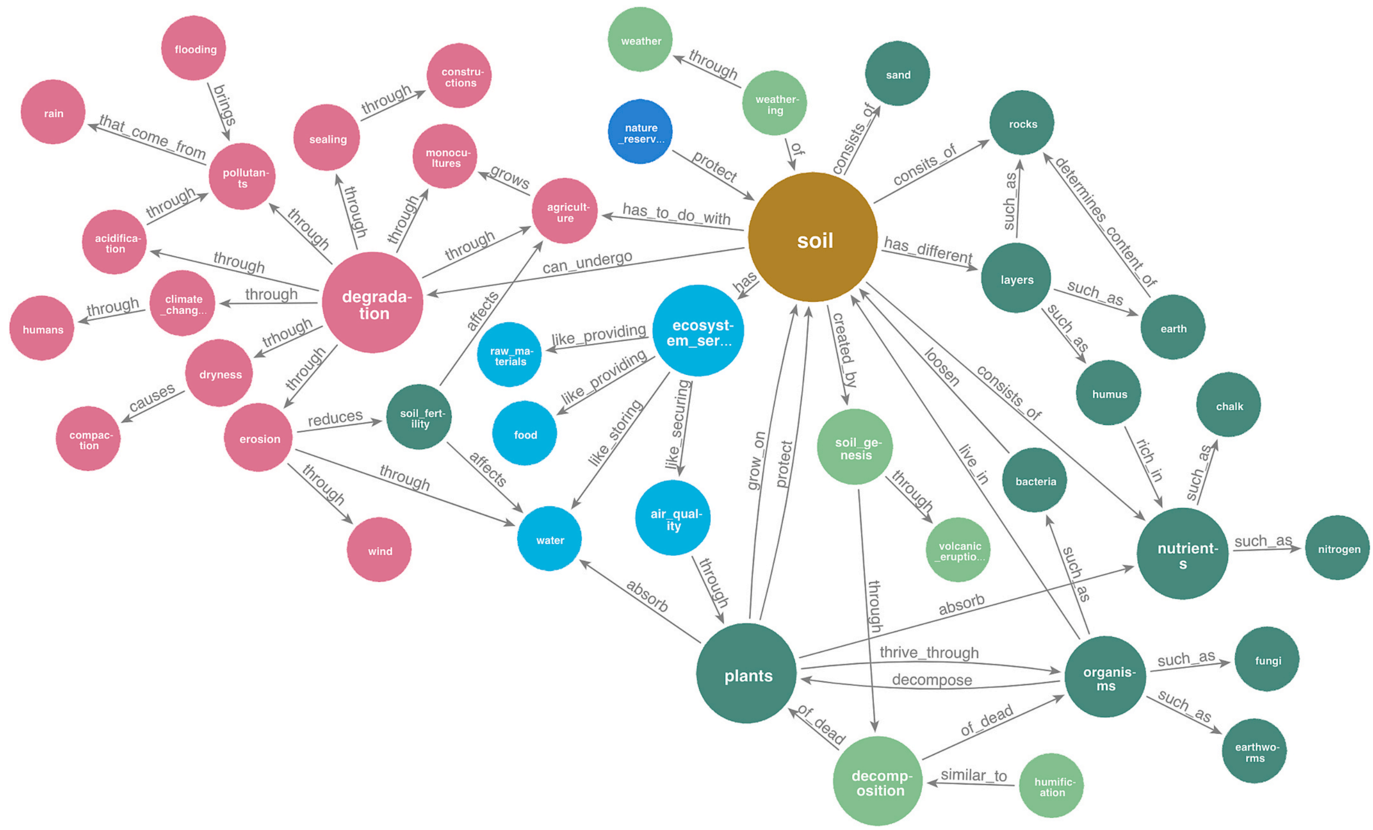

Fig. 5. Example of a large and complex soil concept map created by a layperson. Soil knowledge categories are represented by different colors: soil components (dark green), soil genesis (light green), ecosystem services (light blue), soil protection (dark blue), soil degradation (pink). Mixed colors like purple and turquoise represent nodes, which could be assigned to more than one category. Nodes are sized according to the betweenness centrality score. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

Laypeople in this study appear to have a basic understanding of the interactions between plants and soil, similar to findings in (Ero-Tolliver et al., 2013) study on pupils' perceptions of soil. This knowledge likely comes from activities like gardening, nurturing indoor plants, or familiarity with agricultural practices (Brevik et al., 2022b).

Laypeople lack comprehensive knowledge of soil types, horizons, and the chemical and physical reactions within soil, such as those affecting pH or soil color (Hayhoe, 2013). This may be due to soil being perceived as uninteresting, disgusting, or not attractive enough to explore in detail (Brevik et al., 2022a; Charzyński et al., 2022; Kucharzyk, 2022). Additionally, comprehending the chemical and physical processes occurring in soil requires understanding, which poses an additional barrier (Corrochano et al., 2023; Roca & Ríos, 2019; Urbańska et al., 2022).

4.2.2. *Soil genesis*

A similar reasoning can also explain the limited knowledge of soil genesis, further noting that this knowledge is possibly irrelevant for their daily actions (Hayhoe, 2013, Schrenk et al., 2019). Yet, all laypeople in this study propose that soil undergoes change, with many primarily associating it with decomposition. However, most of these propositions focus on soil that already exists. There seems to be a lack of knowledge regarding how long it takes for new soil to form, and the number of processes involved (Drieling, 2015). Moreover, seems to be limited knowledge of soil genesis, with laypeople often having a vague understanding of weathering and little awareness of humification, a key soil-forming process recognized by experts (Corrochano et al., 2023; Francek, 2013).

4.2.3. *Ecosystem services*

Although ecosystem services of soil are underrepresented in laypeople's concept maps, most associate them with food production, agriculture, water storage, and some link them to nature-related topics like habitat and natural balance (Charzyński et al., 2022; Drieling, 2015). Since knowledge is inherently intertwined with the individual, it is only natural that soil functions are primarily interpreted in terms of their benefits for humans and their well-being. However, this also indicates that the lay participants do not have a non-human-centric view of soil functions and seem unable to perceive soil within a broader context (Kastner-Wilcox et al., 2023; Roczen et al., 2014; Urbańska et al., 2022). Differences between laypeople's and experts' concept maps suggest that laypeople lack a deep understanding of soil's role in climate change, such as in buffering carbon dioxide or cooling the micro-climate (de Sousa et al., 2019; Hartemink et al., 2014). This highlights the need to raise public awareness of soil functions, especially in the context of the climate crisis, as emphasized in the European Commission's "Horizon Europe" project (Dazzi & Lo Papa, 2022).

4.2.4. *Soil degradation and protection*

Laypeople appear to possess a broad understanding of soil-degrading factors, particularly those attributed to human activities, and their impacts on plants (Drieling, 2015). Soil degradation directly impacts people, manifesting in urban heat islands, flooding, and concerns about food quality due to pesticide and fertilizer use. These well-publicized issues evoke negative emotions, likely making them more prominent in people's associations with soil (Carmi et al., 2015; Duerden & Witt, 2010; Kastner-Wilcox et al., 2023). Many laypeople in this study are unfamiliar with or misinterpret the term erosion, similar to Francek's (2013) findings, where weathering and erosion were often conflated due to their complex understanding. Both laypeople and experts recognize the importance of agricultural practices in soil protection, with some laypeople also acknowledging their role as consumers in conservation. However, high school students in Charzyński et al. (2022) were not sufficiently informed about soil protection and its importance. The discrepancy should be addressed in future studies, probably observing socio-cultural, and educational differences in more detail.

4.3. Sociodemographic data

Sociodemographic factors did not appear to influence quantitative as well as qualitative aspects of laypeoplés concept maps. Given that this study aimed to follow an explorative study design to assess laypeople's understanding of soil, the limited sample size may have been insufficient to detect patterns or group differences based on sociodemographic characteristics. Within this sample, variables such as age, gender, income, profession, educational background, or garden ownership did not correlate with a deeper knowledge of soil (Pino et al., 2022; Rossiter et al., 2015). Garden ownership alone is likely not a sufficient indicator of more complex soil knowledge. Rather, it appears that the nature and frequency of garden use are more relevant factors. Passive use, such as spending time in the garden for recreation, may have limited impact on soil understanding, whereas active involvement in gardening practices or soil management is more likely to foster deeper, experience-based knowledge (Brevik et al., 2022b; Charzyński et al., 2022; Kaiser & Fuhrer, 2003). For future research in this area, it may be valuable not only to collect sociodemographic data, but also to examine the sources from which participants acquire their soil knowledge. This approach could potentially reveal patterns of group formation that explain variations in soil knowledge more effectively than sociodemographic variables alone.

5. Conclusion and implications

The aim of this qualitative study was to explore laypeople's knowledge of soil and illustrate it through concept maps. Additionally, experts were asked about fundamental soil knowledge that they consider central and important for laypeople, to contextualize the laypeople's knowledge. Generally, there is a lack of a unified, scientific understanding of soil among the participants. The soil knowledge of laypeople in this study reveals several gaps compared to what experts consider essential. They lack an understanding of soil horizons and the detailed structures of soil, missing key distinctions that experts use to describe soil components and properties. In soil genesis, participants frequently lack process knowledge about how soil forms, often failing to connect weathering to soil creation and having a fragmented understanding of humification. This points to a broader gap in their comprehension of the processes involved in soil formation. Their knowledge of ecosystem services is incomplete, overlooking key aspects such as soil's role in climate regulation and its function as a historical archive. Additionally, while there is general agreement on human impacts, laypeople's views on erosion, acidification, and protective measures are less detailed and cohesive. Given the small scale of this research, it was not possible to determine relationships between sociodemographic data and the qualitative data. This study offers a foundation for future quantitative research on soil knowledge and contributes to the didactic reconstruction framework, supporting the development of effective educational strategies (Kattmann, 2022). Through increased knowledge, people may come to value soil more, as a living system essential to life, and thus become more likely to support land-use protection measures ranging from private gardening and food consumption to recreational habits and political engagement (Charzyński et al., 2022). Such shifts in attitudes and behaviors can make a substantial contribution to long-term, bottom-up soil protection (Brevik et al., 2022a). Considering the principle of knowledge convergence by Kaiser and Fuhrer (2003), it is crucial to recognize that soil-friendly behavior can only be achieved by incorporating all four different forms of knowledge. Laypeople need a comprehensive understanding of soil to make informed decisions, reflect on their actions, and recognize the significance of their behaviors. Social acceptance also plays a key role in motivating engagement with soil knowledge (Ardoin et al., 2020). Therefore, an educational approach should be informative, practical, and build on laypeople's everyday knowledge to foster a broad appreciation of soil's importance, using this as a foundation for further knowledge acquisition. Building on the findings of Winkler et al. (2019), who identified urban gardening as an effective platform for exchanging social values, knowledge, and ideas, a targeted educational program could be developed to address the gaps in soil knowledge discovered here. However, a key distinction must be made: passive garden ownership or just passively participate in urban gardening groups might not be sufficient; rather, active engagement with soil, through hands-on practices may be more relevant for knowledge acquisition. Educational events and workshops in urban gardening spaces, led by gardeners, scientific institutions or participants themselves could directly engage the community in soil conservation practices, and could enhance declarative and procedural knowledge through hands-on learning and discussions, while also fostering effective understanding by contextualizing soil's importance within everyday life. Moreover, such community-based projects could cultivate social knowledge by creating a network of participants who value and share soil-related information. These efforts would not only fill the identified knowledge gaps but also create lasting educational resources that empower societies to understand and protect their soil ecosystems.

6. AI statement

During the preparation of this work the authors used ChatGPT 3.5 in order to revise cypher queries to build the concept maps in Neo4j. After using this tool, the authors reviewed and edited the content as needed and take full responsibility for the content of the publication.

Ethics statement

This study was conducted in accordance with the ethical standards outlined by the Ethics Committee of the University of Hohenheim, which approved the research protocol. No ethical concerns were identified during the course of this study.

CRediT authorship contribution statement

Johanna Schaal: Writing – original draft, Visualization, Software, Resources, Methodology, Data curation, Conceptualization. **Nicolas Neef:** Writing – review & editing, Supervision, Project administration, Conceptualization. **Siegmar Otto:** Writing – review & editing, Supervision.

Declaration of competing interest

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

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Appendix A. Literature review of students' perceptions of soil

Reference	Sample	Method	Results
Baisch, P. (2009): Students' conceptions of material cycles.	N = 100 pupils (9–11 years old)	Intervention study, pre- and post-assessment with interviews	Earth is perceived as an organic component of soil, which also includes sand or stones. However, it is also described as dirty and filthy. Earthworms and other organisms are involved in decomposition processes. Earth is seen as a nutrient reservoir for plants that is continually replenished.
Bakopoulou et al., (2021): Existing and Emerging Students' Alternative Ideas on Geodynamic Phenomena: Development, Controlling Factors, Characteristics	N = 218 pupils (12–13 years old), Greece	Questionnaire anddrwaings	Students illustrate the Earth's core surrounded by soil and stones, while another depicts a spherical core filled with lava, enveloped by a thick layer of soil and stones within a spherical Earth.
Corrochano et al., (2023): A three-pronged method to analyse pre-service teachers' understanding and epistemic reasoning about soil	N = 181 Primary school or Early Childhood Education students from Spain	Questionnaire and drawings	Students generally lack accurate scientific knowledge about soil systems, with common misconceptions regarding soil formation and development. They often perceive soil as unchanging and formed solely through erosion and sedimentation processes, overlooking the role of climate, organisms, and parent materials.
Drieling, K. (2015): Student Conceptions of Soil and Soil Degradation: A Contribution to Geographic Education Reconstruction.	N = 10 pupils (15–16 years old), Germany	Interview, concept mapping of soil topics	Mental constructs: Soil: As a surface, consists of Earth, composed of layers. Earth: As a material, our planet. Soil formation: Has always been present, evolved, material displacement, changes in soil. Soil structure: Uniform material, layer of rock, soil layer, soil and rock layer. Soil functions: Basis of life, habitat/location, production, regulatory function, support function, recreation, information. Soil changes: Remains constant, natural changes, anthropogenic changes, interaction between spheres. Environmental pollution: Entry of substances by humans as a cause, climate warming as a cause, direct and indirect entry, foreign substances, disruption of cycles as a consequence, changes in soil and animal and plant life as a consequence, human affected as a consequence, time, regeneration. Acidification: Environmental pollution as a cause, power plant emissions as a cause, fermentation processes as a cause, burden on the water cycle, pollutants damaging soil and animals as a consequence.
Ero-Tolliver et al. (2013): Young Children's Thinking About Decomposition: Early Modeling Entrees to Complex Ideas in Science	N = 22 pupils (6–7 years old)	Pre- and post- instruction written assessment	Soil as a homogeneous, lifeless substance, primarily associated with contamination and lacking any intrinsic value or significance beyond its functional roles in supporting plants and housing earthworms.
Kastner-Wilcox et al., (2023). Assessing the risk perception of soil degradation using a college student sample	N = 513 college studenets, Florida	Online survey	Individuals that have a greater subjective knowledge of soil and its degradation are more likely to perceive the risk of it.
Kucharzyk, K. (2022): Soil, student conceptions, instruction	N = 102 pupils (14- years old), Germany	Interventioin study, pre- and post-assessment with questionnaires and drawings	Students expressed diverse associations with soil, perceiving it as a habitat for plants and soil organisms and as a crucial resource for agriculture and environmental conservation. Negative aspects such as disease transmission and the use of soil as a waste dump were highlighted, indicating that perceptions of soil encompass both positive and negative dimensions.

Appendix B:. Sociodemographic data of laypeople

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Laypeople	sex	age	High school diploma	Vocational qualification	Profession	Net. income €/month	Garden
chse	w	68	Secondary school diploma	Vocational training	Pensioner	1001–2000	yes
chst	w	24	General Certificate of Education – Advanced Level	Bachelor	Nutritional Science Student	500–1000	no
gael	w	53	General Certificate of Education – Advanced Level	Vocational training	Caregiver	2001–3000	yes
isso	w	23	General Certificate of Education – Advanced Level	Bachelor	Sociology Student	500–1000	no

(*continued on next page*)

(*continued*)

Laypeople	sex	age	High school diploma	Vocational qualification	Profession	Net. income €/month	Garden
tite	m	54	General Certificate of Education – Advanced Level	Diploma	Architect	7001–8000	no
jaan	w	23	General Certificate of Education – Advanced Level	Bachelor	Nutrition Management and Dietetics	<500	yes
jodo	w	25	General Certificate of Education – Advanced Level	Vocational training	Educator	2001–3000	yes
juba	w	22	General Certificate of Education – Advanced Level	Bachelor	Molecular Biology and Physiology Student	<500	no
jure	w	47	General Certificate of Education – Advanced Level	Diploma	Social Pedagogue	2001–3000	no
labe	w	37	General Certificate of Education – Advanced Level	Doctorate	Prof. Sustainable Action and Economics	4001–5000	yes
lubi	m	28	General Certificate of Education – Advanced Level	Bachelor	Development Engineer	2001–3000	yes
lust	m	24	General Certificate of Education – Advanced Level	State examination	English & Philosophy Teaching Student	1001–2000	no
naev	w	42	University entrance qualification	Vocational training	Castle Administration	1000–2000	no
pema	m	64	Secondary school diploma	Vocational training	Car Salesman	4001–5000	yes
phul	m	33	General Certificate of Education – Advanced Level	Master	Traffic Planner	2001–3000	no

Appendix C:. Interview questions for laypeople (translated from German)

Question Block 1: Soil basics.

When you think about soil, what comes to your mind?

- Follow-up: Can you give me your definition of soil?
- Follow-up: Have you noticed any differences in soils? If yes, can you describe these differences?

What components make up soil?

- Follow-up: If “earth” is mentioned: What is earth, do you have an idea?
- If “stones” are mentioned: Where do you think the stones come from?
- Follow-up: If “animals and plants” are mentioned: Why do plants grow in soil/earth? Which animals that live in the soil do you know?

If I mention the term “soil fertility,” what do you associate with it?

- Follow-up: Is there life in the soil?
- If yes: Which living organisms do you think live in the soil?
- Follow-up, if life was already mentioned in question 2: What is the relationship between living organisms and soil fertility?
- If nutrients are mentioned: Ask which ones and where they come from.

Question Block 2: Soil genesis.

How is soil formed, do you have an idea?

- Follow-up: What happens to dead plants and animals lying on the ground if no one removes them?
- Follow-up: Do you have an idea what the terms weathering, decomposition, and humus formation mean in this context?

Have you noticed any changes in soils now or in the past?

- Follow-up: If yes: How have these changes manifested?
- Follow-up: If yes and not mentioned yet: What contribution do you think humans have to soil changes?

Soils in Germany are in poor condition, what do you understand by this statement?

- Reference to soil changes?
- Experts describe negative soil changes as degradation and mention different terms for it. Do you have an idea what the term 1. Erosion, 2. Acidification, 3. Compaction, and 4. Sealing mean in relation to soils?

Question Block 3: Soil ecosystem services.

What function do you think soils have?

- Follow-up: What function do they have for us humans or for you?
  - If not mentioned: “From farm to table” – In what context do you see this phrase regarding the function of soils for us humans?
  - If not mentioned: What importance does soil have in terms of climate? (Carbon storage)

- If not mentioned: What importance does soil have in terms of water? (Filter and storage)

Question Block 4: Soil protection
Suppose the soils in Germany are in poor condition, do you have any ideas on how to protect them?

- Follow-up: How could individuals contribute to soil protection as private citizens?

Question Block 5: Citizen Science.
Instruction interviewer: Brief explanation what Citizen Science is using a vivid example, such as bird counting.
Do you have any idea how to determine if soils are healthy?

- Follow-up: If nothing is mentioned: Provide examples such as counting and identifying animals, identifying plants, determining pH and temperature, assessing dryness…
- Could you imagine participating in a project that tests soil health?
- If yes: What would be your motivation for participating?
- If no: Why can't you imagine it?
- What would motivate you to participate or what support would you wish for?

Appendix D:. Interview questions for experts (translated from German).

Question Block 1: Soil basics.
Which aspects do you think cover basic knowledge about soils?

- Follow-up: In my research on soil knowledge, I found the following categories on basic soil knowledge:
    - Different soil types
    - Mineral soil components
    - Organic soil components such as the carbon cycle, macro-, meso-, microfauna
    - Soil water
    - Soil air
        - o In your opinion, are these components relevant when it comes to general soil fundamentals?

Question Block 2: Soil genesis and degradation
When it comes to soil genesis, what do you think are relevant processes?

- Follow-up: In my research on soil knowledge, I found the following categories on soil genesis, do you think they are important?
  o Define: weathering, decomposition, and humification

In contrast, what do you think are relevant soil degrading processes?

- Follow-up: Do you consider erosion, compaction, sealing, acidification, people, to be worth mentioning in this context?

Question Block 3: Soil ecosystem services.
What aspects would you name to describe the essential functions of soils?

- Follow-up: In my research on soil knowledge I found the following categories on soil functions, do you think they are important? Ecosystem Services, Soil Fertility and Biodiversity, Food security, Climate, Energy.

Question Block 4: Soil protection
In your opinion, could you name proven technologies and management strategies that help protect soils?

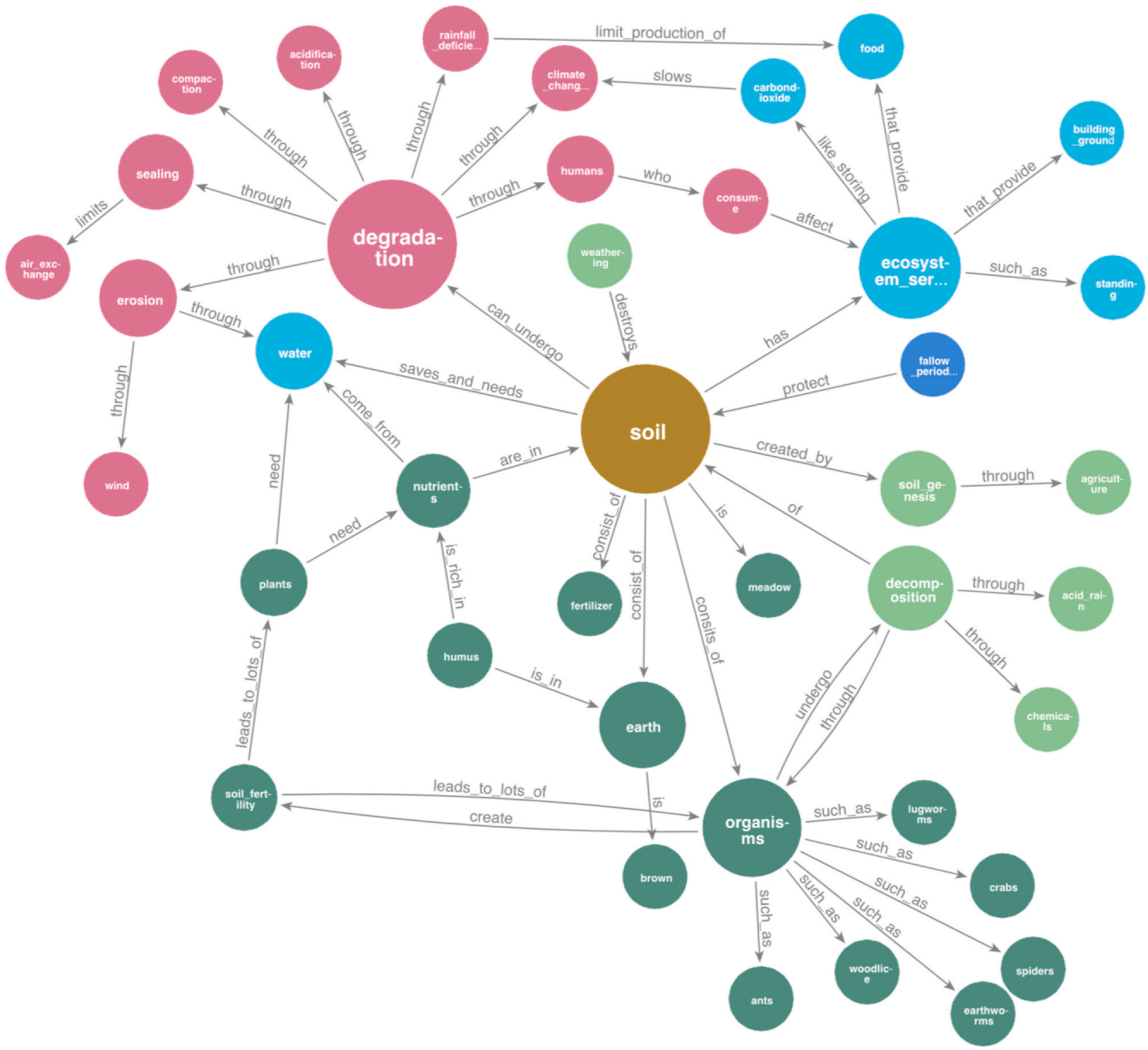
- Follow-up: How could you as a layman contribute to soil protection?

Question Block 5: Citizen Science.
In your estimation, what basic knowledge should citizens/laypeople have to engage in soil health and conservation?

- Follow-up: If no reasoning, ask why exactly these aspects.
- Follow-up: Which of your specialty knowledge do you think lay people should have?
  o What understanding do you think citizens/laypeople should have to be able to grasp soil formation and degradation?
  o Which of the above could provide a tangible entry point for lay people to understand the importance of soil and spark their interest in the topic?

Follow-up: What would you like to see: what should laypeople be interested in this context?

Appendix E. Laypeople's soil concept maps.



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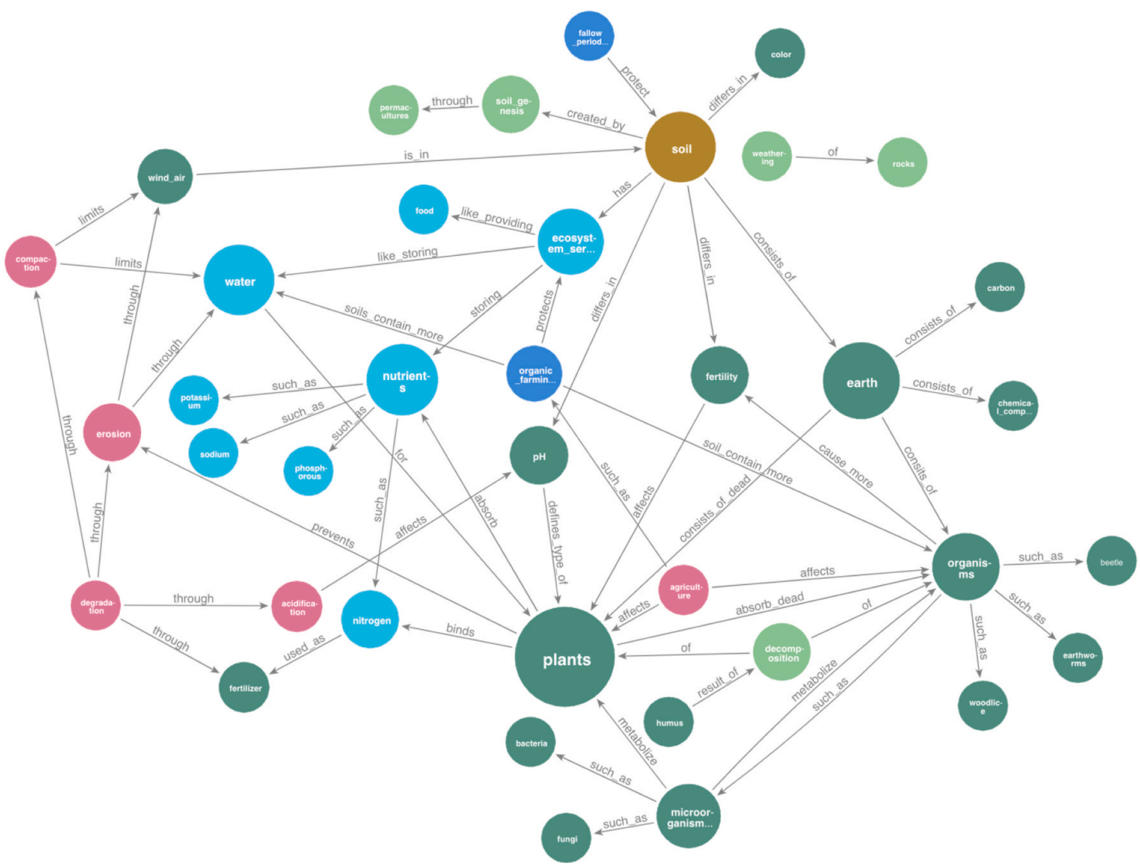
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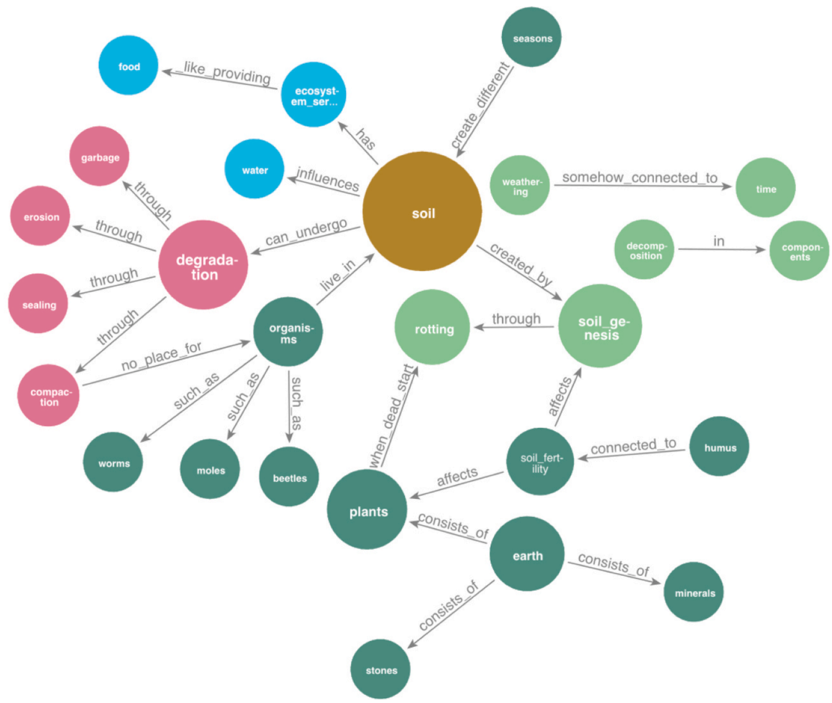
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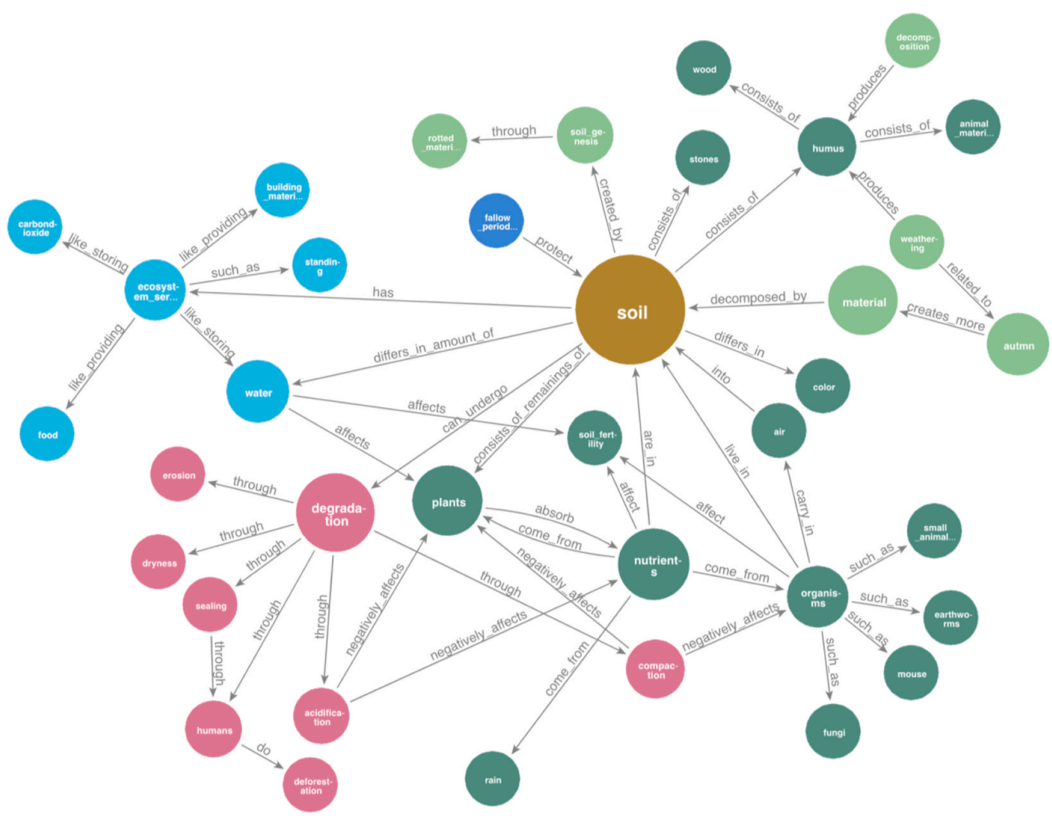
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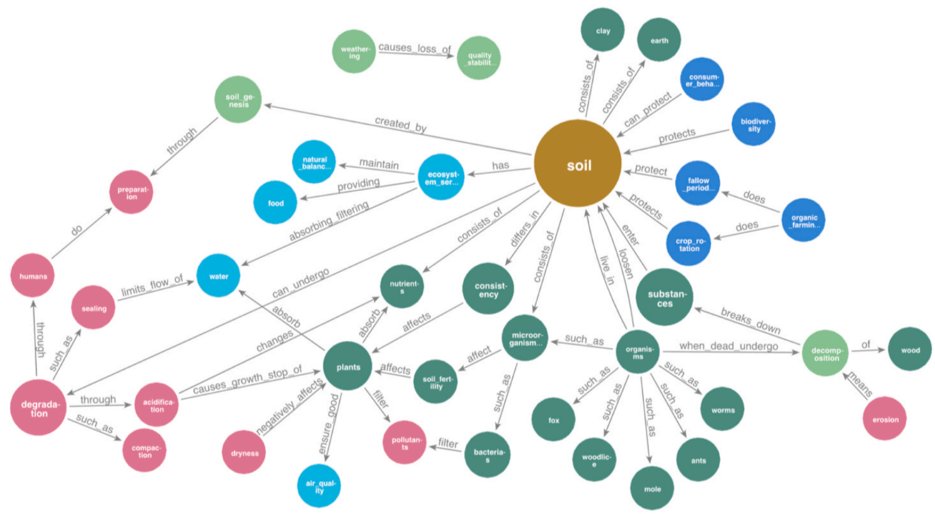

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Data availability

Data will be made available on request.

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