Fostering soil management PRACtices and uptake and developing decision support TOols through LIVing labs in EU (PRAC2LIV)

Deliverable 5.1

PRAC2LIV Final Report — Stocktake and Stakeholder Exchanges on Decision Support Tools for Soil Organic Matter, Nutrient Use Efficiency, and Water Retention Across EJP SOIL Countries

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ABSTRACT

The project PRAC2LIV conducted a stocktake of Decision Support Tools (DSTs) focused on three key themes: soil organic matter, nutrient use efficiency, and water retention, currently in use in EJP SOIL countries. Building on previous stocktakes and an extensive literature review, this assessment included DSTs ranging from simple tools to next-generation support systems. Both the scientific basis of these DSTs, as well as their implementation and adoption at the farm level, were evaluated. In addition, mock-up designs for DSTs (mobile apps) related to the three themes were created. The results of the stocktake were discussed with various stakeholders through regional workshops, within the broader context of soil health. Further elaboration was conducted using a novel visualization method, in a participatory approach, with a focus on "DSTs for Soil Health in Living Labs." By combining the findings from the literature, stocktake, workshops, mock-up designs, and visualization, conclusions and recommendations were made for the future development of DSTs in agro-ecosystems across Europe.

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List of acronyms and abbreviations

ASD	EJP Soil Annual Science Days
EJP SOIL	European Joint Programme on Agricultural Soil Management
EU	European Union
DST	Decision Support Tool
KPI	Key Performance Indicator
MOI	Soil Moisture Retention
NUE	Nutrient use Efficiency
SOM	Soil Organic matter
WP	Work Package

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EXECUTIVE SUMMARY

Background and objectives

EJP SOIL is a European Joint Programme on Agricultural Soil Management (EJP SOIL) addressing key societal challenges, including climate change and future food supply. Threats to soil health and climate change are increasingly impacting farming conditions across Europe, creating an urgent need for advanced Decision Support Tools (DSTs) to effectively manage soil health, water retention, and nutrient efficiency. However, the adoption of these tools varies significantly due to challenges including accessibility, data availability, and regional variations in tool reliability. In response to these challenges, EJP SOIL commissioned a stocktake on the availability and use of DSTs in the EU, focusing on nutrient use efficiency, soil organic matter, and moisture retention. In support of the EU Soil policy, e.g. the Soil Deal for Europe (European Commission, 2022) and the Soil Monitoring Law (European Commission, 2023), PRAC2LIV also discusses DSTs with a wide variety of stakeholders during live meetings.

The overall objective of the PRAC2LIV project was to assess the availability and uptake of DSTs within EJP SOIL countries, and to provide recommendations for their development and broader adoption to promote sustainable soil management. This objective was pursued through a comprehensive research approach that included a detailed literature review, systematic stocktake and evaluation of existing DSTs via surveys, stakeholder workshops, development and testing of mock-up designs, and an example for DSTs for soil health in Living Labs, contributing to a common vision on the advancement of sustainable soil management practices across Europe. The work covered the majority of EJP SOIL countries, providing insights across different agricultural and environmental conditions in Europe.

Key findings

Literature review

Agricultural management practices are significantly shaped by socio-economic, biophysical, and technological factors, including policies, market dynamics, technological advancements, and climate change. These influences affect soil management decisions, ultimately impacting crucial soil functions such as carbon sequestration, water retention, and nutrient cycling, all of which are vital for sustainable agriculture.

The literature emphasizes the need for robust monitoring networks and the integration of soil quality into environmental and agricultural policies. These policies aim to establish common criteria for soil health, promote restoration efforts, and improve data sharing among EU countries, formalizing comprehensive data collection and reporting processes. DSTs play a crucial role in analysing complex soil data, supporting policymakers, and ensuring sustainable land management practices. The review further calls for simple, accurate tools to enhance decision-making at the farm level. However, current DSTs often prioritize productivity over the multi-functionality of soils, limiting their adoption for diverse soil functions due to weak drivers and insufficient legislation. Implementing DSTs in agriculture is further complicated by the varied needs and conditions of farms. A holistic approach that incorporates multiple soil functions and engages stakeholders is essential for effective adoption. The review underscores the importance of aligning DSTs with farmers' real-world needs, supported by appropriate policy frameworks.

The literature review also reveals that scientifically validated DSTs are limited and often obscured by non-scientific ("grey") publications, leading to poor information exchange between researchers, developers, and end-users. Additionally, an expert-driven approach is recommended for regional

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case studies to better incorporate diverse insights, compared to strict scientific protocols. To enhance transparency and accessibility, a centralized public database of DSTs should be developed, allowing farmers, researchers, and policymakers to access organized and practical information, thereby bridging communication gaps and promoting broader adoption of DSTs.

Stocktake and evaluation of Decision Support Tools

The stocktake was conducted with two questionnaires, one distributed via email to the national coordinators of EJP SOIL countries, and the other to farmers' groups. These questionnaires focussed on a wide range of tools for soil organic matter, water retention, and nutrient use efficiency. Survey responses were received from 18 European countries, including Türkiye, and they identified 156 DSTs with 112 fitting the project's definition of digital DSTs. These tools vary significantly in type, technology, and purpose, ranging from simple calculators and activity planners to more complex models, monitoring systems, and remote sensing-based systems. The primary users of these DSTs include agronomists, consultants, advisors, and farmers, with less frequent use by researchers, private companies, NGOs, and policymakers (Figure ES1).

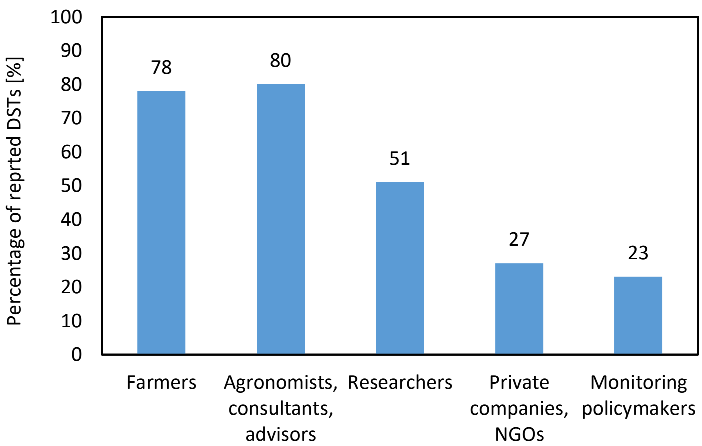

Figure ES1. Users of the commonly used DSTs.

The evaluation shows that the adoption of DSTs by end-users is generally moderate, with factors such as user-friendly interfaces, low costs, and alignment with user goals contributing to their adoption (Table ES1). However, the involvement of end-users in the development of these tools has been modest, indicating a need for greater stakeholder participation in the design process. The information available on the reported DSTs was often limited, presenting another potential hindrance to their adoption.

Table ES1. Average values of features ratings of commonly used DSTs..

Question	Rating	Value
Adoption by end-user	1= little or no use, 5= widely adopted	3.1
Is the use of the tool optional?	1= Yes, 2= No	1.1
Data input	1= few data needed, 5=many data needed	2.7
User friendly interface	1= too complex for users, 5= very user friendly	3.7
Perceived reliability of the DST	1= low reliability, 5= very high reliability	3.8
Cost of the DST	1= Free of charge, 5=Very expensive	1.8
The tool has been developed with participatory approach	1= no users involvement, 5=user-centred design	3.3
Suitable to reach national goals	1= not suitable, 5= very suitable	3.5
Suitable to reach regional goals	1= not suitable, 5= very suitable	3.6
Suitable to reach farmers goals	1= not suitable, 5= very suitable	4.1

The evaluation emphasizes the importance of accounting for local and regional conditions in the development of Decision Support Tools (DSTs) and highlights the need for enhancements to existing tools. Farming needs and challenges differ across regions, and very few DSTs were commonly reported across multiple countries. Proposed improvements include integrating newer practices, such as organic farming and agroforestry, refining process descriptions and data inputs, and optimizing user interfaces to enhance usability (Figure ES2). Additionally, there is a call for new DSTs that address various spatial scales—from individual farms to regional levels—and provide comprehensive data integration. Overall, the evaluation stresses the need for DSTs that are adaptable to local and regional conditions, scientifically rigorous, and user-centered, to better support sustainable soil management practices across Europe.

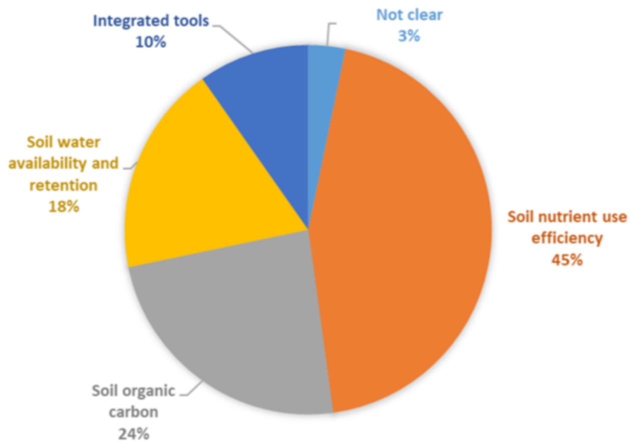

Figure ES2. Percentage of reported development needs in commonly used DSTs by type.

Stakeholder exchanges on DSTs

The results of the stocktake were discussed with a wide variety of stakeholders during live meetings. Regional workshops were held with farmers, advisors, and researchers, following a similar script in Sweden, Latvia, Italy, and Türkiye. Taking into account regional differences in soils and climate, soil-related challenges were addressed, emphasizing the need for DSTs specifically designed for soil nutrient management, particularly for optimizing fertilization practices.

Several barriers to DST adoption were identified, including the high cost of technology, insufficient user-friendliness, lack of technical support, and resistance to change, particularly among older generations. The adoption of DSTs by small and medium-sized farmers was highlighted as a challenge in all four workshops, with participants noting that DSTs are generally more suitable and viable for larger farms. Proposed solutions included positive demonstrations by experienced farmers, financial and technical support for implementation, and the development of simpler, more user-friendly tools accessible to all generations. The magnitude of these barriers varied across different contexts, underscoring the need for tailored solutions and implementation strategies.

In addition, DSTs were also discussed in meetings organized by other parties, such as National Hubs, EJP Soil Annual Science Days, and bilateral meetings with experts in agro-ecological agriculture and business models. The purpose of these meetings was to communicate the results of the stocktake and invite input for the future development of DSTs. Valuable input was obtained on socio-economic and policy aspects of DSTs.

A participatory design approach was also used to develop a common vision on the broader topic of "DSTs for Soil Health in Living Labs." In subsequent meetings led by a moderator, stakeholders discussed this topic while a designer simultaneously created sketches and drawings, which were incorporated into the overall visualization. The final version was reached after several iterations

(Figure ES3). During this process, new subtopics were identified, such as 'digital twin,' 'business model,' and 'ecosystem services.' Furthermore, it was found that the participatory process enhanced stakeholder commitment to the outcomes.

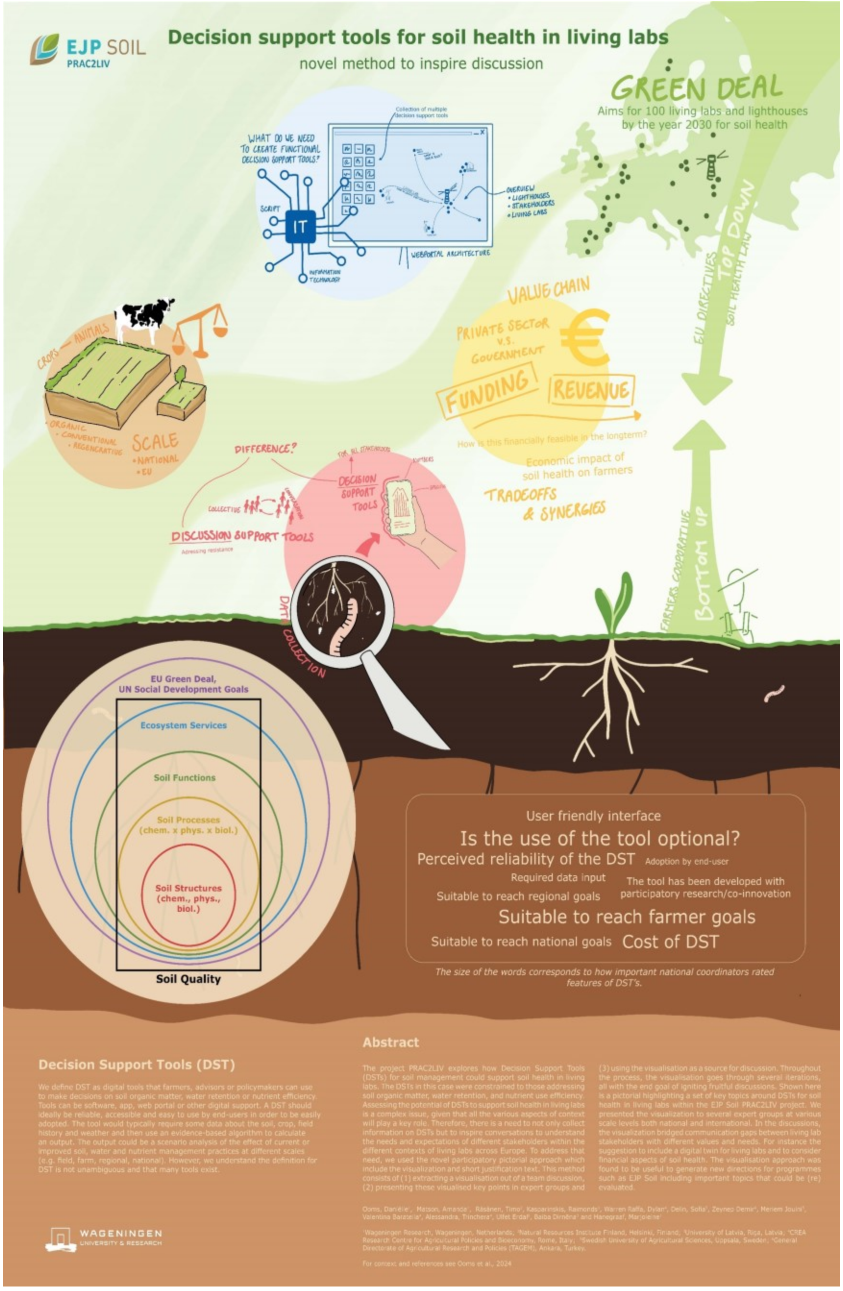

Figure ES3. A poster presenting the results of a participatory design approach for developing a common vision on the wider topic of "DSTs for Soil Health in Living Labs".

Decision Support Tool mock-ups

DSTs may be developed in many different ways, and thus their actual (digital) form and presentation may vary, such as mobile apps, web portals, sensors/instruments, etc. Good DSTs will have algorithms that fit their purpose and deliver satisfying results. This is true not only in terms of reliability and accuracy but also with respect to the desired functions, such as monitoring, registration, or providing advice. Additionally, for high adoption rates of DSTs by end-users, the interface and presentation are considered to be very important. Mock-up designs for DSTs are a

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means to visualize the desired tools, inviting feedback and supporting structured programming. The mock-up designs developed for PRAC2LIV emphasize the importance of user-friendly interfaces, real-time data integration, and adaptability to different farming conditions.

A Web Portal on Decision Support Tools

Finally, the report discusses the development of a web portal for soil health, transitioning from single, stand-alone DSTs to integrated tools that support soil health across various scales. This shift aligns with broader European policy initiatives, such as the Green Deal, Soil Mission, and Climate Change Regionalization, which emphasize the need for tools that address multiple aspects of soil health simultaneously at different levels.

While single-purpose tools remain valuable, there is growing interest in creating web portals that integrate multiple tools to provide comprehensive support for soil health management. The report suggests that these portals should be scientifically robust, user-friendly, and adaptable to various agricultural contexts, supporting sustainable practices in line with European policy objectives.

Conclusions

The report underscores the transformative potential of decision support tools (DSTs) in advancing sustainable agricultural practices while highlighting several gaps that hinder their full effectiveness in enhancing soil management across Europe. Many current DSTs are primarily focused on productivity or single purposes, often neglecting the combined effects of crucial soil functions such as carbon sequestration, water retention, and nutrient cycling, which are vital for long-term environmental and social sustainability. Addressing this limitation requires a shift toward integrated, multifunctional DSTs that not only optimize agricultural outputs but also promote the health and resilience of entire agro-ecosystems. These tools should align with evolving European agricultural and environmental policies, such as the Green Deal and the Soil Mission, to contribute to broader societal goals.

The report's assessment of existing DSTs reveals a diverse range of tools with varying levels of adoption. However, significant improvements are needed in areas such as user-friendliness, adaptability to different farming systems, and better integration of diverse data sources. Additionally, the importance of designing DSTs that can adapt to different scales of operation, from small farms to larger agricultural enterprises, is emphasized. This can be achieved through active user involvement and co-creation during the development process, ensuring that tools are practical, intuitive, and aligned with the realities faced by farmers.

Furthermore, the report advocates for the creation of a European web portal for Soil Health, a centralized platform where various DSTs can be accessed, offering region-specific tools and data integration. This portal would provide a comprehensive solution for managing soil health at multiple scales, enabling farmers and other stakeholders to make informed decisions that align with both productivity and sustainability goals. The incorporation of user feedback, continuous evaluation, and alignment with policy frameworks are also crucial for ensuring the long-term success and relevance of these tools.

Ultimately, the future of DSTs in European agriculture lies in their ability to evolve from simple productivity tools into comprehensive systems that integrate the ecological, social, and economic dimensions of sustainability. This evolution will require collaboration among researchers, policymakers, farmers, and technology developers to design tools that are scientifically sound, practically applicable, and adaptable to local contexts. By addressing the challenges outlined in this report and leveraging emerging technologies, DSTs have the potential to play a key role in achieving sustainable soil management and enhancing agricultural resilience across Europe.

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Recommendations

The work presented here offers a broad understanding of the current use, challenges, and potential of DSTs in enhancing agricultural practices and sustainable soil management. Building on these insights, specific recommendations have been formulated to guide the development and increased adoption of DSTs, as well as the creation of a European web portal for Soil Health. These recommendations are summarized in Table ES2, with a more detailed explanation provided in Section 5.

Table ES2. Summary of recommendations for enhanced adoption and effectiveness of DSTs and for web portal on DSTs for soil health.

Enhanced adoption and effectiveness of DSTs	Web portal on DSTs for soil health
Existing DST effectiveness: • Improve data integration and accessibility • Increase usability and flexibility • Monitor and evaluate DST performance **DST improvement:** • Include soil health and economic indicators • Explore new technologies and guarantee continuous improvement • Focus on multi-functional and integrated tools **Participatory approach on DST use and development:** • Promote knowledge exchange and capacity building • Enhance user engagement and co-creation **EU policy:** • Align with policy and regulatory frameworks • Foster collaboration and cross-border integration	**Participatory approach on web portal on DST development and use:** • Use a participatory approach • Functional design, an architecture • Customizable user dashboards **User-friendly and interoperable interface:** • Centralized access to diverse tools • Interoperability with existing systems • Scalable solutions for different users • Interactive decision-making tools • Real-time data integration • User support and community forums **Data ownership and security:** • Data privacy and security **Customization and user exploitation:** • Regional customization and localization • Educational resources and best practices • Continuous feedback and improvement loop • Integration with policy and regulatory frameworks

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1. Introduction

1.1. Background

Climate change will gradually modify the environmental conditions for farming practices and farm strategies. Some agricultural advisory services across Europe are well equipped with flexible, high-quality Decision Support Tools (DSTs) to address this. Additionally, open-source DSTs may be available, such as those mentioned by Leroux et al. (2018). The trend is toward more complex DSTs that combine production with environmental services. However, the level of implementation of DSTs and guidelines for sustainable soil management in Europe varies considerably among farmers and regions. Limiting factors for adoption include access to the tools, availability of required input data, and uncertainty regarding the reliability of the tools given regional conditions (Nicholson et al., 2020). At the national level, DSTs may be available and could be adapted for wider use across the EU. Scientific papers allow for the export of underlying principles and approaches; however, exchanges at the practical farm level are less frequent. Previous studies have identified a wide range of limiting factors, including differences in advisory frameworks, country-specific data and calibration requirements, and language barriers (Hvarregaard Thorsøe et al., 2019; Rose et al., 2016).

DSTs can be defined in various ways, encompassing different types of tools, media, and services. In PRAC2LIV, the focus was on digital DSTs addressing soil organic matter, water retention, or nutrient efficiency (see Call text), using the following definition:

> *"Digital tools that farmers, advisors, and/or policymakers can use to monitor and/or make decisions addressing soil organic matter, water retention, or nutrient efficiency. Tools can be software, apps, web portals, or other digital platforms. The tool would typically require some data about the soil, crop, field history, and weather, and then use an evidence-based algorithm to calculate an output. The output could be an analysis of the effect of current or improved soil, water, and nutrient management practices at different scales (e.g., field, farm, regional, national)."*

In practice, categorizing DSTs is challenging, or at least limiting, as there are many types of DSTs consisting of different technologies, data, and media, and their purposes vary greatly.

An important step to secure food production in Europe under climate change and restrictive conditions could be the design and development of a web portal that would enable farmers and advisory services to optimize farm management in terms of agricultural production and environmental services. Such a web portal would include the best DSTs for monitoring Key Performance Indicators (KPI) and/or evaluating farm and field practices (e.g., Gallardo et al., 2020). The platform could utilize and reference region-specific tools, reference values, and/or targets to provide qualitative or quantitative information from available tools. To ensure reliable and accurate data, a science-driven foundation is essential, and for success, actionable recommendations are necessary. Therefore, there is a need for apps that emphasize knowledge exchange rather than simply information delivery (Eichler Inwood and Dale, 2019). The co-production of climate-driven decision support tools has been reported as a success factor for adaptation by farmers (Lu et al., 2022).

With this in mind, EJP SOIL commissioned research to perform a stocktake on the availability of DSTs for fostering soil management in the areas of nutrient use efficiency, soil organic matter, and moisture retention within the EU (Leppälä et al., 2022). During the preliminary phase of the project, it was observed that these three topics are part of the broader concept of soil health, which is embraced by the EU's agricultural policy. The Soil Mission aims for 100 Living Labs on soil health by

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2030 (European Commission, 2022). Supporting soil health in Living Labs is a complex issue, both in terms of registration and planning, as well as monitoring. The adoption and use of DSTs within farming communities may play a key role. Therefore, it is necessary not only to collect information on current DSTs for farm-level use but also to inspire conversations to understand the needs and expectations of various stakeholders at higher scales, such as Living Labs and the regional level.

1.2. Objectives

The overall objective of PRAC2LIV was to assess the availability and use of DSTs by performing a stocktake focusing on DSTs for the themes of Soil Organic Matter, Nutrient Use Efficiency, and Water Retention across the EJP SOIL countries. The research was carried out with consideration of current issues such as soil degradation, climate change, other environmental impacts, farm economy, and the EU policy aimed at addressing these issues, particularly soil degradation, through the implementation of living labs.

The specific objectives were:

- Perform a literature review on DSTs and their use.
- Conduct a stocktake on the availability and use of DSTs across Europe.
- Investigate farmers' and stakeholders' experiences with DSTs and their future needs.
- Develop mock-up designs for DSTs focused on the three themes.
- Facilitate stakeholder exchanges to discuss the outcomes of the research with stakeholder groups.
- Provide recommendations for enhancing the adoption and effectiveness of DSTs.

These objectives were achieved through a series of research activities described in this report, which is structured as follows. First, a description of the division of work and the respective methodologies is provided, following the division of work packages and tasks of the project (Section 2). The results of these research activities are then presented in the subsequent sections (Section 3).

The literature review was conducted to explore the definition, types, and drivers of use for Decision Support Tools (DSTs) (Section 3.1). This review also discussed DSTs in the context of living labs, soil quality, and EU policy.

The stocktake was undertaken to assess the availability and use of DSTs across Europe (Section 3.2). The stocktake was based on two surveys, distributed to national coordinators of EJP SOIL and various stakeholders, including farmers and advisors. These surveys examined the use, users, features, and improvement needs of DSTs, along with challenges faced by farmers.

The stakeholder exchanges were held through regional workshops and other meetings (Section 3.3). They served as a platform to discuss the stocktake results and identify further steps to accelerate the successful implementation of DSTs. They were also aimed at investigating the experiences of farmers and other stakeholders with current DSTs and understanding their needs for future tools.

The mock-up designs for DSTs were developed, focusing on three key themes: soil organic matter (SOM), nutrient use efficiency (NUE), and soil moisture indicators (MOI) (Section 3.4). These designs were intended to address the identified gaps and propose practical improvements to enhance DST functionality. The report presents also a discussion on the development of a web portal for soil health, designed for use in Living Labs. This discussion, informed by the findings from the research activities, outlines potential pathways for future implementation and broader adoption of DSTs (Section 3.5).

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Finally, the conclusions from each part of the research are summarized in Section 4, followed by a comprehensive list of recommendations for the further development and adoption of DSTs, as well as the creation of a web portal dedicated to DSTs in Section 5. An AI-assisted approach was employed in developing these sections to enable more data-driven analysis and synthesis.

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2. Methodology

2.1. Literature review

To collect literature, a rapid review methodology was applied (Tricco et al. 2015), recognised as a useful tool for evidence-based decision-making at the policy level (Yost et al. 2014). It was based on the SALSA (Search, Appraisal, Synthesis, and Analysis) framework and was conducted in stages (Figure 1) to ensure the demarcation of literature to be as comprehensive and accurate as possible and to gather as much relevant literature as possible while minimizing the inclusion of irrelevant literature.

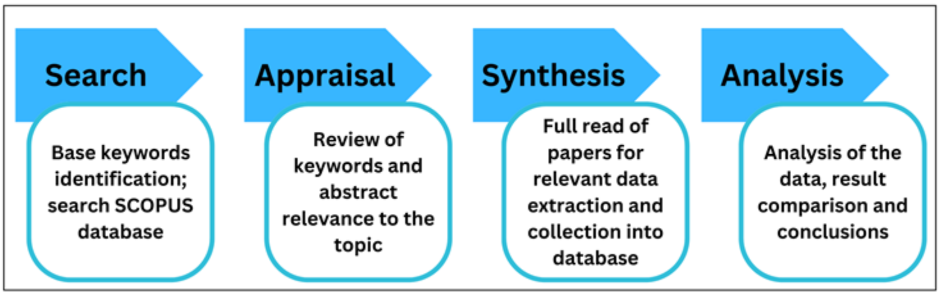

Figure 1. Framework for rapid literature review, based on framework for systematic literature search and review by Bathaei and Štreimikienė (2023).

The first stage – Search: The literature search was conducted by strictly following the identified keywords (decision, support, system, tool, model, living labs, Europe, national, agriculture, land, soil, water, retention, nutrients, carbon) in order to minimize subjectivity. Only peer-reviewed, published papers describing empirical, original research was included. Search was carried out using the online scientific database SCOPUS. The search was conducted only in English language. For example, the final search combinations for literature connected to soil water retention DSTs and DSSs were:

- (TITLE-ABS-KEY (decision AND support) AND TITLE-ABS-KEY (water AND retention) AND TITLE-ABS-KEY (agriculture))
- (TITLE-ABS-KEY (living AND labs) AND TITLE-ABS-KEY (water AND retention))
- (TITLE-ABS-KEY (decision AND support) AND TITLE-ABS-KEY (water AND retention) AND TITLE-ABS-KEY (soil)).

The second stage – Appraisal: All results from the search results were reviewed at title and abstract level to ensure they met a set of defined criteria. Key words were selected for exploratory analysis of the available literature including following criteria:

- **Type of DST:** decision support system; decision support tool; decision support model; living labs
- **Scale:** Europe; national/country scale; regional; local
- **Target groups:** policy decision makers; stakeholders; farmers
- **Target objects:** land quality; soil productivity; soil functions; soil properties; soil threats; soil degradation risks, soil carbon, soil organic carbon, soil organic matter; soil water, water retention; soil nutrients, nitrogen, phosphorus, potassium, nutrient use efficiency
- **Agroecological conditions:** Controlled; actual
- **Agricultural lands:** croplands; arable lands; grasslands; abandoned lands
- **Agricultural systems:** conventional agriculture; organic farming
- **Agricultural management:** intensive; extensive.

The third stage – Synthesis: Publications that passed the inclusion criteria were collected into the database and read in full to extract the relevant information and additional sources to the report.

The fourth stage – Data analysis, comparison of results and conclusions: relevant studies were collected, and their findings were summarized based on key topics such as the characterization and classification of DSTs, their relevance to water retention, soil nutrient and SOM management, connections to living labs, and their role within agricultural policies and soil health. Results were compared across the selected literature by identifying similarities, discrepancies, and patterns. The collected information was then synthesized to provide a holistic understanding of the topic. Practical and policy implications were discussed, leading to conclusions about the effectiveness of DSTs, their impact on agriculture, and recommendations for future development and implementation. A concise summary of the literature review findings is presented in this report.

Several thousand publications were retrieved from the first stage of the literature search. After the appraisal stage most of the papers were selected as inadequate for the literature review. The full scope and analysis of the available literature, provided by the key words used is available in Deliverable D2.1 ''Report on WP2 Scope and demarcation – Literature review'' (Internal Report).

2.2. Stocktake and evaluation of DSTs

2.2.1. Survey of EJP SOIL national coordinators on DSTs

The PRAC2LIV team iteratively developed the questionnaire for EJP SOIL National Coordinators. The goal was to gather quantitative and qualitative information on the most common DSTs used in each EJP country and to identify critical points and opportunities for future improvements in DSTs related to soil organic carbon, soil moisture retention, and nutrient use efficiency. The questionnaire also examined the current use of different DSTs based on specific farm management practices (e.g., organic vs. conventional), problems encountered, adaptation experiences, and future development needs.

The questionnaire consisted of eight sections: personal details of the EJP SOIL national coordinators, definition of DST, current Use of DSTs in the country, users of DSTs, assessment of the reported DSTs, Improvements, factors determining the use of DSTs, and other important aspects not addressed by the questionnaire. It included both open and closed questions. Before distribution, the questionnaire was tested with four researchers.

It was then sent as an Excel file to 27 national coordinators from 25 EJP SOIL member countries, including Türkiye. National coordinators were recommended to mobilize their network in order to gather representative data on the use of DTSs in their country. A help desk was established to assist the national coordinators, and two webinars were conducted to support them in completing the questionnaire. The questionnaire is available in Annex I.

Data collected through the national coordinator's questionnaires were analysed using descriptive statistics. The scores of various criteria for DSTs were compared with the highest adoption rates to the average scores of all reported DSTs, highlighting features that can enhance adoption by end users. Furthermore, DSTs were grouped and analysed by specific themes—soil organic matter, water retention, and nutrient use efficiency—to identify needs and potential improvements within each category. Finally, we run a correlation analysis to relate the different criteria proposed in the assessment section of the questionnaire.

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Current DSTs have been developed with specific goals in mind, often focussing on improving a specific situation that occurs in the respective country. These goals may have little to do with the goals of EJP Soil and/or EU-policies. For instance, tools at farm level may be geared towards advice on crop and soil management, whereas at the European level quantitative data on reducing losses and/or sequestration are required. Important questions to be discussed are:

- How well are current DSTs perceived in terms of user-friendliness and other features?
- In what respect do highly adopted DSTs stand out from the general collection?
- (How) may a DST at farm or regional level be used for monitoring at EU-level?

An integrated evaluation of selected features was made on the base of scores per DST as provided by the national coordinators. For this purpose, DSTs were grouped per functionality (i.e., SOM, NUE, MOI) and the features with highest scores were visualized in polygons. The resulting figures were used for further evaluation by means of comparing and contrasting. In response to question 9 of the national coordinators' questionnaire, 4 topics with majors scores were: Required data-input, User friendliness, Participatory approach, and Costs. As there was no information available on the relative importance of these topics from the literature review, they were considered to be equally important. No normalization and/or weighing was performed on the data which comprised a total of c. 70 DSTs for the types NUE, SOM, and MOI including some biased. Polygons were used to assess differences between the three types. For this purpose, scores per features were re-arranged, if needed, so that high scores represent the most desired feature.

2.2.2. Survey of stakeholders on DSTs

Similarly, as the NC-questionnaire, the questionnaire for stakeholders, which included farmers, agronomists, consultants, and other experts was designed as a collective effort of the PRAC2LIV team. The goal of this questionnaires was to collect data by end users on: the use of DST to take decision in the farming activity, assessment of DSTs and suggestions to improve the current DSTs.

This questionnaire was meant to be shorter and easier to be compiled compared with the NC questionnaires and it was based on closed questions. The questionnaire was anonymous and consisted in 6 sections, namely: responder's details, most important farming challenges in the area, farming and DST (usefulness and criteria important to assess a DSTs), assessment of the DSTs used, DST to take decision at the field level, other aspect that were not taken into account in the questionnaires. The questionnaire was translated in Italian, Latvian, Swedish, Turkish, Finnish and Dutch and uploaded on Netigate and shared with the national stakeholders. The questionnaire was sent to the following stakeholders in the different country:

- Italy: Coldiretti (farmers union) dispatched the questionnaire through its network to agricultural technicians, agronomists and consultants, farmers and representatives of agricultural companies and associations, an official from a public body, researchers and a representative of the E. Mach Foundation.
- Sweden: The questionnaire was distributed to stakeholders through three channels: 1) to farmers within "Odling i Balans", which is a network of 16 pilot farms that focus on balanced agriculture, 2) to farmers' advisors within the national advisory program "Greppa Näringen" and 3) to different stakeholders through a newsletter sent out by "Svensk Kolinlagring", which is an organisation that connects different actors to enable increased carbon storage in agricultural soils.
- The Netherlands: the questionnaire was emailed to stakeholders within the network of WUR, mostly researchers, advisors and/or farmers from regional farmers' groups.

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- Türkiye: the questionnaire was dispatched to farmers, researchers, consultants, employees of a private company working in agriculture or food production, and employees of farmers' cooperatives
- Latvia: The questionnaire was distributed to stakeholders representing various sectors including policy-makers, research community, educational institutions, advisors, farmers' organizations, agro-industry, and NGOs.
- Finland: The questionnaire was dispatched to Living Labs, and other well-known farms and farming communities, including researchers involved in farming activities.

2.3. Stakeholder exchanges on the use of DSTs

The results of the stocktakes were discussed with a wide variety of stakeholders in live meetings: 1) regional workshops were organised with farmers, advisors, and researchers; 2) contributions were given to meetings organised by others, e.g. National Hubs, EJP Soil Annual Sciences Days, and/or bilateral meetings with experts; 3) a participatory approach was used to develop a common vision for future use of DSTs. The methodology and results of these have been described in D4.1. Therefore, the present report includes the highlights of the activities only.

2.3.1. Regional multi-stakeholder workshops

Regional workshops were organised to discuss results from the stocktake with stakeholders and assess which steps are needed to accelerate successful implementation of tools. For this purpose, a script was developed that not only suited the communication of results, but also the discussion on the larger topic of improving sustainable soil management. The following types of stakeholders were to be invited: farmers, advisors, DST providers, researchers, and policy makers. The aim was to limit the number of participants to around 25, to create good conditions for discussion. Parts of the discussions were made in smaller groups.

Each workshop started with a plenary session with an introduction of the EJP SOIL and PRAC2LIV project and a presentation of some selected findings and examples from the European and national stocktake of available DSTs. In the first part of the workshop, participants were asked individually what they thought was main soil-related challenge, what was their objective with using a DST and if they had any other DSTs to add to the list.

In the second part of the workshop, the participants were divided in smaller groups to facilitate the discussions on specific topics. They discussed in smaller groups about barriers to DST adoption, and potential solutions to break them. They were also asked to discuss what features they miss in DSTs that they currently use and for what decisions the tools are still missing but needed and to make a ranking of the most important features of a tool. Some statements were selected to participants for opening a discussion about their agreement/disagreement and why. After the group discussions, the main results were presented to all participants, in order to draw the main conclusions of the workshop.

If so desired by the contact person of the respective workshop, in a third part of the workshop specific attention would be given to either one of the themes soil organic matter, nutrient use efficiency, and/or soil moisture retention.

As part of each workshop, an interview was set up with one or a few of the participants. These interviews have been recorded and presented in the form of short videos summarizing highlights of each workshop, the main discussions and results.

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2.3.2. Exchanges in other meetings

National Hubs

In addition to mere 'sending' information about the research via the newsletter, interaction was actively sought with participants of the national hub in The Netherlands. For this purpose, contributions were given to two meetings of the national hub. During the first one, participants were informed about the project and the questionnaires, and in the second, their cooperation was sought as part of the participatory approach for making a visualisation on DSTs (see also next paragraph). A meeting with the national hub of in Türkiye is scheduled for a later date in 2024.

EJP SOIL Annual Science days (ASD) 2023 and 2024

During ASD 2023, exchanges with fellow researchers were facilitated by presentation of two posters, i.e. one to invite stakeholder groups, in particular Living Labs, to participate in the workshops, and the other on a candidate stakeholder group in The Netherlands. In addition, exchanges with researchers were organised in the co-convened session 'Using participatory design for developing farmer friendly tools for soil practices and schemes '. The session focused on the EJP SOIL aims to promote the use of regionally specific tools to provide either qualitative or quantitative information on agricultural soil-based ecosystem services, e.g., climate change. In ASD2024, exchanges with fellow researchers were sought to discuss results of the stocktake during the co-convened session "Leveraging different approaches in the development of farmer-friendly tools for sustainable soil practices and schemes", to engage in the participatory approach for making a visualisation on DSTs, and for engaging in policy related aspects during the science to policy session focused on future development and adoption of DSTs.

Lighthouse Farm

Intermediate results of the research indicated the importance of a business model for living labs. With that in mind, researchers from EU projects 'InBestSoil' and 'SoilValues' were consulted. During these discussions, attention was drawn to Ekoboerderij De Lingehof in the Betuwe region, the Netherlands, and subsequently a meeting was organised. In this case with only stakeholders from the farm, a different agenda was followed than the above-mentioned script. Major focus of the discussion was the ambition for being a lighthouse and the possible involvement in a Living Lab.

2.3.3. Participatory approach in designing future development of DSTs

The aim of this part of the research was to explore the use of narrative mapping for inspiring and discussing the perspectives for integrated DSTs to support soil health in living labs. For this purpose, a method based on 'narrative mapping' has been used. This method is an innovative technique to support and inspire discussion among a variety of stakeholders in complex case studies (Lapum et al., 2015). The method derives from the technical design domain in which complex systems are visualised, often complemented with a textual narrative on the discussions and background justification ('pictorial'). A major advantage of this method is the opportunity to document and present qualitative research that would otherwise not be seen in a traditional paper.

The narrative mapping method was used following the steps outlined by Ooms (2021, 2022):

1. Extracting key points for a visualisation out of a moderated team discussion
2. Presenting these visualised key points in several expert groups to receive feedback, eacht time improving the visualisation
3. Finally, using the visualisation as an inspiration for discussion.

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Throughout the process, the draft visualisation was presented as 'work in progress' with the goal of igniting fruitful discussions on the topic 'perspectives for integrated DSTs to support soil health in living labs. Ideas and information were collected to add to the picture. After several iterations, the endpoint was reached as major stakeholder groups had been involved and few new discussion points were given.

2.4.Mock-up designs for DSTs

As DSTs can be developed in many different ways, their actual (digital) form and presentation of the DST may vary, e.g. mobile app, web portal, sensor/instrument, etc. Good DSTs will have algorithms that fit the purpose and deliver satisfying results. The latter is true not only in terms of reliability and accuracy, but also with respect to the desired function(s), e.g. monitoring, registration, advice, etc. In addition, for high adoption rates of DSTs by end-users, the interface and presentation of DSTs are considered to be very important. To illustrate this, examples (mock-ups) were made for SOM, NUE, and MOI. They are based on the design and format of a mock-up for agricultural biodiversity (Van Opstal & Van der Gugten, 2023), which is currently being elaborated into a real app by Earthwatch Europe and Wageningen University.

Preliminary, a specification shortlist was written to indicate major considerations and acquire the necessary information for the designing phase. It also indicates the functionality of the DSTs to fulfil the needs of stakeholder groups. The specification shortlist covers three subjects: Aim of the DST, expected end-users, and required elements. With these requirements in mind, mock-ups designs were made for SOM, NUE and MOI dedicated for use at farm level as covering all options (functions) for the design of DSTs would be beyond the scope of this project. A two-step process was used. First, a flow-diagram was drawn including and connecting all proposed elements of the DST. Secondly, the actual designs of the respective screens were made in MS Powerpoint. To show how these would be aligned, the presentations were made into an interactive pdf. This report presents the mock-up for SOM only. Full results of this part of the research are described in a separate report (D5.2).

2.5. Artificial Intelligence assisted synthesis

The content of the report is extensive covering results from different research methods with range of diverse findings on DSTs and their use. Therefore, ChatGPT 4o from OpenAI (https://openai.com) was used to assist the development of report sections that synthesise the findings from different parts of the report: executive summary, conclusions, and recommendations. First, draft texts were written of the contents of these sections by the authors, and ChatGPT4o was asked to provide texts for these sections based on its reading of the other sections of the report. The content from these two texts were then merged and revised to accurately reflect the findings and the authors perceptions. This approach was used to ensure a more thorough and data-driven analysis and synthesis of the findings.

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3. Results and discussion

3.1. Literature review

3.1.1. Overview of DSTs

To characterize decision support systems and determine the scope of decision support tools available in literature, it was important to understand the decision support process. It was best described in detail by Sullivan (2002) and can be summarized as a process that integrates expert knowledge and specific data to address particular problems by developing and analysing conceptual models. This process typically involves five stages: gathering site-specific information, creating simple conceptual models, analysing the information with computer tools, interpreting the results, and presenting the findings to decision-makers. The output helps evaluate different remedial options, balancing technical feasibility, cost, and regulatory compliance. Ultimately, decision-makers review this structured, transparent information, incorporating stakeholder feedback, to reach an informed decision, potentially repeating the process if further data is needed.

When analysing what exactly is a decision support system or specific tool that could participate in this process, various definitions and characterization were offered by different authors (Sánchez et al., 2020; Mir et al., 2015; Power, 2002; Shim et al., 2002; Druzdzel and Flynn, 1999; Turban, 1995; Finlay et al., 1994; et al.), showing that various models and systems could be used as DST and that it is not possible to restrict development of DST into one particular framework. Although, some key features were reported, like ability to support end-users in different scales, ability to support various input and processing styles as well as interactive use to support changing environment and that benefits of these systems should exceed the cost. It was clarified that decision support for agriculture can come in the form of a specific tool with specific purpose (e.g. P index) or a support system that integrates several separate tools (e.g. farmer conservation plans, nutrient calculators, independent databases, weather forecasts, external computer models, etc.) (Rose et al., 2016).

Literature analysis revealed that geographic information system (GIS) incorporation into DST was a very important stepping stone for improving regional agricultural management (Huy, 2009; Yongzheng, 2002; Guhathakurta, 1999). It was reported that even though GIS provides all the biophysical information for DST, geospatial technologies can be too difficult for non-professionals to understand. DST should be developed using only some GIS features and in such a manner that they are easy understandable and attractive to the end-users (Huy, 2009; Esnard and MacDougall, 1997).

More detailed focus and analysis in the DST that provide specific information for water retention, nutrient efficiency, and soil organic matter showed additional features and conditions. For example, in water management, DST provide the needed support for the precise management of crop water requirements, therefore optimizing yields and reducing costs (FAO, 2017; Payero and Irmak, 2013; Ventura et al., 2001). Traditional methods for estimating these requirements often fall short due to discrepancies between actual crop characteristics and published coefficients. Advances in agronomic models, remote sensing, and GIS have improved the ability to assess drought impacts more accurately (McVicar et al., 1992). On-site monitoring techniques and advanced DSTs are emerging to enhance water management (Rallo et al., 2017; Gharsallah et al., 2013), though it was mentioned that many existing systems may be overly complex for general use (Ramírez-Cuesta et al., 2019; Dzikiti et al., 2018; Soulis et al., 2018; Rana et al., 2005). It was noted that recent developments seek to simplify this process, providing reliable water estimations without relying on site-specific data. Additionally, integrating remote sensing technology into DSTs helps address spatial heterogeneity in crop water needs. The literature review shows that several DSTs have been developed for water and drought management, including tools that model water flow and predict landscape responses (Ramírez-Cuesta et al., 2019; Mir et al., 2015; Verrelst et al., 2012; Moreno-Rivera et al., 2009;

Steduto et al.,2009; Loi and Tangtham, 2004; Watkins and McKinney, 1995; Sojda et.al, 1994). Overall, employing these innovative tools and models can significantly improve water retention and management practices in agriculture.

When analysing literature on DSTs that focus on nutrient management, it was obvious that they play an important role in helping farmers manage nutrients effectively, cutting down on fertilizer costs and reducing environmental risks (Mir et al., 2015; Karmakar et al., 2007; Gibbons et al., 2005; Lemberg et al., 1992). These systems can simulate cropping schemes to provide tailored recommendations based on site-specific conditions, optimizing fertilizer use and improving crop yield efficiency (Quemada and Cabreva, 1995; Chai et al., 1994). With many DSTs now available online, farmers can easily access them to plan nutrient use and irrigation without needing direct access to advanced technology (Achilea et al., 2005; Jorgensen et al., 2005). In many regions, DSTs are being developed to enhance nutrient and micronutrient management, contributing to more sustainable agricultural practices (Mir et al., 2015). The literature review showed that when managing nutrients, DSTs focus mainly on Nitrogen (N) and Phosphorus (P) management (Drohan et al., 2019; Teagasc, 2017; Nicholson et al., 2013; Chambers et al., 1999). Even though implementation of DST for P management can be challenging in large scale, as there are many different variables connected to P leaching (Withers and Bowes, 2018).

Literature review on DST on soil organic matter (SOM) revealed, that SOM is usually one of the key components of soil health indication, therefore majority of DST on SOM content are parts of tools with broader aim. Some studies link management practices on sustainability indicators with environmental targets (Cabrera-Pérez et al., 2022; Vaudour et al., 2022; Young et al., 2021; Greiner et al., 2018; Schröder et al., 2018; Dal Ferro et al., 2016). For example, Young et. al (2021) based their framework on meta-analysis data and long-term experimental sites across several European regions, therefore it could be used in different climatic and soil regions for management production mapping to achieve, for example, soil organic carbon targets. While analysing the scope of various agricultural DST available in literature, it was noticed that many available DST are not specific to farmers, but can be focused on other stakeholders, for example, policy makers (Table 1). Various DSTs were mentioned, that can be used for political decisions, land management planning, evaluation of environmental risks or evaluation of ecosystem services provided by soil.

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Table 1. Examples of DSTs used by European stakeholders for policy planning (based on Sánchez et al., 2020 with author's modifications).

Name of DST	Purpose of the DST	Source
DeSurvey	System aims to support political decisions related to sustainable agriculture, water resource management, and land degradation.	Van Delden et.al, 2009
Water Resources	An educational tool for non-technical users and stakeholders to simulate and predict likely impacts in sectors such as agriculture.	Zaman et.al, 2009
AQUATOOL	For basins and water resource planning and management.	Andreu et.al, 2009
MicroLEIS	Multifunctional evaluation of the biophysical quality of the soil, using the characteristics of the soil such as place, climate, and cultivation as input data.	De la Rosa and Anaya-Romero, 2010
Environmental Risk Software (FARMERS)	For the safe and sustainable management of livestock manure as a fertilizer in order to control and limit the accumulation of metals in the soil and to reduce metal bio-transference from the floor to other compartments.	Río et.al, 2011
VULPES	System aims to transfer scientific knowledge for evaluating environmental risks from pesticides.	Di Guardo and Finizio, 2015
ALL_WATER_gw	Developed for groundwater management (water demand, minimization of water cost, maximum reduction, and compliance with water salinity restrictions).	Nouiri et.al, 2015
DESTISOL	Evaluates the ecosystem services that are provided by the soil, such as food production, air quality, flood mitigation, or climate regulation.	Anne et al., 2018
FaST	Digital service platform for farmers, farm advisors, EU Member States' Paying Agencies and researchers about environment and agriculture sustainability.	Fast, 2020

The other objective of the literature review also was to characterise the DST status considering Living Labs. Even though there were not that many resources in SCOPUS describing Living labs as they are still an innovative way of conducting research, it was possible to discuss the potential of living labs in connection to DSTs. They function as both practical entities that promote open, collaborative innovation and as real-life settings where user-driven innovation processes can be observed, tested, and refined, leading to the development of new solutions. By actively involving users and communities, living labs ensure that innovations are relevant to real-world needs while also contributing to the academic understanding of open and user innovation principles (Schuurman and Tõnurist, 2017). They also serve as platforms for research groups to engage with practical cases, fostering inter-organizational knowledge sharing through events, publications, and collaborative efforts (Dutilleul et al., 2010). This knowledge exchange helps bridge the gap between science and society, particularly in contexts like agriculture, where individual stakeholders, such as farmers, may selectively adopt innovations based on their specific needs and conditions (Bouma et al., 2021; Leminen and Westerlund, 2017). It was concluded that the scientific community must acknowledge this selective approach as a valid method for applying research outcomes in real-world situations. Especially, when research and soil-related policies have predominantly targeted enhancing individual soil functions, leading to inconsistent and often conflicting recommendations that complicate management decisions for farmers (ten Berge et al., 2017). To aid in their daily decision-making, farmers and farm advisors would significantly benefit from the real-life evidence-based DST (Debeljak et al., 2019).

3.1.2. Drivers for DST use

The literature analysis highlighted different driving forces behind the use of DST, which can be combined in three main categories – biophysical, socio-economic, and technological drivers. One of the main biophysical drivers is climate change, its importance and weight was highlighted in the context of water scarcity. In terms of extreme weather events, the role of the complex water systems and reservoirs management is increasing (Yordanova and Ilcheva, 2019). For various countries,

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especially in southern part of Europe, managing water for its various necessary functions, especially under drought conditions might be a big challenge, making it crucial to adapt irrigation practices to conserve water resources effectively (Mirás-Avalos et al., 2019; Turral et al., 2011). This may be the primary rationale behind the initial development of water regulating DST.

Socio-economic drivers such as policy regulations, subsidies, prices, etc. were mentioned as one of the main drivers for agricultural soil management as governments have the potential to shape soil management practices and adjust them through policy changes to align with society goals. Also, technological drivers such as different tillage technology, communication technology and robotics can be an important driver for farmers to choose to implement new methods. It was concluded that all these drivers should be looked from soil health perspective. As it is important to assess the impact of agricultural soil management on soil functions, which further will impact the soil health and yield. It can be best described by analytical framework put together by Paul and Helming (2019) which describes five steps of the Driver-Pressure-State-Impact-Response (DPSIR) system (Figure 2).

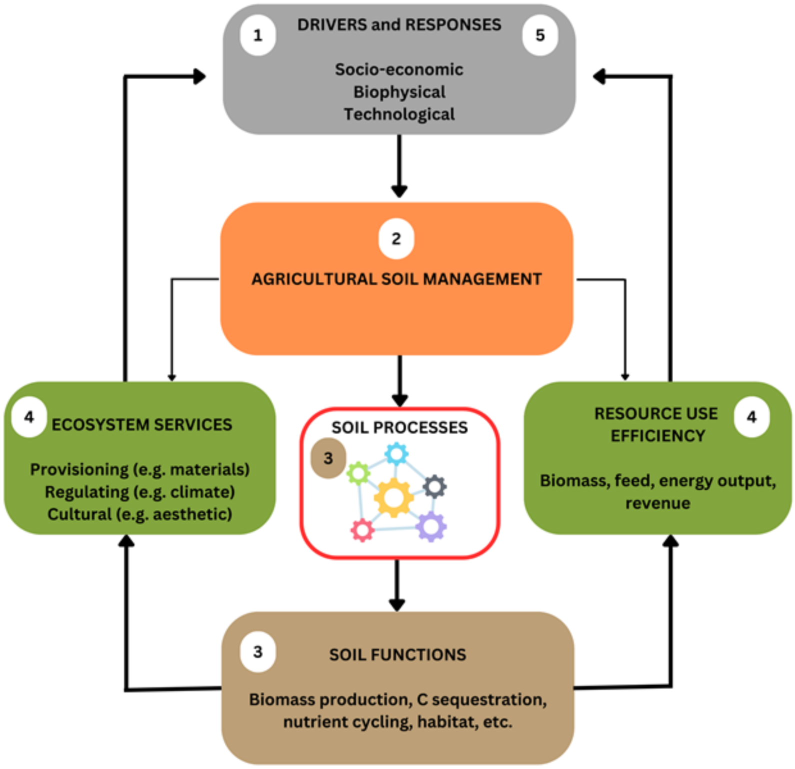

Figure 2. Analytical Framework for impact assessment of agricultural soil management and soil functions. Numbers refer to the five steps of the Driver-Pressure-State-Impact-Response (DPSIR) system (Paul and Helming 2019 with modifications by authors).

This system shows that relationships between the DST, farmers and soil are not as simple. The interconnected relationship between external factors and agricultural soil management, which in turn influences key processes within the soil is complicated. These processes directly affect soil functions, contributing to critical outcomes like biomass production and nutrient cycling. The use of DST can play a significant role in optimizing resource use, including maximizing outputs like biomass and energy while improving efficiency. Although, there might be other external factors influencing the decision of scientist developing the tool and farmer choosing to implement the tool. The complicated scheme shows that there cannot be such thing as a one size (or soil) fits all soil strategy, which is in line with the findings of Sandén et al. (2018). Decisions must therefore be based on careful considerations accounting for local demands, their soils' potential to deliver functions and

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even ecosystem services, as well as synergies and trade-offs between soil functions and the weightings of alternative options for achieving these services (Debeljak et al., 2019).

3.1.3. DSTs in the context of soil quality

Assessing soil quality is challenging due to soil's heterogeneous nature, making it difficult to establish universal standards. Proper soil functioning involves sustaining its natural, social, and economic roles over time (Blum, 2008). The extent of soil degradation varies significantly across European countries, with no specific legislation in place for soil protection. A single soil management strategy cannot accommodate the diverse soil types, regions, and uses across Europe (Virto et al., 2015). The first step in decision modelling for DST is identifying the decision problem. In the agricultural sector, if the other strong drivers or legislative framework is absent (Bünemann et al., 2018), farmers and advisers typically focus on maximizing primary productivity, such as crop and livestock outputs, with limited emphasis on soil multifunctionality like water purification, carbon sequestration, habitat for biodiversity and recycling of nutrients and (agro)chemicals (Schulte et al., 2014). However, farmers tend to prioritize soil health when they notice reduced yields, often due to soil degradation or climate change impacts (Olesen et al., 2011). Despite this, accessing information on whether current management practices support soil multifunctionality, or how to improve them, remains challenging. As a result, determining the best agricultural practices to enhance all soil functions is a complex decision-making process (Debeljak et al., 2019). A multi-criteria decision analysis framework, focusing on functions essential for soil health, such as supporting primary production and the cycling of vital nutrients like carbon, water, nitrogen, and phosphorus is needed to assess soil quality, and further policies in soil protection may serve as the main driving factors for the development of such tools. The study by Volchko et al. (2014) demonstrates that DSTs like that are feasible, as shown by their model originally developed to assess soil quality in remediated sites using key indicators such as soil texture, organic matter, available water, pH, mineralizable nitrogen, and phosphorus availability. This tool integrates all indicators into a comprehensive soil quality index, providing a clear picture of how well the soil functions after remediation. This approach offers a systematic way to measure the success of soil restoration by evaluating how effectively these essential functions are restored, meaning it could be used to assess the soil functions on a farm level. The systematic monitoring of farm management practices, their environmental effects, and their compliance with recommended or legislated standards can facilitate the early detection and comprehensive assessment of soil quality degradation (Piorr, 2013). This corresponds to strategies offered by Virto et al. (2015) for increasing the awareness of soil quality. Some of them can be connected with DST use, like research for accurate, yet ideally simple, tools for monitoring soil quality, alongside the implementation of multi-actor and multi-target strategies to raise awareness and effectively promote the adoption of management practices that enhance soil health.

A significant challenge for the future is developing a suitable soil quality index (Kibblewhite et al., 2008) and understanding how its levels relate to soil functions across different areas and land uses in Western Europe, particularly regarding soil organic matter (Hanegraaf et al., 2009). While progress has been made in areas such as climate change mitigation and adaptation, research on soil quality assessment tools and indices in other domains remains incomplete.

Several decision model descriptions for soil functions were offered by different authors (Debeljak et al., 2019; Rutgers et al., 2019; Sandén et al.,2019; Schröder et al., 2018; Wall et al., 2018; Rose et al., 2016). Some of the above-mentioned models cover primary productivity decision model that incorporates environmental conditions, inherent soil properties, soil management, and crop characteristics to evaluate a soil's biomass production capacity. Other focuses on the nutrient cycling by assessing soil's nutrient provision and cycling capabilities through sub-models that focus on fertilizer replacement value, nutrient uptake by crops, and harvest efficiency. Additionally, the climate regulation and carbon sequestration model that examines carbon inputs and emissions, distinguishing between direct and indirect N_2O emissions and factors affecting CH_4 emissions. The water regulation and purification model that includes sub-models for water storage, runoff, and percolation to analyse soil water pathways. Also, the biodiversity and habitat provisioning model that integrates various aspects of soil nutrients, biology, structure, and hydrology. However, we need to keep in mind that for holistic approach these models need to be designed to address both croplands and grasslands, resulting in enhanced sensitivity of output to input data changes complicating the DST usage. Rose et at. (2016) offers a specific DST ''Soil Navigator'' that integrates various components to facilitate above mentioned tasks while still providing a user-friendly graphical interface that helps farmers and advisors achieve sustainable agricultural practices. This leads to a question, whether complexity of DST usage might impact the actual use of the DST.

3.1.4. Soil quality and decision support in the context of agricultural policies

The EU Soil Strategy for 2030 (European Commission, 2019) aims to protect and restore soil health while promoting sustainable usage, with a vision for healthy soils by 2050 and specific actions by 2030. A new Soil Health Law is set to be introduced in 2023 to enhance environmental and health protections, contributing to the broader goals of the European Green Deal (Fetting, 2020). Healthy soils are crucial for achieving climate neutrality, fostering a clean circular economy, and combating desertification and biodiversity loss, while also ensuring food security and public health. The mission “A Soil Deal for Europe” focuses on research and innovation to implement this strategy by identifying solutions for soil health restoration (European Commission, 2019).

The European Commission has also released a Communication on Sustainable Carbon Cycles, promoting carbon farming as a viable green business model through initiatives under the Common Agricultural Policy (Kyriakarakos et.al, 2024). Various carbon farming practices, such as no-till and biochar application, have been discussed as effective strategies for improving soil health. However, it is reported (Juerges and Hansjürgens, 2018; Paleari, 2017; Glæsner et al., 2014; Kutter et al., 2011) that soil governance in the EU is currently under-researched, with existing policies lacking coherence due to the absence of a Soil Framework Directive, resulting in insufficient sustainable soil management efforts.

It is highlighted by Paul and Helming et al. (2019) that future governance frameworks should leverage existing knowledge while adapting to new political objectives. The assessment of agricultural soil management needs to balance ecological interactions with socio-economic influences, where governance serves as a bridge to facilitate sustainable bioeconomic strategies. The promotion of Living Labs is also encouraged (European Commission, 2022), as these can act as influential models for other stakeholders, emphasizing the importance of engaging land users, particularly farmers, in achieving successful soil management outcomes.

This only validates the before mentioned statement that policy restrictions have potential to be one of the most influential drivers that can regulate the implementation of DST. With successfully regulated DST implementation (both quality of the supply and demand from farmers) it is possible to prevent the situation when one or more soil functions are impeded and threats to soil functions may arise (e.g., compaction, erosion, loss of biodiversity, loss of organic matter, etc.) (Creamer et al., 2010; Stolte et al., 2016; Creamer and Holden, 2010; Blum et al., 2004).

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3.2. Stocktake and evaluation of DSTs

3.2.1. Questionnaire to national coordinators of EJP SOIL

Respondents and definition of DST

Q2: Country and institution?

Responses were received from the national coordinators of EJP SOIL from 18 countries, including 14 EU countries, as well as Norway, the United Kingdom, Switzerland, and Türkiye (Figure 3, Table A1.3 in Annex 1). Two responses were received from Belgium, representing the regions of Flanders and Wallonia, respectively. The national coordinators were based at research institutes, universities, and government agencies, and many reached out to experts for support in filling out the questionnaire. In Norway, responses were also provided by the private sector. The responses covered 75% of EJP SOIL countries (24), 52% of EU member states (27), and 39% of European countries, in addition to Türkiye. The countries represented a range of agricultural conditions across Europe, from North to South and West to East.

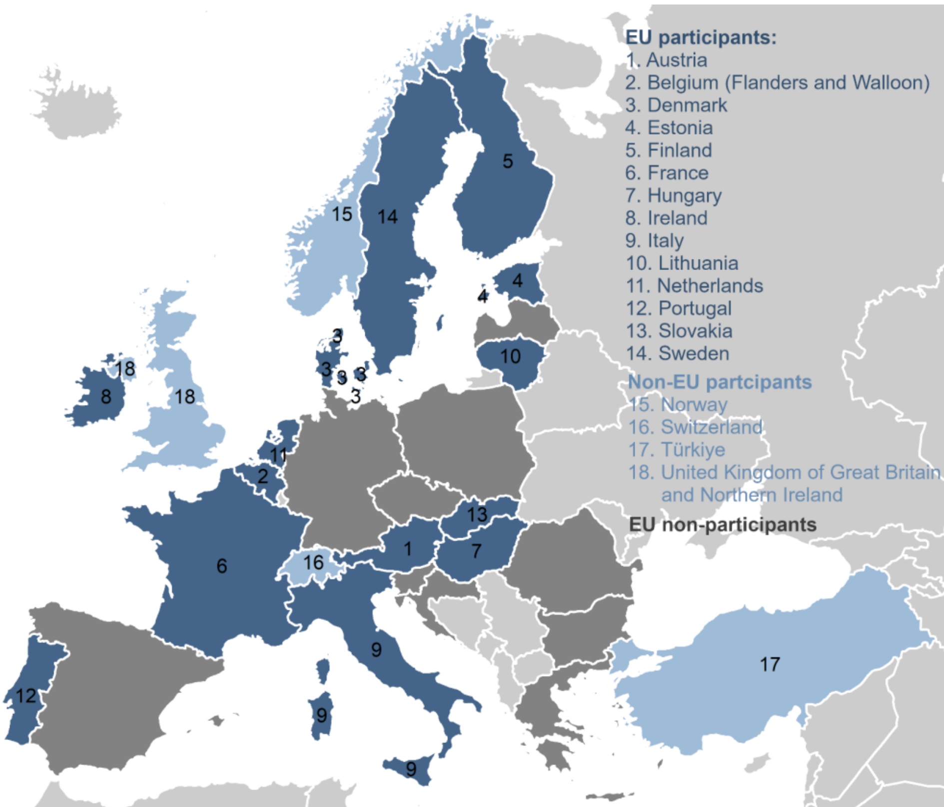

Figure 3. EU and non-EU participants of the survey on the national coordinators of EJP SOIL on DSTs.

Q3: Would you agree with this definition for DSTs: "DST are digital tools that farmers, advisors or policymakers can use to make decisions addressing soil organic matter, water retention or nutrient efficiency. Tools can be software, apps, web portals or on other digital supports. The tool would typically require some data about the soil, crop, field history and weather and then use an evidence-based algorithm to calculate an output. The output could be an analysis of the effect of current or improved soil, water, and nutrient management practices at different scales (e.g., field, farm, regional, national)"?

The majority of respondents agreed with the provided definition of DSTs, except for one respondent from Finland and one of the six respondents from Norway. They indicated that other decision support technologies could exist and that digital tools do not have to be exclusively based on algorithms.

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Use and users

Q4: What type of decisions can be facilitated by using DST?
The respondents considered that DSTs can support decision-making at farm, advisory, regional, and policy levels (Table A1.4 in Annex 1). All respondents (100%) who answered the question indicated that DSTs can facilitate decisions at the farm level, 94% considered that DSTs can facilitate decisions at the advisory level, 56% suggested that DSTs can facilitate decisions at the regional level, and 63% indicated that DSTs can facilitate decisions at the policy level. Additionally, field and national levels were mentioned as relevant in the responses.

The types of decisions that DSTs can facilitate at the farm level, according to the respondents, include soil management, yield improvement, farm management, economic profitability of the farm, nutrient use, fertilization schedules, fertilization limits, soil compaction risk, field mapping, water management, irrigation scheduling, estimation of soil properties (organic matter, nitrogen, phosphorus, potassium, and pH H2O), SOM preservation and build-up, and reduction of soil erosion (Table A1.5 in Annex 1).

At the advisory level, DSTs were seen to facilitate similar decisions as at the farm level. However, one respondent noted that DSTs enable advisors to validate, objectify, and make their advice to farmers more reliable and trustworthy in technical, economic, and environmental terms.

At the regional level, DSTs were reported to facilitate decisions related to nutrient input, water management, and soil organic matter, but also broader-level decisions or uses (Table A1.5 in Annex 1). DSTs were seen as tools that enable the collection and synthesis of information for the development of agricultural policies and regulations that align with society's expectations.

At the policy level, DSTs were reported to support the development of agricultural policies, regulations, and environmental support (Table A1.5 in Annex 1). The respondents also highlighted similar decisions as those at the farm and advisory levels, including nutrient inputs, water management, soil organic matter, and economic considerations, indicating that this level of information is also valuable at the policy level.

Q5, Q6, and Q7: What is/are the most used DSTs in your country on soil water availability and retention, soil organic carbon, and soil nutrient use efficiency?
The respondents reported a broad range of DSTs, not all of which aligned with our DST definition (Section 1). For soil water availability and retention, 41 DSTs were reported, of which 31 aligned with our definition (Table 2) For soil organic carbon, 50 DSTs were reported, of which 37 aligned with our definition (Table 3). For soil nutrient use efficiency, 75 DSTs were reported, of which 64 aligned with our definition (Table 4). The DSTs that did not align with the PRAC2LIV definition were typically maps with static information, web pages or portals with static information, guideline documents, etc. Interestingly, agricultural advisors were also reported as DSTs, emphasizing their role in decision making, although they do not align with our definition.

The resulting stock-take includes a total of 115 DSTs that align with our definition. The classification of DSTs according to our definition, however, involved some subjectivity, as the reported tools varied considerably in type, technology, and purpose. The reported DSTs cover a range of tool types (activity planners, simple calculators, monitoring-based, remote sensing-based, models), technologies (online, offline, mobile applications, tools with hardware components), and purposes (single-purpose, multi-purpose). Interestingly, each DST was mainly reported by only one country, except for AquaCrop (Salman et al., 2021) Atfarm (Atfarm, 2023), which were reported by two countries. The level of detail provided for each DST also varied, and the DSTs listed in Table 2, Table

3, and Table 4 may be variably included in further analyses of this report. In some questions, the responses were not complete for all DSTs.

The resulting stock-take of 115 DSTs can be considered a representative sample of commonly used DSTs in Europe across the three subject categories, but it does not include all the tools in use and is therefore not exhaustive. The number of reported DSTs in each subject category indicates that more emphasis has been placed on developing DSTs for nutrient management compared to DSTs for carbon and water management. Additionally, it appears that the same tools are rarely used across different countries, which may suggest that tools are being developed and used for local requirements in local languages and that they are not well-marketed across country borders.

Table 2. The most used DSTs on soil water availability and retention according to the responses. Both the DSTs aligning and not aligning with our definition (Section 1) are shown.

Country	Name	Description	References
DSTs aligning with our definition			
Austria	eo4water	Earth observation-based tool for optimizing water and fertilizer inputs. Uses satellite images, agro-meteorological data, and a suite of models that consider soil, plants, and crop management.	IVFL and ASAP, 2023.
Belgium (Flanders)	AquaCrop	A crop-water productivity model that assess the effect of the environment and management on crop production.	Salman et al 2021.
Belgium (Flanders)	SWAP-WOFOST	A combined agro-hydrological (Soil Water Atmosphere Plant, SWAP) and crop growth model (WOrld FOod Studies, WOFOST).	Kroes et al. 2017. De Wit et al., 2019.
Belgium (Flanders)	Waterradar	A tool for searching alternative water sources for agriculture.	Inagro, ILVO, VITO and Vlakwa, 2021.
Denmark	Vandregnskab Online	Water management tool for irrigation.	SEGES Innovation, 2023.
Finland	Soil Scout sensor	A real time soil moisture monitoring tool with soil sensors and dashboard.	Soil Scout, 2023.
Finland	Field Observatory	An online field observatory that collects near real-time data on vegetation, soil, and the atmosphere from farms and study sites, and use these data for modelling and to estimate carbon storage and other ecosystem functioning.	Carbon action, 2023.
Finland	EU MARS crop monitoring	Remote sensing-based monitoring information on crop growing conditions and quantitative crop yield forecasts in the EU.	EU JRC, 2023.
France	MAELIA	Multi-agent platform for integrated assessment of low-water management issues (MAELIA).	Tribouillois et al. 2022a, 2022b.
Italy	vite.net	An interactive web tool for wine-grape growers, using sustainable and precision viticulture techniques. Supports for example, scheduling of irrigation and fertigation based on actual soil water levels.	HORT@, 2023.
Italy	granoduro.net	An interactive web tool for durum wheat growers, using sustainable and precision agriculture techniques. Supports for example, scheduling of irrigation and fertigation based on actual soil water levels.	HORT@, 2023.
Italy	Elaisian	AI decision support system to treat, irrigate, and fertilise your fields at the right time.	Elaisan, 2023.
Netherlands	FarmSoilWaterPlan ('bedrijfsbodemwaterplan')	Evaluates and provides recommendations for clean water and nutrient use efficiency.	NMI and ZLTO, 2024
Netherlands	Irrigation Advice	Estimates soil moisture content per plot, gives tailor-made advice.	Farmmaps, 2024.
Netherlands	Trijntje	Helps in making the soil climate proof.	Farmmaps, 2024.
Norway	Calculating water balance	Online calculator for water balance and irrigation.	NIBIO, 2023.
Norway	Agdir Freeland sensor	Outdoor sensor on air and soil with real-time connection to mobile/web.	Agdir, 2023.

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Table 2. (Continued).

Country	Name	Description	References
DSTs aligning with our definition			
Portugal	IrrigaSys	A web-based irrigation decision support system.	Simionesei et al 2020.
Portugal	Irristrat	Irrigation management tool processing real-time field information.	Hidrosoph, 2023.
Portugal	MOGRA	Irrigation management model.	COTR, 2023.
Portugal	Calendário de Rega (Irrigation calendar)	Decision support system for monitoring evolution of irrigation needs, with real time irrigation alerts and notifications	COTR, 2023.
Sweden	Vattennivå i brunn (Water level in wells)	A real-time ground water monitoring system.	Aqvify, 2023.
Sweden	Raindancer	Irrigation management and monitoring system.	IT-Direkt Business Technologies, 2023.
Sweden	Soil Moisture Sensor	Soil moisture sensor system for real time-monitoring.	SenseFarm, 2023.
Sweden	P-T Soil Station Service	Real-time monitoring system for soil conditions.	Paul-Tech, 2023.
Sweden	Hur mår min jord? (How is my soil doing?)	An application on soil properties for improving soil quality	Swedish Agricultural Agency and SLU, 2021.
Türkiye	TAGEM -SuET	TAGEM SuET; is water management and plant water consumption of online system, including irrigation requirements and planning.	TAGEM 2023
Türkiye	TAGEM Soil Fertilizer and Water Resources Central Research Institute National Soil Information System	TAGEM Soil Fertilizer and Water Resources Central Research Institute National Soil Information System. Under development.	TAGEM-SFWRCRI, 2023
Türkiye	AgroCares Digital Soil Analysis Device	Tool for analysing and planning fertilizer input.	AgroCares, 2024.
Türkiye	Filiz& Filizpro	Filiz Agricultural Sensor on soil and weather conditions in the field, irrigation needs, disease risks, optimal spraying times.	DHOT, 2024
Türkiye	AquaCrop	AquaCrop is a crop modeling software developed for optimizing water use in crop production and managing agricultural resources more efficiently	Salman et al. 2021.
DSTs not aligning with our definition			
Estonia	EstSoil-EH	Dataset of modelled (by pedotransfer functions) soil hydrological parameters integrated to large-scale (1:10000) soil map.	Kmoch et al. 2021.
Finland	Soil NIR -analysis	Soil NIR-analysis on soil properties, including soil water retention characteristics.	Eurofins Agro, 2023.
Hungary	Trained advisors and experts	-	-
Portugal	SAGRA NET	Platform for access to daily meterological information from SAGRA weather stations.	COTR, 2023.
Slovakia	Hydrological reporting	On-line real-time information on hydrological conditions .	SHMU, 2023.
Slovakia	Intersucho - Interdrought,	Online map service for soil drought, vegetation, and yield conditions. Historical data and predictions.	Intersucho, 2023.
Sweden	SmartNet	System for managing irrigation.	Östorps Bevattning 2023.
Sweden	RIC online	Control and monitoring system for irrigation	Rosenqvists, 2023.
Switzerland	Water Retention map.	Online water storage capacity map.	FOAG, 2023.
Türkiye	Farmer Registration System (ÇKS)	Farmer Registration System (ÇKS) is the agricultural database created by the Ministry of Agriculture and Forestry, where farmers are registered.	TAGEM 2023.

Table 3. The most used DSTs on soil organic carbon according to the responses. Both the DSTs aligning and not aligning with our definition (Section 1) are shown.

Country	Name	Description	References
DSTs aligning with our definition			
Austria	Austrian Carbon calculator	A tool for humus management based on CANDY Carbon Balance (CCB) model describing turnover of decomposable carbon in annual time steps for average site conditions.	Franko and Spiegel, 2015; BWSB, 2015.
Belgium (Flanders)	Demeter tool	Tool for calculating optimal and sustainable fertilization that considers also organic matter content in the soil, based on ROTHCa.	VLM, 2023.
Belgium (Flanders)	C-slim	A web application that allows to estimate the long-term evolution of the organic carbon content in arable land.	Soil Survey of Belgium, 2023.
Belgium (Flanders)	CARAT	A tool for calculating soil organic carbon development, based on RothC model.	Vanneste et al., 2022.
Belgium (Walloon)	DECIDE	A tool for the agroecological transition to carbon neutrality.	CRA-W, 2023.
Belgium (Walloon)	Cool Farm Tool	A tool for decreasing emissions in agriculture.	Gold Standard, 2023.
Belgium (Walloon)	CAP'2ER	A calculator for greenhouse gas (GHG) emissions associated with a farm and to identify options for mitigation	French Livestock Institute, 2023.
Denmark	ESGreenTool Climate;	Calculator for the climate impact of farms	SEGES Innovation, 2023.
Estonia	Humus balance calculator (Huumusbilansi kalkulaator	Spreadsheet-based tool for calculating field scale soil organic carbon stock change is mineral arable soils.	Institute of Agricultural and Environmental Sciences, 2023.
Estonia	RothC model	A model for the turnover of organic carbon in topsoil. Applied in few local studies and testing its suitability for upgrading national GHG inventory to Tier3 level.	Rothamsted research, 2023.
Estonia	Yasso model	Dynamic model of the cycling of organic carbon in soil. Applied in few local studies and testing its suitability for upgrading national GHG inventory to Tier3 level.	Viskari, et al. 2022.
Finland	Pro Agria-WISU	A general tool for planning agricultural activities, includes a carbon balance calculator.	Proagria, 2023.
Finland	Agrineuvos	A general tool for planning agricultural activities.	Suonenetieto, 2023.
Finland	Crop rotation comparison tool Viljelykierto-laskuri)	A spreadsheet-based tool for planning and comparing crop rotations.	Mattila et al. 2023.
France	SIMEOS AMG	A tool for simulating the evolution of soil organic C contents and stocks at plot and farm scale.	Clivot et al. 2019; INRA, Agro-Transfert RT, Arvalis, LDAR, Terres Innovia, 2023.
France	ABC'Terre	A tool for quantifying, on a regional scale, the impacts of agricultural practices on long-term variations in organic carbon stocks in the surface layer of soils, including these stock variations in the GHG assessment.	Agro-Transfert RT, 2023.
France	MAELIA	Multi-agent platform for integrated assessment of low-water management issues (MAELIA)	Tribouillois et al 2022a, 2022b.
Ireland	Carbon Navigator	A tool for reducing greenhouse gas emissions from livestock production systems	Murphy et al., 2013.; Teagasc, 2023.
Ireland	AgNav	A tool to support decision making on farm to help meet agriculture's Climate Action	Teagasc, ICBF, and Bord Bia 2023.
Italy	vite.net	An interactive web tool for wine-grape growers, using sustainable and precision viticulture techniques.	HORT@, 2023.
Italy	granoduro.net	An interactive web tool for durum wheat growers, using sustainable and precision agriculture techniques.	HORT@, 2023.
Italy	Elaisian	AI decision support system to treat, irrigate, and fertilise your fields at the right time.	Elaisan, 2023.
Netherlands	Soil C Tool	Gives insight in SOM change and support field and farmlevel decisions for improvement	Farmmaps, 2024.
Netherlands	Carbon calculator	Calculate the effect of crop rotation plan and fertilization on the carbon storage.	Eurofins Agro, 2024.
Netherlands	Veris Soilscan	Scan for EC, pH and organic matter.	CZAV, 2024
Norway	Jordplan	A web-based tool for planning work on the farm, including management of soil samples, fields, and crops with maps.	Jordplan, 2023.
Norway	Skifteplan	A tool for planning fertilization.	Agromatic, 2023.

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Table 3. (Continued).

Country	Name	Description	References
DSTs aligning with our definition			
Portugal	VirtuaCrop	An application for precision farming. Enables mobile phone-based soil analysis.	VirtuaCrop, 2023.
Portugal	Fertile	A program for managing fertilization, acidity, alkalinity, and organic carbon in the soil.	Softimbra, 2023.
Sweden	Hur mår min jord? (How is my soil doing?)	An application on soil properties for improving soil quality.	Swedish Agricultural Agency and SLU, 2021.
Sweden	Odlingsperpektiv (Cultivation perspective)	Advisory service with simulation of humus content.	Greppa Näringen, 2023.
Switzerland	Humus balance calculator (Humusbilan-Rechner)	A calculator for maintaining humus content.	Agrosope, 2023.
Türkiye	TAGEM Soil Fertilizer and Water Resources Central Research Institute National Soil Information System	TAGEM Soil Fertilizer and Water Resources Central Research Institute National Soil Information System. Under development.	TAGEM-SFWRCRI, 2023
United Kingdom	PLANET	A nutrient management decision support tool or field level nutrient planning and for assessing and demonstrating compliance with the Nitrate Vulnerable Zone (NVZ) rules.	ADAS, 2023.
United Kingdom	MANNER-NPK	A software tool that provides farmers and advisers with a quick estimate of crop available nitrogen, phosphate, and potash supply from applications of organic manure.	ADAS, 2023.
United Kingdom	Farm Crap App Pro	A tool for slurry and manure management.	SWARM, 2023.
DSTs not aligning with our definition			
Finland	Soil analysis	Soil analyses based on soil samples.	Eurofins Agro, 2023.
Finland	Carbon check	Analysis package for the assessment of soil carbon sequestration: how much carbon has been stored in the soil, in which for the carbon is, and how to improve the soil carbon content.	Eurofins Agro, 2023.
Finland	NIR analysis	Soil NIR-analysis on soil properties, including soil organic matter.	Eurofins Agro, 2023.
Finland	Greenhouse gas inventory	Greenhouse gas inventory	Statistics Finland, 2023.
Hungary	Trained advisors and experts	-	-
Lithuania	Soil organic carbon studies in agricultural land	A document with information and recommendations on soil organic carbon and its management.	LAMMC, 2022a.
Lithuania	Code of Good Agricultural Practice	A document with information and recommendations on good agricultural practices.	Ministry of Agriculture of the Republic of Lithuania, 2019.
Norway	Soil analyses	Soil analyses based on soil samples.	Eurofins Norway, 2023.
Slovakia	Soil Portal	An online system for information on soils.	NPPC, 2019.
Türkiye	Farmer Registration System (ÇKS)*	Farmer Registration System (ÇKS) is the agricultural database created by the Ministry of Agriculture and Forestry, where farmers are registered.	TAGEM, 2023.
Türkiye	The National SOC Map	The National Soil Organic Carbon (SOC) map was produced using above data in 2017 and it contributed FAO GSP GSCO Map for Country. It is available for all users.	FAO and ITPS. 2018
Türkiye	The National SOCseq Map	The National SOCseq Potential Map was produced using above data in 2021 and it contributed FAO GSP GSOCseq Map. It is available for all users.	FAO 2022.
United Kingdom	MuddyBoots	Digital solutions provider.	Muddyboots, 2023.

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Table 4. The most used DSTs on soil nutrient use efficiency according to the responses. Both the DST's aligning and not aligning with our definition (Section 1) are shown.

Country	Name	Description	References
DSTs aligning with our definition			
Austria	ÖDüPlan Plus	Fertilization planning	ÖDüPlan Plus, 2023
Austria	Terrazo	Tool for making fertilization maps from vegetation maps.	Wieselburg, 2023.
Belgium (Flanders)	NEMO	model used to provide insight into current and future water quality N and P losses are calculated at subcatchment level. Scenarios are used to calculate the effect of proposed management measures in agriculture.	VMM, 2024
Belgium (Flanders)	DEMETER	Evaluate and assess fertilisation and soil organic matter	VLM, 2023
Belgium (Walloon)	REQUAFERTI	Computer module for laboratories for advisory service to farmers in Wallonia	Requasud, 2024
Belgium (Walloon)	FaST	Digital tool on nutrient management, provides data about their parcel of land	Goffart, 2023
Belgium (Walloon)	BELCAM	Free services to improve agricultural practices in Belgium. Satellite imagery, vegetation and nutrition indices, site-specific meteorology, advices for fertilisation based on different data sources.	Belcam, 2003
Belgium (Walloon)	DECIDE	Tool to assess the environmental impacts, socio-economic performance and overall sustainability	CRA-W, 2023.
Denmark	CropManager	Program to retrieve and manage spatial data for precision farming – coupled to other crop planning programs	SEGES Innovation, 2023.
Denmark	MarkOnline	Program for crop management planning	SEGES Innovation, 2023.
Estonia	NPK balance calculator	Excel based tool for calculating field scale NPK balances.	EMU, 2023
Estonia	Fertilizer requirement maps	Rule-based model gives based on agro-chemical soil sample analysis, crop type, yield goal etc. site-specific recommendation for N, P and K requirement	Metk, 2023
Estonia	Lime requirement maps	Rule-based model gives based on agro-chemical soil sample analysis, soil map data etc site-specific recommendation for liming requirement.	Not available
Estonia	EstModel	Calculates annual load and retention of nitrogen and phosphorus from catchment areas.	Estmodel, 2023
Finland	Phosphorus planning tool	A tool for estimating the economically optimal amount of phosphorus fertilization of field plots	LUKE, 2023
Finland	Nitrogen balance calculator	A method to assess the nitrogen levels of field plots and apply the information to develop farming with both the environment and financial results in mind	LUKE, 2023
Finland	Pro Agria-WISU	A crop planning software with nutrient balance calculation	Proagria, 2023.
Finland	PeltotukiPro	An arable farming planning and monitoring program. Includes crop planning, field plot accounting, electronic subsidy application support, restrictions on the use of pesticides, and calculates also profitability.	Softsalo Ltd, 2023
Finland	Agrineuvos	A tool for planning agricultural activities. Includes calculation of the difference between nutrient accumulation and nutrient demand and calculation of nutrient requirements and fertilization	Suonentieto, 2023
Finland	Nutrient calculator	Regional and national scale calculator and planning tool of nutrient and biomass balances and recycling.	LUKE, 2023.
Finland	Biomassa-atlas (Biomass Atlas)	A map service for viewing, reporting, and analysing forest, field, manure, and waste biomass. Supports planning of investments and acquisition of raw materials. (Open access version of Nutrient calculator)	LUKE, 2023.
France	Syst-N	Estimate nitrogen losses. Works at the plot scale and over the long term of a succession of crops. It is a software that includes a database where nitrogen loss results from measurements or simulations	RMT Bouclage, 2003
France	Azofert	Software based on a complete and dynamic balance of nitrogen input and output. Reports the couplings between carbon and nitrogen dynamics.	Machet et al., 2017; RMT Bouclage, 2003b

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Table 4. (Continued).

Country	Name	Description	References
DSTs aligning with our definition			
France	MAELIA	Tool to assess the environmental, economic and social impacts of combined changes in agricultural activities, including recycling. Works at plot-, farm- and territory scales.	Misslin et al., 2022
Hungary	PROPLANTA	Tool for fertilization decisions based on data from long term field experiments	Proplanta, 2023
Ireland	NMP On-line	Tool for making nutrient balances at plot & farm scale.	Teagasc, 2023
Ireland	Pasturebase Irl	Grassland/pasture management	Teagasc, 2023
Italy	vite.net	An interactive web tool for wine-grape growers, using sustainable and precision viticulture techniques	Hort@, 2023
Italy	granoduro.net	An interactive web tool for the cultivation of high-quality durum wheat according to the principles of sustainable and precision agriculture	Hort@, 2023
Italy	Elaisian	AI to treat, irrigate, and fertilise your fields at the right time.	Elaisian, 2003
Lithuania	Digital N-fertilization with sensors (agriPORT?)	From the demand analysis to automatic balancing	Agricon, 2023
Lithuania	Apply nitrogen fertilizer in various proportions	Fertilization maps	Agricon, 2023
Lithuania	Geoface	Nitrogen fertilization mapping	Geoface, 2003
Netherlands	NDICEA	Choices related to crops, crop sequence, green manures and fertilizer application rate and timing (both manure and artificial fertilizer) can be evaluated in backview and preview.	Louis Bolk Instituut, 2024
Netherlands	VRA Top-Dress N	App to create maps for variable N top dressing in potatoes	Farmmaps, 2024
Netherlands	Dutch Fertilizer Recommendation Advice	An R package giving the required agronomic nutrient dose at field level. Applied in various studies on field, farm and regional scale and in use by agricultural labs.	Nutrient Management Institute, 2024
Norway	Skifteplan (Agromatic)	A tool for planning fertilization that uses data from soil samples and expected yield to calculate doses.	Skifteplan, 2023
Norway	Jordplan	Fertilization plan and storage of soil data.	Jordplan, 2023
Norway	Klimakalkulatoren	Overview of emissions and what opportunities exist both to reduce emissions and sequester carbon that exists at farm level	Klimatsmartlantbruk, 2023
Norway	Atfarm	Fertilization maps from satellite images	Atfarm, 2023
Norway	Cropplan	Web-based tool to plan, document and analyze crops	Dataväxt, 2023
Norway	Pix4dFields	Web portal for analyzing drone data for creating fertilizing maps	Pix4d, 2023
Norway	Biodrone	Web portal for analyzing drone data for creating fertilizing maps	Biodrone, 2023
Portugal	OneSoil	Tool for precision fertilization	Onesoil, 2023
Portugal	Fertil	Calculation of fertilization and corrections of acidity and alkalinity, as well as the Organic Correction of the soil.	Softimbra, 2023
Portugal	WiseCrop	Tool for analysing water stress, plant heath, fertilization etc.	Wisecrop, 2023
Slovakia	ÚKSÚP	Calculator for nutrients calculating	Uksup, 2023
Slovakia	Fertilization schedule	Tool for planning fertilization	Uksup, 2023
Slovakia	Animal storage capacities	Manure storage and planning	Uksup, 2023
Sweden	Atfarm	Fertilization maps from satellite images	Atfarm, 2023
Sweden	Yara N-sensor	N fertilization recommendation from sensor measurements for within field vartiable rate	Yara, 2023
Sweden	CropSat	Fertilization maps from satellite images	Cropsat, 2023
Sweden	Winter oilseed rape nitrogen estimator (Kvävevågen)	N fertilization to winter oilseed rape	SFO, 2023
Sweden	Fertilizer calculator (Gödselkalkylen)	Compare different fertilization strategies of manure	Greppa näringen, 2023b
Sweden	Vera	Nutrient balance	Greppa näringen, 2023c
Sweden	Växtnäringsbalans på nätet	Nutrient balance, web based	Greppa näringen, 2023d

Table 4. (Continued).

Country	Name	Description	References
DSTs aligning with our definition			
Sweden	Yara Växtnäringsberäkning (Yara palnt nutrient calculator)	Tool for calculating field balance of nutrients (NPK) to assess plant nutrient efficiency.	Yara, 2023
Sweden	Yara Checkit	Help to identify nutrient deficiency symptoms in various crops	Yara, 2023
Türkiye	TAGEM Soil Fertilizer and Water Resources Central Research Institute National Soil Information System	TAGEM Soil Fertilizer and Water Resources Central Research Institute National Soil Information System was established in 2015 with in collaboration FAO. The system includes soil physical, chemical soil properties provided by more than 30 000 soil samples colllected from agricultural areas at national scale. The system sis till under construction and when completed, it will serve the benefit of all users including farmers, researchers, academia and policy makers in relation to these soil properties.	TAGEM, 2023a.
UK	PLANET (Planning Land Applications of Nutrients for Efficiency and the environmenT)	Nutrient management decision support tool for use by farmers and advisers for field level nutrient planning and for assessing and demonstrating compliance with the Nitrate Vulnerable Zone (NVZ) rules	ADAS, 2023
UK	MANNER-NPK (MANure Nitrogen Evaluation Routine)	Practical software tool that provides farmers and advisers with a quick estimate of crop available nitrogen, phosphate and potash supply from applications of organic manure	ADAS, 2023
UK	Gatekeeper - Farmplan	Manage all cropping activities in one place	Farmplan, 2023
UK	Farm Crap App Pro	Manage and record slurry spreading information and data on manure	SWARM, 2023
DSTs not aligning with our definition			
Belgium (Flanders)	KNS Flanders	Fertilizer recommendation system for vegetables that takes current season into consideration.	VLM, 2014.
Lithuania	Novel recomendations for different crops with different practices	Yearly booklet with recommendations	LAMMC, 2023 LAMMC, 2022b LAMMC, 2021
Lithuania	Code of Good Agricultural Practice	Integrated Plant Protection Information System for Information, Consultation and Training	Ikimis, 2023
Norway	Aena skifte	Aena Field helps you to log field work, keep track of work done, and delegate tasks	Mimiro, 2023
Norway	NLR Surfôrtolken Excel-fil	Assess fertilization and adjust the fertilization plan	NLR, 2024.
Norway	Handelsbalanse/ Næringsstoff-regnskap excel-fil	Excel file that can be used for calculating nutrient balances	Agropub, 2023
Norway	Gårdskart/Kilden NIBIO	Provide maps with data that could be input for a DST	NIBIO, 2023b
Türkiye	Farmer Registration System (ÇKS)	Farmer Registration System (ÇKS) is the agricultural database created by the Ministry of Agriculture and Forestry, where farmers are registered. inspected, and used in the formation of agricultural policies.	TAGEM, 2023b.
Türkiye	Fertilizer Tracking System (GTS)	Fertilizer Tracking System to ensure that the fertilizers supplied to the market are tracked from the packaging stage to the end user, to prevent imitation, adulteration and counterfeiting of the fertilizers used in the country's agriculture and to distribute them in accordance with their purpose, to use them safely and in this sense to increase agricultural productivity and to record fertilizer production and consumption.	MAF,2023
Türkiye	Türkiye National Boron Map	Türkiye National Boron Map was produced by TAGEM Soil Fertilizer and Water Resources Central Research Institute in collaboration with The National Boron Institute in 2010.	TAGEM-SFWRCRI, 2023
UK	MuddyBoots	Digital solutions provider.	Muddyboots, 2023

Q8: Who are the major users of the main DSTs in your county (same DSTs as indicated in Q5, Q6 and Q7)?

According to the responses, 80% of the DSTs are used by agronomists, consultants, and advisors; 78% by farmers; 51% by researchers; 27% by private companies and NGOs; and 23% by policymakers responsible for monitoring. One respondent also noted education as a user group, and another

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highlighted that users consist of two groups: those who use the models and those who use only the outputs of the models. The user groups for individual DSTs are shown in Table A1.6 in Annex 1.

There is also overlap in the use of the same DSTs across different user groups, though with some variation. For example, 78% of the DSTs used by agronomists, consultants, and advisors; 78% by researchers; 68% by private companies and NGOs; and 52% by policymakers responsible for monitoring are also used by farmers (Table 5). These findings indicate that agronomists, consultants, advisors, and farmers make up the largest user groups. While some DSTs serve multiple groups, others are better suited to specific user groups.

Table 5. Matrix with number of the reported DSTs with overlapping use across user groups. Total number of DSTs in the analysis was 91, and the number of DSTs used per user group is shown on the diagonal of the table in bold.

	Farmers	Researchers	Agronomists, consultants, advisors	Private companies, NGO's	Monitoring policy makers
Farmers	**71**	36	57	17	11
Researchers	36	**46**	41	18	19
Agronomists, consultants, advisors	57	41	**73**	22	18
Private companies, NGO's	17	18	22	**25**	11
Monitoring policy makers	11	19	18	11	**21**

Assessment

Q9: How would YOU rate from 1 to 5 the DST you indicated in questions 5, 6 and 7 in terms of…
According to the ratings of DSTs (on a scale of 1-5) provided by the respondents, the adoption of DSTs by end-users is not very high (Table 6). The average rating for adoption was 3.1. In terms of suitability for reaching goals, the DSTs were considered well-suited for achieving farmer goals, with an average rating of 4.1. They were rated slightly less suitable for reaching regional and national-level goals, with average ratings of 3.6 and 3.5, respectively.

The DSTs were considered to have modest levels of participation or co-innovation in their development, with an average rating of 3.3 (Table 6). Data input requirements were also viewed as modest, with an average rating of 2.7. The interfaces were mostly considered user-friendly, receiving an average rating of 3.7. The cost of using DSTs was found to be low for users, with an average rating of 1.8. A positive finding was that the DSTs were largely perceived as reliable, with an average rating of 3.9 (Table 6).

The DSTs with the highest adoption rate (rating = 5; 15% of all DSTs) were found to have more user-friendly interfaces (average rating +0.8) (Table 6). They were also considered more suitable for reaching farmer, regional, and national goals (+0.5 to +1.0). Additionally, their costs were somewhat lower (-0.3), but their data input requirements were higher (+0.5) compared to the average for all DSTs.

The ratings of individual DST varied considerably. These ratings are shown Table A1.7 in Annex 1.

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Table 6. Average rating of DST by the respondents.

Question	Rating	Average	Standard deviation	n
A. Adoption by end-user	1= little or no use 5= widely adopted	3.1	1.3	81
B. Is the use of the tool optional?	1= Yes 2= No	1.1	0.4	87
C. Data input	1= few data needed 5=many data needed	2.7	1.2	82
D. User friendly interface	1= too complex for users 5= very user friendly	3.7	1.0	83
E. Perceived reliability of the DST	1= low reliability 5= very high reliability	3.8	0.8	80
F. Cost of the DST	1= Free of charge 5=Very expensive	1.8	1.2	82
G. The tool has been developed with participatory research/co-innovation	1= no users involvement in the design 5=user-centred design	3.3	1.3	74
H. Suitable to reach national goals	1= not suitable 5= very suitable	3.5	1.4	80
I. Suitable to reach regional goals	1= not suitable 5= very suitable	3.6	1.4	79
J. Suitable to reach farmers goals	1= not suitable 5= very suitable	4.1	1.0	89

The correlation analysis of the ratings given for individual DSTs revealed mostly low to modest correlations, which were statistically significant ($p < 0.01$) across the ten questions in Table 6 (Annex 1, Table A1.8). The highest statistically significant correlations were observed between the suitability of DSTs for farmer, national, and regional goals. DSTs that were suitable for regional goals were also found to be suitable for national goals, with a high correlation of 0.82. Additionally, some DSTs that were suitable for reaching farmer goals appeared to also be suitable for regional and national goals, with correlations of 0.52 and 0.38, respectively. This indicates that many DSTs can be suitable for reaching goals at multiple levels, but those suited for farmer goals tend to differ more from those suited for national goals.

The analysis further showed that adoption by end-users depends on the suitability of the DSTs to reach goals at all three levels, with correlations ranging from 0.4 to 0.52, and on the user-friendly nature of the interface, with a correlation of 0.41. Surprisingly, the adoption by end-users did not show a clear relationship with data input requirements, perceived reliability, cost, or participatory development, as the correlations in these areas were not statistically significant, ranging from -0.12 to 0.13. However, a statistically significant correlation was found between perceived reliability and the suitability to reach farmer and regional goals, with correlations of 0.42 and 0.35, respectively.

Integrated evaluation of selected features

Visualizing the integrated evaluation of selected features, the polygons are drawn such that wider circles represent the most desired scores. The average scores for DSTs related to nutrient use efficiency (NUE) (Figure 4A) and water management (Figure 4B) showed higher (i.e., 'best') scores for costs and user-friendliness compared with DSTs related to soil organic matter (SOM) management (Figure 4C). Data input scores were comparable across the different DST types. End-user participation in the design phase of DSTs was modest overall for all DST types. Notably, we observed higher variability in the national coordinators' responses regarding DSTs related to NUE compared with other DST types.

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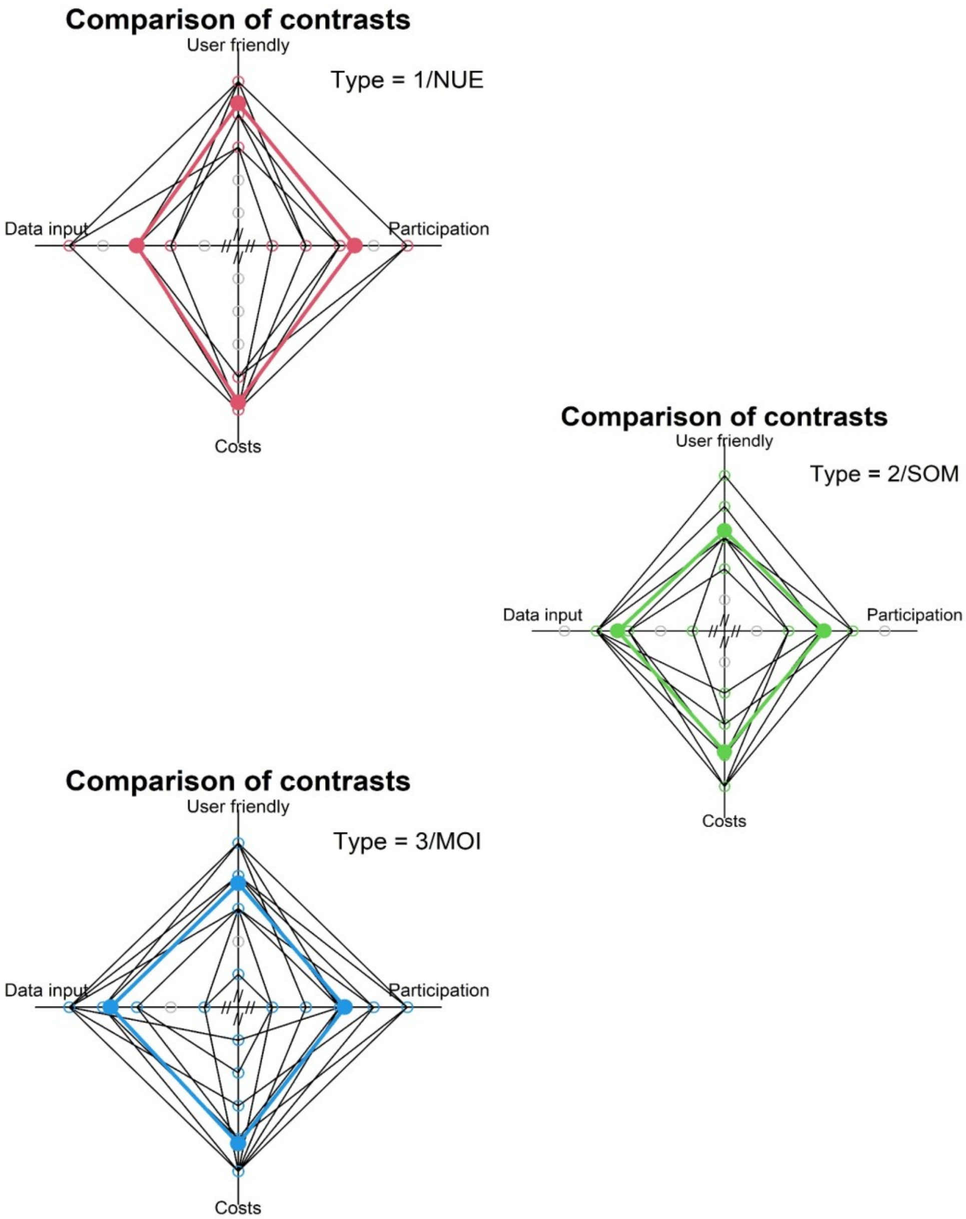

Figure 4. Results of integrated evaluation of 4 selected features for DST's; averages indicated by coloured lines. Top- DST on nutrient management; middle- DST on soil organic matter management; below- DST on water management; axes are scaled 1-5.

High adoption DSTs showed some differences as compared to the total dataset. Figure 2 shows the results for data input, participation level, cost and user-friendliness for those DSTs that scored high on adoption. Focusing on the selected features, these high adopted DSTs are characterised low costs high user-friendliness. A similar trend is shown for the most adopted DSTs on nutrient management (Figure 2, B) as compared to all DSTs on NUE. The most adopted DSTs on water management stand out by lower data-input (Figure 2C). For SOM no figure could be made as there were not enough DSTs with high adoption.

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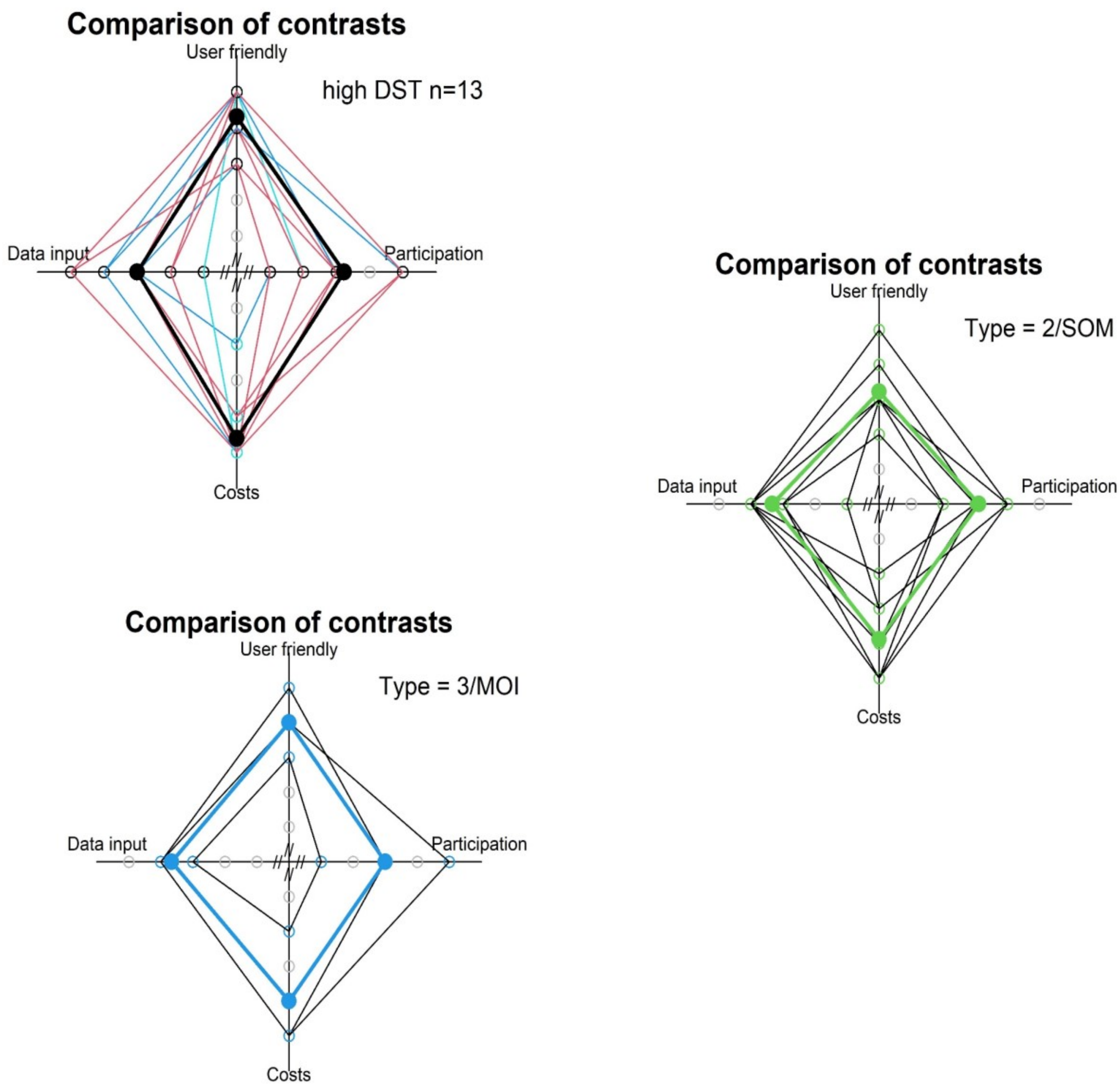

Figure 2. Assessment of major features in highly adopted DST's; averages indicated by coloured lines. Top- Most adopted DST (all) (n=13); middle- most adopted DST on nutrient management; below- most adopted DST on water management; axes are scaled 1-5.

Improvement

Q10: How could the specific DSTs you indicated in question 5,6 and 7 as main DSTs be improved?
The respondents provided a range of views on how different DSTs could be improved for nutrient use efficiency, soil carbon, and soil water availability and retention, based on the lists of the most used tools in each country. The responses indicated that 45% of the DSTs identified for improvement relate to soil nutrient use efficiency, 24% to soil organic carbon, and 18% to soil water availability and retention. Only 10% of the DSTs identified for improvement are integrated tools (Figure 5).

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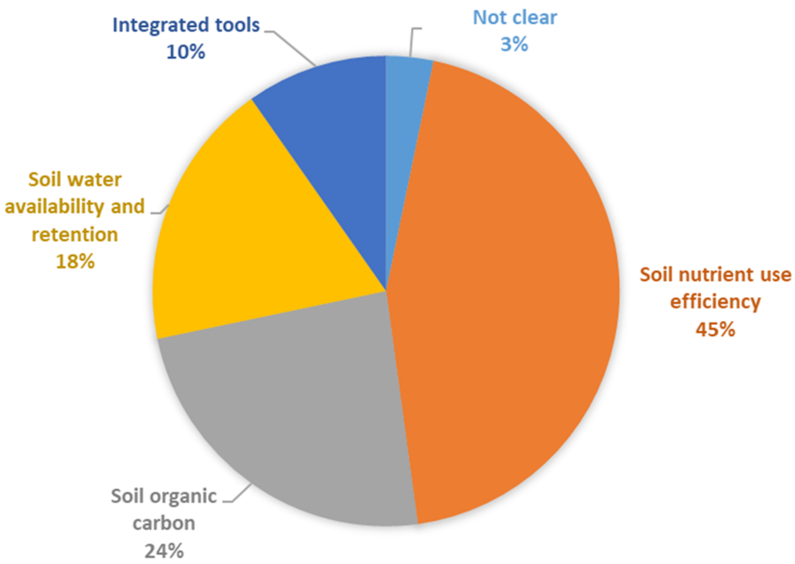

Figure 5. Percentage of DST types that can be improved defined by EJP SOIL national coordinators.

The suggested improvements address various aspects. Most often, they concern the inclusion of new systems (e.g., organic farming, agroforestry), the incorporation of additional processes (e.g., SOC stocks and sequestration, P and K fertilization), enhancements in calculations and estimations (e.g., improved process descriptions, suitability for different conditions), and better validation against observations across diverse conditions. Other common areas for improvement include data inputs (e.g., more up-to-date data, greater user flexibility, the ability to incorporate various data sources, and reduced data input requirements) and user-friendliness (e.g., design, user interface, visualization, and interpretation of results). Additional reported improvement needs include the development of web and mobile applications, options for scenario calculations, scalability across space and time, and suitability to support regulatory compliance. Detailed improvement needs for individual DSTs are listed in Table A1.9 in Annex 1.

Q11: Which type of tools are now not available but are needed and/or planned to be developed?
The responses regarding DSTs that are not currently available but are needed and/or planned to be developed were limited, with only about half of the respondents answering this question. Most respondents did not identify any integrated tools that could be developed. However, the results emphasized the importance of using decision support tools at different scales, ranging from field and farm levels to regional and national scales (Table 7). The responses indicated that the DSTs needed for development are primarily tools to aid decision-making at the farm and field levels. For the parameter of soil water availability and retention, a different scale was identified: the catchment scale, to support water management planning.

Table 7. Percentage of responses on the type of tools are now not available but are needed and/or planned to be developed and the relevant scales for each parameter.

	Soil organic matter (%)	Nutrient use efficiency (%)	Water retention (%)
Field	9	24	18
Farm	36	47	35
Catchment	-	-	6
Regional	27	18	18
National	27	12	18

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The responses regarding the types of tools that could be developed provided a wide range of suggestions for soil organic matter (SOM), nutrient use efficiency (NUE), and water retention. The respondents identified a general need for software, applications, and web-based tools, as well as sensors, monitoring tools, remote sensing, and forecasting tools. For soil organic matter, suggestions included DSTs that account for soil health indicators, thresholds for SOM/SOC, carbon credits, regional carbon balances, and life cycle analysis. For nutrient use efficiency, DSTs were recommended to address soil nutrient status, fertilization balance, and over-fertilization. For water retention, DSTs were suggested to account for soil moisture status, water requirements, and irrigation needs, as well as tools that forecast soil moisture conditions. Additionally, a DST providing information on the trafficability of fields was proposed.

In the case of integrated DSTs, respondents suggested developing a single-entry web portal instead of multiple individual tools. For example, one suggestion was a tool that integrates multiple sustainability goals related to soil functions, such as primary production, water quality, climate change, nutrient cycling, and biodiversity. The individual suggestions are listed in Table A1.10 in Annex 1.

According to the respondents, the use of these tools could help achieve both farmers' and regional objectives (Table 8). DSTs could aid in making informed management decisions, achieving regional SOC targets, and developing sustainable climate policies. For farmers, DSTs could help reduce inputs and increase the economic profitability of farms while offering sustainable recommendations for soil management, fertility, and crop rotation. Additionally, DSTs could help meet environmental targets, optimize resource and input use, and boost productivity.

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Table 8. Farmers' and regional goals that could be reached more easily if tools indicated in Question 11 are used.

	Which regional goals could be reached more easily if those tools are used?	Which farmers goals could be reached more easily if those tools are used?
Soil organic matter	• LULUCF targets • Climate policies • Retention of soil carbon, Soil C balance • Regional SOC targets • Informed management decisions • Need to better identify C_{org} • Sustaining / improving soil carbon • In terms of soil fertility and soil health, it could contribute to monitor, maintain and increase SOC	• Strategies to gain carbon credit • Reduce inputs and increase the economic profitability of farms • Recommendations for crop rotations • Soil management • Farm-level carbon budget calculation • Increase carbon content • Reduce costs and sustainable production • To make informed management decisions • Sustainable soil management monitoring • Sustaining/improving soil fertility and moisture retention • Increasing and maintaining the productivity of farmer's land, will provide more income, protect soil against climate change
Nutrient use efficiency / nutrient management	• Reduce GHG emission without reducing yield • Reduced nitrate leaching • Nitrates Directive • Environmental policies • Water quality maintenance / improvement and GHG mitigation • Less soil package and use of nutrition • Informed management decisions • In terms of soil fertility and soil health, it could contribute to achieve nutrient balance and better nutrient management in soil.	• Fertilizer use efficiency • Reduce inputs and increase the economic profitability of farms • Reduce N & P surplus and risk of loss per hectare. • Reduce fertiliser quantity & costs. • Increased soil fertility due to improved nutrient (incl. manure) distribution within the farm • Better yield, more sustainable farm, historical data • Reduce costs and sustainable production • To make informed management decisions • Increasing and maintaining the productivity of farmer's land, will provide more income, protect soil against climate change.
Water retention	• Demand of water for irrigation • Drought preparedness • Improving soil health and soil functions. Minimising the risk of nutrient runoff due to reduced water infiltration rates • Water saving • Proper irrigation management and early detection of drought	• Reduced use of irrigation water • Irrigation scheduling, yield estimations • Farm specific and cost-effective interventions • Irrigation efficiency • Optimising soil moisture • Increasing and maintaining the productivity of farmer's land, will provide more income, protect soil against climate change.
Integrated tools	• Reducing nutrient losses and carbon footprint of agriculture, etc	• Profit, lower environmental impact (incl. preserving soil health/quality) • All farmers and advisory services

Factors related to the use

Q12: What are the factors determining the use of DSTs in your country?

The majority of respondents (68%) considered farmer education as a key driver for the use of DSTs by farmers (Table 9). In contrast, farmers' participation in associations or cooperatives was seen as a less important factor, with 50% of responses falling between "strongly agree" and "somewhat agree." Similarly, respondents reported that crop farmers are more likely to use DSTs compared to livestock farmers (50% of responses), although a quarter of the respondents indicated limited knowledge on this topic. Around 40% of the responses indicated unfamiliarity with activities related to DSTs in living labs. Responses concerning digital illiteracy were inconclusive. Lastly, respondents

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indicated that the use of DSTs is not significantly influenced by specific management approaches, such as biodynamic or organic farming.

Table 9. The respondent's views on factors determining the use of DSTs.

	Strongly agree (%)	Somewhat agree (%)	Neither agree or disagree (%)	Somewhat disagree (%)	Strongly disagree (%)	I don't know (%)
Farmer education is a critical factor in determining the use of DSTs by farmers	32	36	14	14	0	5
Members of farmers' associations and cooperatives tend to use DSTs more than individual farmers	10	40	30	5	5	10
Crop farmers tend to use DSTs more than livestock farmers	10	40	20	5	0	25
DSTs are used by living labs	21	11	26	5	0	37
DSTs are used by living labs						
Digital illiteracy is among the main factors hampering the use of DSTs	14	29	19	19	14	5
Organic and biodynamic farmers tend to use DSTs more than conventional farmers	0	17	30	22	9	22

Other aspects

Q13 and Q15: In your opinion, what additional aspects – that we did not mention -should be considered concerning the use and the improvement of DST related to soil water retention (13), soil organic carbon (14), and nutrient use efficiency (15)?

The respondent's answers covered several themes for enhancing DST concerning soil water retention, soil organic matter, and nutrient use efficiency (Table 10, individual answers are shown in Table A1.11 Annex 1).

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Table 10. Additional aspects that were not mentioned in the questionnaire but could be considered in the use and development of DST's related to soil water retention, soil organic carbon, and nutrient use efficiency.

Theme	Additional aspects
Soil water retention	
Comprehensive Data Integration	Respondents emphasized the necessity of integrating accurate and comprehensive data on soil characteristics and soil hydrology into DSTs. These data serve as foundational elements for effective decision-making in soil water retention and irrigation management.
Incorporating Farming Practices	To enhance the practicality and relevance of DSTs, it is recommended to include information on farming practices, such as the use of cover crops and tillage. These practices significantly impact soil water dynamics and should be integral components of the decision-making process.
Pedotransfer Functions	The inclusion of pedostransfer functions within DSTs is advised to improve the accuracy of soil hydrological data. Pedostransfer functions enable the estimation of essential hydrological parameters directly within the model, thereby enhancing precision in soil water retention predictions.
Economic Module Integration	Given the increasing profitability of irrigation in regions like Finland due to climate change, there is a compelling argument for integrating an economic module into DSTs. This module would support farmers in making economically sound decisions regarding irrigation and water management, not limited to Finland.
Co-creation during DST development	Engaging end users during the development stage of DST was flagged as a critical step to ensure (i) relevance of the DST for end users and (ii) actual use of the DST by end user in the decision-making process.
Soil organic carbon	
Comprehensive Soil Testing	NCs emphasized the importance of accurate soil testing that incorporates a broad spectrum of soil parameters. This includes specific considerations for sampling depth. Such comprehensive data are crucial for improving the precision and utility of DSTs in SOM management.
Temporal Considerations	Recognizing the temporal dimension of SOM stabilization emerged as a significant recommendation. Soil organic matter processes can span years, and DSTs should account for this extended timeframe to provide realistic and effective results based on different management strategies.
Historical Data Integration	To enhance the robustness of DSTs, it is advisable to incorporate historical data. Historical information allows for accurate validation and calibration of models, thereby increasing their reliability in predicting SOM dynamics.
Influence on Soil Health	Respondents recommended integrating the influence of SOM on chemical, physical, and biological soil health. This addition can make the benefits of improving SOM more explicit to end users and emphasize the broader positive impacts on soil quality and productivity.
Microorganism Modules	An intriguing suggestion is the integration of specific modules related to microorganisms. These modules would offer a more comprehensive view of the processes associated with SOM stabilization, considering the critical role microorganisms play in SOM dynamics.
Nutrient use efficiency	
Incorporating SOM Data	Respondents underscored the significance of incorporating data on soil organic matter into DSTs. This inclusion would enable DSTs to provide estimates of soil nutrient pools and the nutrients available for mineralization, offering critical information for nutrient management.
Integration of Farm Management and Crop Yield Data	It is recommended to integrate farm management practices and crop yield data into DSTs. This integration would facilitate the calculation of nutrient use efficiency under varying circumstances, enabling farmers to optimize nutrient utilization.
Multi-Year Monitoring	Acknowledging the temporal dynamics of soil processes, respondents advocated for multi-year monitoring within DSTs. Such an approach would enhance tool reliability by accounting for variability across cropping seasons and capturing long-term trends in nutrient management.
Expanded Analytical Scales	To provide a more holistic perspective, respondents suggested expanding the analytical scales beyond the farm gate. Assessing nutrient efficiency at regional and national levels would offer valuable insights into the environmental performance of specific areas or countries, supporting more informed policy decisions.
Integration of GHG module	Given the potential negative impact of over N-fertilization, respondents recommended to include a module able to calculate potential and actual gaseous N losses in DST related to nutrient use efficiency. This would serve to make visible the impact of fertilization on GHG emission.

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3.2.2. Questionnaire to stakeholders

Respondents

Q1: Responder details.
A total of 125 responses were received for the questionnaire from Finland (n=2), the Netherlands (n=7), Italy (n=5), Latvia (n=14), Sweden (n=13), and Türkiye (n=84). The responses cover only a few European countries and are imbalanced in terms of the number of responses per country. Additionally, the responses from Finland and Italy were largely incomplete. Therefore, the results from this survey are primarily interpreted using country averages (average response by country) to allow for comparison without bias from the varying number of responses per country. Only questions that had an adequate number of answers to allow meaningful analysis are included here. While the results of the stakeholder survey are not fully representative of Europe as a whole, they still provide useful insights from different regions and conditions across Europe.

The respondents consisted of farmers, consultants or agronomists, and researchers (Table 11). The largest share of farmers was in Latvia, Sweden, and Türkiye, while in the Netherlands, a large share of respondents were employees of farmers' cooperatives. Among the respondents who practiced farming, the majority were crop farmers, with the most common farming types being conventional and organic agriculture. More details on the respondents are provided in Table A1.12 in Annex 1.

Table 11. Stakeholders' questionnaire: Respondent's occupation and farming activities. Note that respondents may have given more than one answers for each question and percentages refer to share of respondents.

Occupation	Finland	Netherlands	Italy	Latvia	Sweden	Türkiye
A. Farmer	0%	0%	20%	79%	62%	56%
B. Researcher	0%	29%	0%	29%	0%	11%
C. Consultant/Agronomist	0%	29%	60%	7%	46%	25%
D. Employee of a private company working in agriculture or food production	0%	0%	0%	7%	0%	5%
E. Employee of a farmer's cooperative	0%	43%	0%	0%	0%	1%
F. Others	100%	29%	60%	7%	8%	15%
n of respondents	2	7	5	14	13	84
Crop and livestock farming						
A. Livestock farmer	-	0%	0%	36%	43%	86%
B. Crop farmer	-	100%	100%	64%	57%	14%
n of respondents	-	1	1	11	7	49
Farming type						
A. Conventional agriculture	0 %	100 %	0 %	64 %	75 %	52 %
B. Agro-ecological approach – not certified	0 %	0 %	0 %	9 %	0 %	21 %
C. Organic certified	100 %	100 %	100 %	27 %	25 %	23 %
D. Biodynamic	0 %	0 %	0 %	0 %	0 %	2 %
E. Other	0 %	0 %	0 %	9 %	0 %	20 %
n of respondents	1	1	1	11	8	56

Farming challenges

Q2: What do you think are the most important soil related challenges of the local agriculture?
Out of the listed soil challenges, "low soil organic matter or soil organic matter depletion" and "soil water management" were the most frequently reported challenges (Table 12). "Soil compaction" was also commonly reported in the Netherlands, Sweden, and Finland, while "low nutrient use efficiency" was often reported in Latvia. In Sweden, "soil compaction" was the most reported challenge, whereas "low soil organic matter or soil organic matter depletion" was less frequently mentioned compared to other countries. Soil erosion was reported by only one-fifth of the respondents in Italy

and Sweden and even less in other countries. Additional soil-related challenges mentioned included soil fertility in Italy and Türkiye, and biodiversity management in Italy.

Table 12. Reported farming challenges. Note that respondents may have given more than one answers and percentages refer to share of respondents.

Farming challenge	Finland	Netherlands	Italy	Latvia	Sweden	Türkiye
A. Soil erosion	0 %	0 %	20 %	7 %	23 %	14 %
B. Low soil organic matter or soil organic matter depletion	50 %	57 %	100 %	64 %	38 %	53 %
C. Low nutrient use efficiency (Fertilizers are applied but crops have low response)	50 %	14 %	0 %	43 %	8 %	28 %
D. Soil water management	50 %	71 %	60 %	36 %	31 %	65 %
E. Soil compaction	50 %	43 %	20 %	36 %	54 %	15 %
F. Others	50 %	0 %	20 %	21 %	8 %	13 %
n of respondents	2	7	5	14	13	80

Farming and DSTs

Q3: Are you familiar with decision support tools (DST) or systems?

Respondents' familiarity with DSTs was highest in Sweden, the Netherlands, and Italy, where 50-72% (n=4-11) of respondents reported having used or currently using them (Table A1.13 in Annex 1). In Latvia, the usage rate was 23% (n=13), and in Türkiye, it was 11% (n=67). These rates are based on the experiences of a relatively small number of respondents and may not be representative of the countries as a whole.

Q4: Do you agree with the following statements on DSTs?

According to the average agreement with the seven statements, the majority of respondents tend to believe that DST results can be trusted and that DSTs are useful, though some reservations were expressed (Table 13). Specifically, 47% of respondents disagreed with the statement "I do not trust DST results," while 22% agreed. Similarly, 56% disagreed with the statement "I do not think DSTs are useful," but 12% agreed.

In terms of use-related statements (Table 13), DSTs were sometimes reported as too complex, but respondents generally indicated that they have the necessary devices to use them and can provide the required data. Additionally, DSTs were often considered not time-consuming and helpful. Specifically, 57% disagreed with the statement "I do not have devices to use DSTs," while 9% agreed. Similarly, 30% disagreed with the statement "DSTs require too much data that I cannot provide," and 13% agreed. Regarding time consumption, 30% disagreed with the statement "Working with DSTs is time-consuming and not so helpful," while 22% agreed. The variation in responses between countries is detailed in Table A1.14 in Annex 1.

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Table 13. Average agreement with statements on DSTs. *The values in the table are calculated from relative shares (%) of answers from each country to account for the imbalanced number of answers per each country.*

Statements	Strongly agree	Somewhat agree	Neither agree or disagree	Somewhat disagree	Strongly disagree	Don't know	n
A. I do not trust DSTs results	2 %	20 %	17 %	35 %	12 %	14 %	44
B. I do not think DSTs are useful	1 %	11 %	19 %	34 %	22 %	13 %	44
C. DSTs are usually too complex	6 %	25 %	16 %	30 %	8 %	15 %	42
D. I do not have devices to use DSTs	7 %	2 %	15 %	27 %	30 %	19 %	45
E. DTSs require too many data that I cannot provide	1 %	12 %	39 %	19 %	11 %	17 %	43
F. Working with DSTs is time consuming and not so helpful	1 %	21 %	30 %	11 %	19 %	18 %	40

Q7: If you use DSTs, how would you rank from 1 to 5 the most important features of a DST (where 1 is the most important, 2 the second most important etc.)?

Very few responses were received for this question, which limits the generalizability of the results. However, based on the average responses from each country, low data requirements were identified as the most important feature (average rating 2.3), followed by trust and confidence in the results (average rating 2.7) (Table 14). Additionally, respondents valued DSTs that provide outcomes that are easily applicable and delivered in real time (average rating 2.9). The least important features were whether the design of the DST was carried out in collaboration with end-users (average rating 3.9) and the clear visualization of results (average rating 3.9). Detailed country-specific answers are provided in Table A1.15 in Annex 1.

Table 14. Most important featured of DST on average according to the respondents (1=most important, 2= second most important etc.). The values in the table are calculated from averages of answers of each country to account for the imbalanced number of answers per each country.

Feature	Average	Stdev	Min	Max	n
A. Do not require too many data from my hand	2.3	1.1	1	3.3	21
B User-friendly interface	3.5	0.4	3	4	16
C. Clear visualization of results	3.9	0.9	2.7	5	22
D. Trust/confidence in the results (based on scientific publications or on-farm calibration)	2.7	0.7	2.1	3.7	20
E. Easy to access both in terms of costs and hardware requirement	3.1	0.3	2.8	3.7	23
F. The design of the DST has been carried out in collaboration with end-users	3.9	1.3	2.5	5	11
G. DST provide outcomes which are easy applicable and in real time (when I need info to manage the crop and not too late)	2.9	1.4	1	4	22

Question 8-10. How do you make decisions concerning nutrient (8), water (9), and soil organic matter management (10)? Please, list here what tools, data sources, platforms, sensors, remote sensing, etc. are used concerning nutrient management and nutrient use efficiency. (For example, soil nutrient status, fertilizer recommendation, predicting nutrient release from mineralization, predicting crop residues from harvesting, estimating crop production, exploring the effect of cover crop on soil nutrient status etc.)

Very few responses were received for these questions, but those that were received are shown in Table 15.

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Table 15. How decisions are made concerning nutrient, water, and soil organic matter management.

Theme	Additional aspects
Nutrient management	
Italy	Most of the responders argued the decision-making process is based on the observation and analysis of crops and soils. One responder specified that the importance of the humic balance to make decision concerning soil organic matter management.
Sweden	Use guidelines, soil maps, zero-fertilized plots, crop sensors (Green-seeker, Yara N-sensor, Yara N-stester) or satellite images (Cropsat, Atfarm), use the winter oilseed rape nitrogen estimator, do tissue analysis, my advisor´s equipment, nutrient balances, own experience and advice from agricultural community.
Türkiye	Soil analyses, fertilisers and fertilisation guidelines, remote monitoring and sensor technology, my own experience and advice from agricultural advisors.
Water management	
Italy	Visual observation of crop and soil were reported to be the primary source of information to guide decision making process concerning water management. One responder reported the use of soil moisture sensor.
Sweden	Weather forecast, visual judgement, spade or hand on soil, inspection of drainage wells, inspection of map for erosion risk and water movement
Türkiye	Climate data, humidity sensors, based on my own experience and then consulting with authorised persons or consultants, meteorological stations in the field, sensors measuring parameters such as soil moisture, air relative humidity and air temperature, tensiometer, soil moisture analysis, early warning system thanks to remote monitoring and sensor technology.
Soil organic carbon management	
Sweden	Few or no tools. My advisor (Växtab), modules in GREPPA (cultivation perspective), soil maps, use organic fertilizers
Türkiye	Soil analysis devices, based on my experience, then consulting with competent persons, taking into account the results of soil analysis, farm manure application to increase organic matter, using microbiological soil fertiliser.

3.3. Stakeholder exchanges

This section includes the highlights of the stakeholder exchanges in the workshops, national hub, ASDs, Lighthouse farm, and from the participatory approach. For a full report on this part of the research see project deliverable D4.1.

3.3.1. Regional Workshops

Stakeholders' participation and representation in the workshops

Table 16 Stakeholder participation in the four regional workshops varied between 20 and 30 participants per workshop (Table 16). Each workshop aimed to involve a diverse representation of stakeholders, including farmers, advisors, DSTs developers, as well as other relevant actors if possible (Table 16). Farmers and advisors were the main participants, with the exception of Latvia, where policy-makers and farmers union representatives were also invited, bringing insightful perspectives to the issues addressed. In addition, the farmers could also represent different types of farms, where for instance the farmers in Sweden were selected by their advisors to represent those with special interest in and experiences of DSTs.

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Table 16. Workshop participants at the different workshops.

Profession	Sweden	Latvia	Italy	Türkiye
Farmers	11	2	9	12
Advisors	2	2	10	7
DST providers	4	4	-	1
Researchers	4	9	5	12
Farmers union representatives	-	2	-	-
Policy makers	-	4	1	-
Total	21	23	25	32

Soil related challenges and objectives for using DST

The main soil related challenges as indicated by the workshop participants (Table A2.1) varied between the different workshops. In Latvia and Italy, soil fertility and soil organic matter was the top mentioned challenges, whereas in Sweden, soil compaction was considered the main challenge (Table 17). In Türkiye, they considered water management the most important challenge. Several workshop participants in Italy also mentioned water availability. These align with the regional differences in the farming challenges reported in the questionnaire for stakeholders (Section 3.2.2).

Table 17. Main soil related challenges identified by participants at the workshops in the different countries. The figures indicate the numbers of participants voting for each challenge

	Sweden	Latvia	Italy	Türkiye
Soil compaction	5	1	1	2
Soil fertility	1	3	6	5
Soil erosion	-	2	-	2
Soil organic matter	2	9	6	3
Acidification	-	4	-	-
Climate adaption	1	-	2	1
Nitrogen efficiency	1	-	0	-
Water availability	2	-	5	-
Soil water management	-	-	-	14

Although different challenges were identified, common objectives for using DSTs are related to fertilization (Table 18). This includes both seasonal adjustments of nitrogen with regard to crop status and fertilization and liming according to soil maps. This applies also to several Italian big or medium companies, involved in industrial crops production, which utilize DSTs to manage their fertilization based on maps. Similarly, by mapping soil moisture, it is possible to anticipate the crop need in terms of water supply and irrigation.

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Table 18. Objectives for using a DST as mentioned by the workshop participants in the different countries.

Country	Objective
Sweden	The general objective for using a DST mentioned by farmers was to increase profitability by minimizing inputs and optimize production. Advisors also mentioned "facilitate daily work" and "comply with regulations" as objectives. More specifically farmers mentioned objectives mainly related to fertilization, such as "Know optimal fertilization", "Distribution of fertilizers between fields", "Detect deficiencies in nutrients", and "Choose the right type of fertilizer". They also mentioned objectives connected to soil water such as "choose the right tillage for optimising soil moisture based on the season" and "when to irrigate". One also mentions "strategy for improved organic matter." Researchers added "yield forecast" as that is an unsolved challenge they are working on.
Lativa	In Latvia the objective with using DST is first of nitrogen fertilization doses, in order to save money and not fertilize fields unnecessarily. They also mentioned soil agrochemical analyses to monitor the general condition of the field, but also because regulation requires it and soil pH to plan initial and repeated liming and to be able to apply for support. The objective can also be to bypass obstacles and accurately draw boundaries between fields with GPS or to follow the development of the crop and the health of the plant. The objective can also be to improve the efficiency of work volume planning.
Italy	Several Italian big or medium companies, involved in industrial crops production, utilize decision support systems to manage their fertilization plan and optimize the crop nutrient use efficiency, based on a graphical mapping of the field, where the soil N content is associated to a colour gradient. Similarly, mapping soil water moisture it is possible to anticipate the crop need in terms of water supply and irrigation mode for saving water.
Türkiye	In Türkiye, the farmers as well as researchers, DST providers and advisors mentioned the general objective "increase yield and quality" and support regarding fertilization, irrigation ,and pesticide use. In addition to this, advisors also mentioned "saving time", "reducing costs", "contributing to the ecosystem" and "implementation in sustainable agricultural policies". Researchers added "growing heathy products" and "prevent environmental pollution".

The reason behind such a discrepancy between the farming challenge mentioned and the use of DTS for fertilizers, could be that challenges were considered as "major" just because they are still not as easily solved with using a DST. The commonly used DSTs are mainly supporting tools to decision making related to fertilization and irrigation. These are decisions that require a lot of inputs that may vary spatially and in time and therefore a DST with access to detailed and updated data is often very useful. But when it comes to challenges related to soil organic matter content, soil compaction and how to cope with weather fluctuations or drought and flooding, sometimes in the same season, completely different type of decisions and consequently also different types of tools are required. For water, these could include everything from planning water regulation through drainage and the construction of dams to adapting the tillage for adequate drying for the upcoming crop or adapting the choice of crops to ones that can withstand strong weather fluctuations. About the soil organic matter, more long-term decisions come into picture, such as regular supply of stable manure, straw return, catch crops, etc.: for this reason, several Italian farmers are asking for advanced DSTs able to adequately support the management of organic inputs (selection of cover crops, organic amendments, time of application) to increase soil organic carbon in function of soil properties and weather conditions.

Barriers and solutions for adoption

The barriers for implementation and suggestions for how to break these barriers were mainly discussed at the two workshops in Latvia and Italy. At both workshops, very similar barriers were addressed (Table 19). Even though DSTs are adopted on larger farms, small farms, which for instance are common in Italy, have more difficulties in using DSTs, mainly due to lower economic resources, lack of easy-to-access solutions for farmers and average age of farmers, not always so friendly with digital tools. In Latvia, farmers use their experience of their farm, passed down through generations, and many of them already think they know what to do, depending on visual characteristics of the crop, their soil tests and weather conditions and that a digital DST would not add anything more useful. Not enough user-friendly technology and lack of technical support was also addressed at the

Swedish workshop, and the differences in adoption between generations was mentioned also in the Netherlands.

Table 19. Barriers identified and solutions suggested from the workshops in Latvia and Italy.

Identified barriers	Suggested solutions
Expensive technology and not enough economic resources for adoption	Positive demonstrations by experienced farmers without economic interests in the tool,
Not enough user-friendly technology and lack of technical support and	Financial and technical support for implementation
Old generation with sticking to traditions.	Simplified data-entry (also by farmers) and tools that all generations can understand.

Good technical support was addressed as something very important for adoption also at the Swedish workshop. One suggestion to improve the support was to bring farmers using the same tool together into farmers groups that can exchange experiences either in physical meetings or just in a chat group. In Türkiye, they also addressed that the tools need to be user friendly, meaning that the need to be easy to operate, understandable, with available user manual and support in the local language and possible to use also without internet connection. They also addressed the importance of accuracy, reliability and up to date information compatible with the terrain.

Suggested features

At the workshops in Sweden and Türkiye much of the discussion concerned requested features of a tool. In Sweden, where the workshop participants were mainly farmers with large farms with experience of several tools, much of the discussion was based on experiences on tools they already use and the requests they listed were focused on functionality of the tools. They think transparency is important, so that the user can understand what lies behind. In that way they can more easily judge whether it is relevant and valid for their situation. Some decisions need to be taken in real time, such as when fertilization is adapted to current crop status and weather conditions. On the other hand, some settings in the tool may need adjustments to fit their farm and if they have the knowledge and data for that they would like to be able to do so. Therefore, they want to be able to get answers quickly when needed through an app in the mobile phone, and at the same time have the opportunity to influence settings etc. in a computer version when time is available. Through the app, they want to be able to access the tools and previous documentation anytime and anywhere. They also want to easily store new observations through the app when they are out in the field. It should also be possible to share data between different tools, so that a soil map made from one company could easily be combined with satellite data from another in any DST most suitable for their purpose. At the Italian workshop it was also addressed that it is important to be able to access different databases on private and public platforms.

In Türkiye and the other workshops with larger part of the participants from other stakeholder groups than farmers this discussion was generally broader. They addressed that functionality and usefulness for farmers is important and that that the tools should be user-friendly both concerning interface and operation, that they should benefit yield, quality and environmental impact and be reliable.

Responses to statements

The response to the statement “All tools should have an app for a smartphone” had very similar answers at all four workshops (Table 20). The common answer was that it would be useful in many cases as it allows for real-time updates when you are in the field. However, some functions such as more advanced data management may be much better on the computer, so in most cases the tool

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should be able to use in both a computer version and in an app on the smartphone. The statement "In addition to plant production and soil quality, tools should also provide information on environmental impact" got a bit various response (Table 20). In Türkiye, all agreed that it would be important not only for the sake of the environment, but also for warning to take precautions in case of natural disasters. In Latvia they were also positive and mentioned it would be educating, provided it has a solid scientific base. In Sweden, there were some scepticisms whether it should be mandatory to combine it in all tools, since making it more complex may contribute to that the development of the tool is slowed down and that the tool is unnecessary complicated. At all workshops it was agreed that weather is important for many decisions, and that updated and site-specific weather forecasts therefor are needed. However, it is difficult to get reliable weather forecasts, and it is not realistic that all decision support tools can cover all details.

Table 20. Summary from each workshop of the responses during group discussions to different statements.

Country	Responses to statement
All tools should have an app for a smartphone	
Sweden	Often, but not necessarily. It depends on how quickly you need the answer and for what you need it.
Latvia	Yes, for functions that need to and can be used in the field, as it allows for real-time changes. But there should also be a PC version, because data management and other databases and programs are more easily available on the computer.
Italy	It was remarked that, even if it is preferable to use DSTs as mobile apps, sometimes map viewing requires the use of PC.
Türkiye	Yes, it is necessary, accessible and quite practical in the field, provided that it is easy to understand. There may be a computer version for detailed information.
In addition to plant production and soil quality, tools should also provide information on environmental impact	
Sweden	Not necessarily. It could slow down the development of the tool if it is unnecessarily complicated and not focused enough. Could be coupled to environmental labelling.
Latvia	Many agree, as it is important and nobody wants to harm the environment and it is mandatory to take the environment into account, considering regulations. It could also be educating. But it is only useful if it has a solid scientific base. Some think it should instead be already built into the algorithm that gives advice to the farmer.
Türkiye	Yes, it should provide information of the negative or positive effects of crop production and soil quality as well as environmental impacts. Warnings can be given in advance of natural disasters, measuring the economic damage threshold of diseases and pests and taking precautions. For example, it is necessary to investigate whether plant protection products harm bees. The persistence, pollution, etc. of the pesticides we use should also be investigated. Yes. It should be useful in all areas so that a single decision support tool is useful. Yes. It is also necessary to provide information on environmental impacts for sustainable agriculture.
Tools must be flexible and take into account actual weather conditions	
Sweden	Flexibility is important, but not always weather forecast. It is also difficult to get reliable weather forecasts.
Latvia	Yes, farming is greatly influenced by the weather and the more detailed the data in real time, the better the conclusions and the better the decisions. However, only if accuracy can be ensured.
Türkiye	It should be flexible and take into account real weather conditions. Since weather conditions are constantly changing, data should be updated. It is very important to have it in real time. Time is crucial for correct technique application and precaution. But it is difficult to get reliable weather forecasts, and it is not possible for decision support tools to cover every point.

Similarities and differences between the workshop outputs

The workshops organized in the various countries involved different types of agricultural stakeholders, which may have influenced what was discussed. In the Swedish workshop most participants were farmers that were all early adopters of DSTs and did not represent an average farmer in Sweden. Their discussions concerned much about how to improve DSTs that they already used and was additional DSTs they would like. At the other workshops it was more difficult to attract farmers, and the discussion was more focused on barriers to use DSTs and have to overcome these barriers.

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Common conclusions and differences emerged from the discussions. During the workshops, it was emphasized that simpler, more user-friendly interfaces are needed. Farmers appreciated that the tools should have a smartphone application. However, DST providers, advisors and researchers all agreed that it is preferable to use DSTs in the form of mobile applications, but not always possible. Therefore, using a tool on a smartphone depends on the type of tool. However, with a PC version parallel to the app, there is the possibility to get the advantage of having both the advantage of detailed functions and visualisation in the PC simultaneously as the tool is always at all times and locations in the app.

It was agreed that DSTs should be flexible and easy to use. Another important point concerns the clear visualization of results. A tool should not require a lot of information to be entered by users. While farmers focus on the ease of use of decision support tools and the real-time application decision. Other stakeholders all underlined the importance of results being reliable and based on science and farm calibration in the region. Another point discussed at the workshops was whether the tools should also provide information on environmental impact. For Italy and Latvia, all stakeholders indicated the importance of this functionality in order to know how practices affect the environment and to ensure food quality and safety. However, in the case of Sweden, participants pointed out that this could make the tool unnecessarily complicated, and that the buyers define what should be done for measures for environmental labelling and the market then decides whether they want to pay extra.

A similarity between the countries was that all stakeholders in the various countries indicated the need for even simpler and more accessible tools. However, in some countries there were at the same time wishes for more complex tools. In the case of Italy, participants would like DSTs to take account not only of SOC, nutrients and water supply, but also of information on introduced cover crop species, inorganic vs organic inputs, weeding strategies, management of crop residues, etc. However, in Latvia, it was noted that it was not possible to combine the different functions of separate tools into a single multifunctional tool, as there are too many actors involved in DST activities and each actor has his or her own format, making it is impossible to combine them successfully.

Discussions on data management and use varied between the different countries. For Italy and Latvia, stakeholders indicated that the tool should be able to interface easily with existing databases. For the Latvian workshop, it was suggested that the tool should be synchronized with a database shared by all institutions and research centres involved in agriculture. This database would contain the latest information from the whole country, and would therefore be relevant for all Latvia, and it would be possible to select locally specific information relevant to each farm. For the Swedish workshop, the discussion on this point focused on access to historical data of the farm. Future DSTs should allow easy access to previous documentation at any time and in any place, preferably via an application on the phone. Finally, only for the atelier in Italy, it was suggested that future tools should enable calculation of the farm's carbon footprint.

Consistency between stocktake and workshop outputs

The outputs from the workshop do confirm much of what was found from the stocktake. For instance, the concerning main soil related challenges and objectives for using DSTs. However, there was a difference concerning costs, where stocktake results indicated that most DSTs are for free or at low costs, whereas stakeholders mentioned cost as one of the major barriers for implementation. Even when the cost for the software is insignificant, there could be other costs for other implements or infrastructure that are necessary for the use of the tool that is costly and something that many small farmers cannot afford. Only the workshop in Sweden had many participating farmers that

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already used several DSTs. In that workshop three additional tools on water management and five additional tools related to nutrient management were added to the list of tools in Sweden from the stock-take. Even though some of these tools were mentioned by other counties, the additions implies that the list of tools from the stocktake is not complete.

3.3.2. Exchanges in other meetings

National Hubs

In addition to contributions via the newsletter, two contributions were given to meetings of the national hubs in The Netherlands. During the first one, participants were informed about the project and the questionnaires, and in the second, their cooperation was sought as part of the participatory approach for making the visualisation on DSTs (see next paragraph). A major outcome of the discussion was the notion to respect anonymity and ownership when sharing (farm) data.

EJP SOIL Annual Science days (ASD) 2023 and 2024

During ASD 2023, exchanges with fellow researchers were facilitated by presentation of two posters, i.e. one to invite stakeholder groups, in particular Living Labs, to participate in the workshops, and the other on a candidate stakeholder group in The Netherlands. These encounters highlighted differences between Member States with respect to the use of DSTs and also yielded suitable literature to read. In addition, PRAC2LIV co-convened a session with the title ‘Using participatory design for developing farmer friendly tools for soil practices and schemes ‘. The session focused on the EJP SOIL aims to promote the use of regionally specific tools to provide either qualitative or quantitative information on agricultural soil-based ecosystem services, e.g., climate change. One of the outcomes was the importance of explaining to stakeholders the need for, i.e. carbon sequestration to have them engaged. Also, soil management was discussed as part of a farming system that may be evaluated by an integral tool such as FAO’s “Tool for Agroecological Performance Evaluation” (2019).

During ASD2024, exchanges with fellow researchers involved the making of the visualisation (Figure 6). At a higher scale-level than individual DSTs, the socio-economic impacts and challenges of implementing sustainable practices was discussed and the possible role that DSTs may play. PRAC2LIV also co-convened a session intitled “Leveraging different approaches in the development of farmer-friendly tools for sustainable soil practices and schemes”. The session aimed to elucidate experiences from projects concerning end-users' engagement, development and adoption of new tools and methods or implementation of new agroecological strategies. A common outcome was the importance of participatory approach for future agriculture development and the need for tailored solutions and recommendation for sustainable soil management.

Moreover, PRAC2LIV participated in the science to policy session, fostering soil management practices and uptake in Europe, involving by expertise from other EJP Soil projects. The outcomes of the discussion were:

1. The importance of considering different spatial scales in assessment and monitoring, including DSTs, from the field and farm scales to the regional and national scales
2. The adoption by end-users depends on the suitability for reaching end-user goals
3. Regional scale is relevant but more focus is needed for farm scale to consider farmers conditions ensuring sustainable development and policies at different level
4. Regional stakeholder is needed for future development of DSTs, such as Living Labs where participatory approach is essential and can be implemented to involve all concerned parties in the implementation of DSTs to support soil health in Europe and to coordinate the different initiatives aimed at this matter.

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In addition, in the Workshop Advisors, the point was stressed that researchers may not be familiar with the role of advisors in a changing context and therefore their opinions need not reflect those of real advisors, and the present role of advisors is often focussed on a specific theme, and hence it was suggested to invest in the broadening of their scope and skills. Again, the need for a bottom-up approach was mentioned.

Lighthouse Farm

The meeting yielded insight in the natural emergence of a Living Lab. The initiative and challenge for the Ekoboerderij was discussed in view of being an organic farm and labour availability. The farm has developed several collaborations with local parties, also to sell produce locally. In the future, the farm may evolve to being the centre of a living lab with other farms in the region. A major point mentioned in the discussion on DST was the safety and ownership of data.

3.3.3. Participatory Approach

During the iteration process of the visualization, drafts were presented to, and discussed with, several expert groups at various scale levels both national and international. These included: Project team PRAC2LIV; National Hub (NL); Soil Health Institute (USA); Annual Sciences Days 2024. After ASD2024, final comments were included in the drawing and the visualisation made finite.

New Insights from the method

Regarding the topic "DSTs for Soil health in Living Labs", all relevant aspects to consider for developing DSTs/web portals have been integrally discussed, while the participatory process enhances commitment for the outcomes. In addition, new subtopics could be identified that were not explicitly included in the questionnaires, e.g. 'digital twin', 'business model', and 'ecosystem services.

As for the method itself, it was found that a participatory approach method has high potential for inspiring, focussing and accelerating the development of a common vision on complex matters such as soil health in living labs in the EU (Figure 6). It was considered a useful additional research method for conceptual ('vision') data collection and interpretation, combining research and communication. At a more general terms, the method may need some standardisation for quality assurance.

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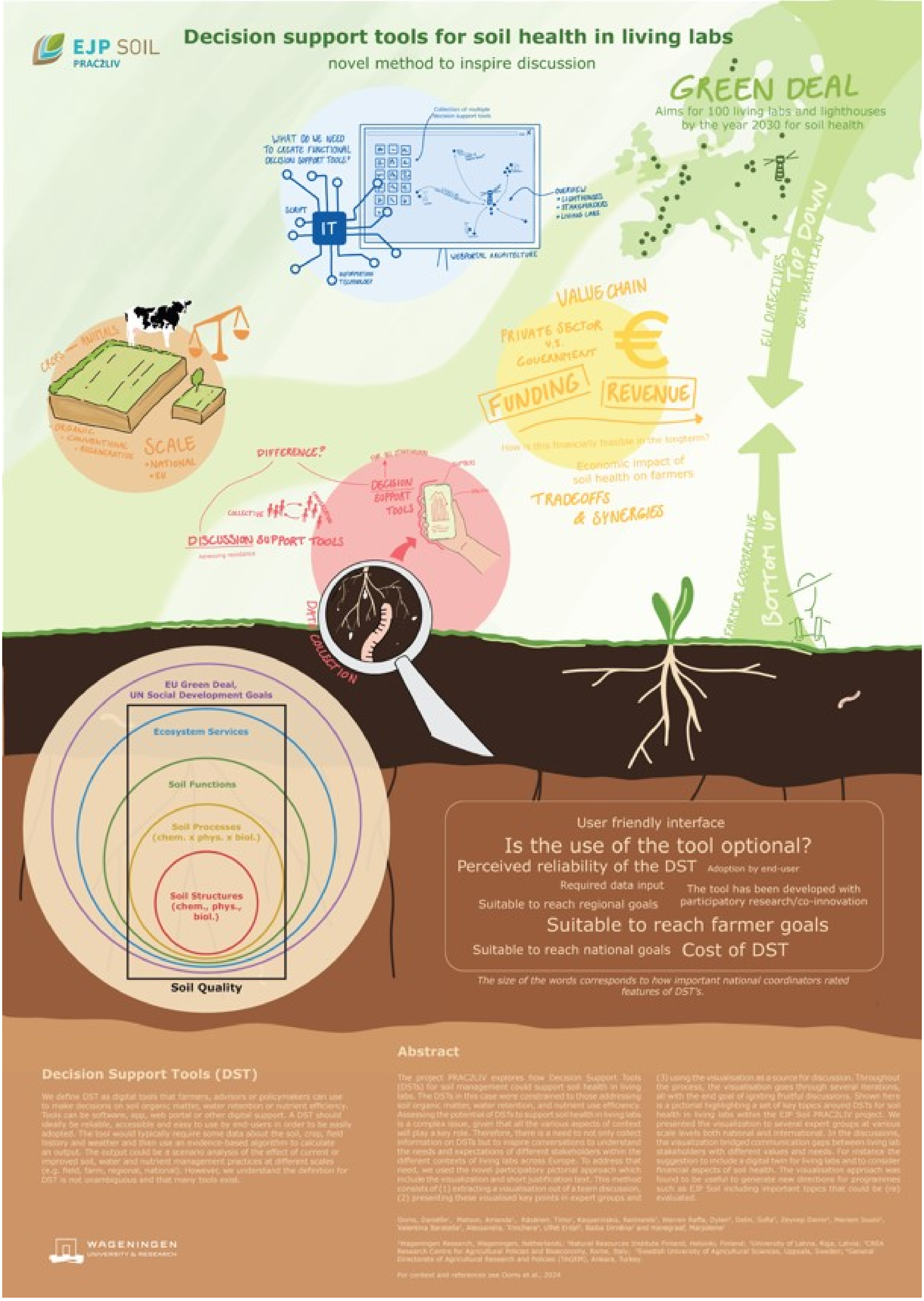

Figure 6. Final version of the visualisation in a poster format.

3.4. Mock-up designs for DSTs

To illustrate what a DST on soil organic matter, water holding capacity of nutrient use efficiency could look like, three different mock-ups have been designed. The mock-ups are presented in the separate report D5.2. To give an indication of what the mock-up could look like, this section will give a short description of the soil organic matter mock-up.

Note that the mock-ups that have been designed are solely meant to give inspiration on what the visualisation of the app might look like and what a DST should at least contain. Yet, they are not actually working apps and do not give a complete description of the application to be made.

Starting screens

The first few screens of the app give farmers the possibility to create an account and specify their farm type. This is done for all the mock-up designs, as they require similar data like the location of the farm and the corresponding soil type. After the starting screens, a farmer can decide whether he wants to create an organic matter balance on field or farm level.

Field level

The field level calculation consists of the screens, which are the input, output, and the actual balance. In the input screen, a farmer can indicate what organic matter inputs are applied on the field. This can be different kind of fertilizers, such as manure or compost. Another source of organic matter are the possible crop residues. Finally, the cultivation of a cover crop can be indicated. This is presented in Figure 7.

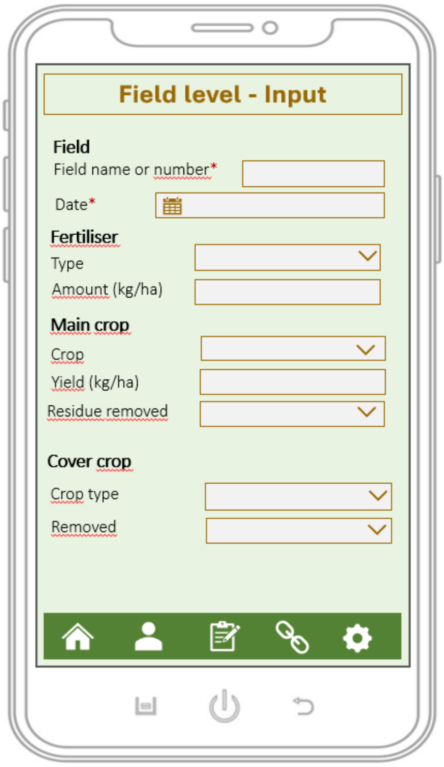

Figure 7. Different carbon input sources on field level.

The output level allows the calculation of the organic matter degradation. A default rate can be chosen based on the soil type, but another rate can be indicated when a farmer has more insight in this. The final screen subtracts the output from the input, thus calculating the organic matter balance on field level. All input is calculated as the effective organic matter input, which is the organic matter that is still present in a soil one year after application.

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Farm level
The organic matter balance on farm level is calculated in a similar way but combines the activities on all the fields. This includes the different input sources, such as the crop residues, fertilizer type and the possible cover crop that was grown. Figure 8 gives an indication on what the input of a cover crop on a specific field might look like. After adding all the inputs, a degradation rate can be indicated. After subtracting both numbers, the organic matter balance on farm level is calculated.

At present, in some countries more elaborate DST for soil organic matter are available of being developed. These tools may be based on dynamic SOC-models such as the ROTHC model, and/or include other ecosystem services, e.g. the Cool Farm Tool (Cool Farm Tool, https://coolfarm.org/).

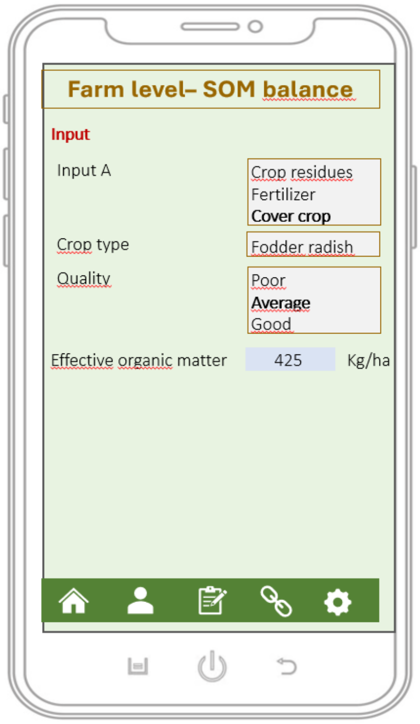

Figure 8. Soil organic matter input on farm level.

3.5 Towards a web portal to support Soil Health within Living labs

During the course of PRAC2LIV, the scope of the project transgressed from a focus on single stand-alone DSTs (on nutrient use efficiency, soil organic matter and moisture retention) to a focus on the development of DSTs for soil health in living labs. Single stand-alone apps may possibly remain very useful for farmers, in particular for nutrient use efficiency (EU-project NutriCheck (https://nutri-checknet.eu/). In view of the proposed Green Deal, Soil Mission, Climate Change, Regionalisation, and other policies initiatives, the development of web portals with several apps may be favoured. These are certainly the more complex, in particular if outcomes of the apps are required at various scale levels, e.g. field, farm, living lab or catchment. Current and expected initiatives for discussing the design of a web portal for next generation tools include those initiated by the Mission Board on Soil Health and Food, e.g., lighthouse farms and PREPSOIL, as well as EUSO and the FaST digital service platform.

The uptake of soil management measures to sustain food production and safeguard and/or improve ecosystem services such as moisture retention capacity of the soil, nutrient management, soil organic matter, carbon sequestration and biodiversity will remain on the agenda in the coming

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decades. Natural boundaries and social interactions have put a focus on stakeholder communities at regional level. Taking living labs as an example, the development of a web portal for soil health in living labs could support cooperation and reaching targets.

The web portal would allow the performing a series of functions (e.g. registration, monitoring, planning) in an intuitive and effective way. It could comprise both agricultural production and environmental services. Such web portals may thus have a major impact on promoting soil health and supporting agricultural and environmental decision-making on the above-mentioned topics. Consulting with target groups about their potential uses is an important first step. This could involve:

- Farmers and their advisors: obtain recommendation, registration, planning, learning
- Regional government (city/province) and NGOs: monitoring, policy development and implementation'; education, facilitation
- Living lab communities: regional ambitions and boundaries
- National government: policy development and implementation
- EU: policy development and implementation, research
- A methodology for participatory approach could be used such as the one in PRAC2LIV, with a moderator from the socio-economic sciences or with ecological/agricultural background.

Next steps require IT-expertise to develop the architecture of the web portal, identifying its layers and interactions. It is advisable to invest in a "functional design" of a web portal and dashboard, including architecture, criteria, specifications, and design considerations. This design can serve as a blueprint for technical design and elaboration of a wide range of dashboards depending on regional requirements. Alternatively, integration of parts of the functional design with existing web portals could be an option. In general, elements to consider are:

- Participatory approach from beginning, testing to end-result
- End result with high user friendliness, 'foolproof', help function
- Flexible design, to allow for a large variation in agro-ecological systems and goals
- Multi-purpose, meeting stakeholders needs, commitment, and acceptance

Business Models for DSTs

Business models for developing web portals or Decision Support Tools (DSTs) for agriculture require careful consideration. Good service and continuous development are essential for the successful uptake and use of DSTs. These tools must be maintained, user support needs to be provided, and new features must be added to meet evolving user needs. The key question is, what are the optimal business models for ensuring good service and continuous development?

DSTs are often developed by universities, research institutes, and the private sector, with end-users sometimes included in the development process. Academia has a strong knowledge foundation for developing these tools, but long-term maintenance and development may be limited by the interests and capabilities of individual researchers or research groups, and there is often no long-term funding for these purposes. In project-oriented organizations, sustaining long-term commitment can be challenging. The private sector may have a long-term commitment through financial incentives, but they may lack the necessary knowledge and data base for developing DSTs. End-users, in turn, have the best understanding of day-to-day farming activities and the specific needs DSTs should address.

Depending on the type of tool and whether it is part of a regulatory system, different business models may be appropriate. A potentially fruitful business model could involve collaboration among academia, the private sector, and end-users. In this model, academia provides the knowledge base during the development phase, end-users ensure the tools support day-to-day decision-making, and the private sector handles the long-term maintenance and development of DSTs as a business activity. Such business models could be established through tailored EU funding calls that engage academia, farmers or Living Labs, and private companies or startups in equal collaboration. Ideally, such collaboration could advance the development of an industry towards a wider variety and better quality of DSTs.

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4. Conclusions

The exploration of DSTs included a diverse range of methods, including literature review, surveys, stakeholder consultations, mock-ups, and visualizations, creating an integrative, participatory, and user-centred research approach. The AI-assisted synthesis of findings proved to be highly effective in generating data-driven conclusions and recommendations from these varied research methods. The results underscored the crucial role that DSTs can play in advancing agricultural practices toward greater sustainability. However, they also revealed significant gaps and challenges that need to be addressed to fully utilize the potential of DSTs in enhancing soil management across Europe.

One key conclusion is the recognition that while DSTs have been developed to address specific agricultural needs, their current scope is often too narrow, focusing primarily on productivity or a single purpose rather than encompassing the full range of soil functions, such as carbon sequestration, water retention, and nutrient cycling. This narrow focus limits the ability of DSTs to contribute to broader environmental and social goals, which are increasingly important in the context of European agricultural and environmental policies.

To overcome this limitation, a shift toward more integrated, multi-functional DSTs is essential. These tools must be designed not only to optimize agricultural outputs but also to support the sustainability of the entire agro-ecosystem. This will require a more holistic approach to DST development, one that incorporates diverse soil functions and actively engages stakeholders throughout the design process. By doing so, DSTs can become powerful instruments for achieving the dual goals of productivity and sustainability.

The report's stocktake of existing DSTs across Europe reveals a landscape marked by diversity in tool types, technologies, and user adoption. The largest share of reported tools focused on nutrient use efficiency, but many tools were also reported for soil organic matter and water retention management. While some tools have seen moderate uptake, there is a clear need for improvement, particularly in areas such as user-friendliness, data integration, and adaptability to different scales of operation. The findings suggest that for DSTs to be more widely adopted, they must be more aligned with the practical realities and constraints faced by farmers and other end-users, including better coverage of different types of farming systems. Additionally, DSTs need to be accessible, cost-effective, and supported by robust technical assistance.

The stakeholder exchanges conducted as part of this study further underscore the importance of a user-centered approach to DST development and the consideration of local conditions in DST functionality. Barriers to adoption, such as technical complexity and resistance to change, must be addressed through targeted interventions. These could include providing technical support and designing tools that are intuitive and easy to use. The active involvement of end-users in the co-creation of DSTs will be crucial in ensuring that these tools meet their needs and gain their trust. The findings from the stakeholder exchanges aligned well with the findings from the stocktake.

The development of mock-up designs for DSTs serves as a practical demonstration of how future tools can be both scientifically sound and user-friendly. These prototypes show that it is possible to create tools that are not only effective in optimizing soil management practices but also adaptable to the diverse conditions and challenges faced by farmers across Europe. Additionally, the novel pictorial visualization method proved valuable for discussing and exchanging information around DSTs and soil health. At a higher level, the visualization method was useful for generating new directions for programs such as EJP SOIL, including important topics that could be (re)evaluated. Together, mock-up designs and pictorial visualization methods offer a fruitful approach for engaging end-users and stakeholders in the development of DSTs and aligning research efforts.

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Moreover, the concept of a web portal for Soil Health represents a forward-thinking approach to DST integration. By creating a platform that brings together multiple tools and resources, this web portal could serve as a comprehensive solution for managing soil health at various scales, from individual fields to broader regional landscapes. This approach aligns with European policy initiatives such as the Green Deal and the Soil Mission, which call for innovative tools that can address multiple dimensions of soil health and sustainability.

To actualize the significant opportunities provided by DSTs, a series of specific recommendations have been proposed to enhance both the adoption and effectiveness of DSTs, as well as the development of a European web portal (Section 5). These recommendations address key areas such as tool development, usability, functionality, adaptability to diverse regional conditions, integration of soil health and economic indicators, data integration, and interoperability with existing systems. They also emphasize continuous evaluation and improvement, as well as alignment with policy and regulatory frameworks. By summarizing the report's findings, these recommendations offer clear and practical guidance for advancing DSTs that simultaneously meet the practical needs of users and broader societal sustainability goals.

In conclusion, the future of DSTs in European agriculture lies in their ability to evolve beyond simple productivity tools to become integral components of a sustainable farming system. This evolution will require a concerted effort from all stakeholders—researchers, policymakers, farmers, and technology developers—to collaborate in the design and implementation of tools that are both scientifically robust and practically applicable. By addressing the challenges identified in this report and building on the opportunities presented by emerging technologies and policies, DSTs can play a transformative role in achieving sustainable soil management and advancing the broader goals of environmental sustainability and agricultural resilience in Europe.

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5. Recommendations

The work presented here offers a broad understanding of the current use, challenges, and potential of DSTs in enhancing agricultural practices and sustainable soil management. Building on these insights, specific recommendations were formulated to guide the development, increased adoption, and effectiveness of DSTs, as well as the creation of a European web portal for Soil Health. These recommendations are presented in in Table 21 and Table 22.

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Table 21. Recommendations for enhancing the adoption and effectiveness of DSTs in promoting sustainable soil management practices across Europe.

Recommendations for DSTs		
Existing DST effectiveness	***Improve data integration and accessibility***	Ensure that DSTs incorporate accurate, use case- and region-specific data inputs, such as soil characteristics, climate conditions, and crop history. Enhance the accessibility of these tools by developing user-friendly interfaces that allow seamless integration of various data sources, including real-time sensor data.
	Increase usability and flexibility	Simplify the user interfaces of DSTs to make them more accessible to a wider range of users, including those with limited technical expertise. Develop tools that are flexible and adaptable to different farming systems, regions, and spatial and temporal scales, allowing users to customize the tools according to their specific needs and conditions.
	Monitor and evaluate DST performance	Establish monitoring and evaluation frameworks to assess the effectiveness of DSTs in improving soil management practices. Use these evaluations to identify areas for improvement and to guide future development efforts, ensuring that DSTs remain relevant and effective in addressing emerging challenges in agriculture.
DST improvement	***Include soil health and economic indicators***	Incorporate indicators that align with both soil health and economic objectives, providing measurable targets to assess the impact of farming decisions. These indicators promote a more holistic approach, encouraging practices that support both sustainable soil management and economic viability.
	Explore new technologies and guarantee continuous improvement	Promote the continuous development and improvement of DSTs by integrating the latest scientific research and technological advancements. Encourage innovation through research collaborations, pilot projects, and the exploration of new technologies, such as artificial intelligence and remote sensing, to enhance the capabilities of DSTs to meet the needs of users.
	Focus on multi-functional and integrated tools	Develop DSTs that support multiple soil functions simultaneously, such as soil organic matter, water retention, and nutrient efficiency, while considering crop yield and economic outcomes. This integrated approach will help address the broader goals of sustainable soil management and align with European policy initiatives like the Green Deal and Soil Mission, while considering the user goals.
Participatory approach on DST use and development	***Promote knowledge exchange and capacity building***	Create platforms that emphasize knowledge exchange rather than simply delivering information. Facilitate the sharing of best practices, case studies, and success stories to demonstrate the effectiveness of DSTs in improving soil management. Provide training and support to build the capacity of farmers and advisors to effectively use these tools.
	Enhance user engagement and co-creation	Actively involve end-users, including farmers and advisors, in the design and development process of DSTs. This will ensure tools to meet the practical user' needs and enhance adoption rates. Engage stakeholders through participatory methods, such as workshops, focus groups, and co-design of DST mock-up's, to capture diverse perspectives and tailor DSTs to local conditions.
EU policy	***Align with policy and regulatory frameworks***	Ensure that DSTs are aligned with national and European policy frameworks, such as the Common Agricultural Policy (CAP) and the EU Soil Strategy. This alignment will encourage the adoption of DSTs by demonstrating their relevance to achieving policy goals and compliance with regulations.
	Foster collaboration and cross-border integration	Encourage cross-border collaboration among EU and EJP SOIL Member States to share knowledge, tools, and best practices related to DSTs. Develop standardized frameworks that allow for the adaptation and use of DSTs across different regions, considering the specific pedo-climatic conditions of each area.

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Table 22. Recommendations to create a comprehensive, user-friendly, and effective DST-based web portal that empowers users to manage soil health sustainably and efficiently across diverse agricultural landscapes in Europe.

Recommendations for web portal on DSTs		
Participatory approach on web portal on DST development and use	***Use a participatory approach***	Ambitions and options on the web portal to be discussed with stakeholders, favoring exchanges to set common goals and restrictions
	Functional design, an architecture	Web portal design should encompass the levels of available knowledge and their interactions, to be enough flexible allowing further adaptation and extension
	Customizable user dashboards	Implement customizable dashboards that allow users to select and display the most relevant tools and data for their specific needs. This feature should enable users to integrate various data sources, visualize trends, and monitor soil health indicators in real-time.
User-friendly and interoperable interface	***Centralized access to diverse tools***	Create a web portal that serves as a centralized hub where users can access a wide range of DSTs tailored to different aspects of soil health (e.g., SOM, water retention, nutrient efficiency). Ensure the portal provides easy navigation and categorization based on user needs, such as crop type, climate zone, or specific soil issues.
	Interoperability with existing systems	Ensure the portal is interoperable with existing farm management systems, databases, and other digital tools. This will allow users to import and export data seamlessly, enhancing the utility of the portal within the broader ecosystem of agricultural technology
	Scalable solutions for different users	Design the web portal to accommodate a wide range of users, from smallholder farmers to large agribusinesses. Provide scalable solutions that can address the needs of users at different operational scales, whether they manage small plots or extensive agricultural enterprises
	Interactive decision-making tools	Incorporate interactive tools that allow users to simulate different soil management scenarios and visualize potential outcomes. These tools should provide actionable insights and recommendations based on the specific conditions of the user's farm or region
	Real-time data integration	Enable the portal to integrate real-time data feeds from sensors, weather stations, and remote sensing technologies. This feature will allow users to make informed decisions based on the latest available data, improving the accuracy of soil health assessments
	User support and community forums	Provide robust user support through FAQs, helpdesks, and live chat options. Additionally, create community forums where users can share experiences, ask questions, and collaborate on soil health management strategies
Data ownership and security	***Data privacy and security***	Ensure that the web portal includes strong data privacy and security measures to protect users' information. Provide clear guidelines on data ownership, use, and sharing to build trust among users
Customization and user exploitation	***Regional customization and localization***	Include features that allow the portal to be customized for different regions, incorporating local soil data, climate conditions, and agricultural practices. This localization will ensure that recommendations and tools are relevant to the specific challenges faced by users in different parts of Europe
	Educational resources and best practices	Integrate a comprehensive library of educational materials, including tutorials, case studies, and best practice guides. This resource should support users in understanding how to effectively use DSTs and apply them to improve soil health
	Continuous feedback and improvement loop	Establish a system for continuous feedback from users to regularly update and improve the portal. This loop should include periodic user surveys, beta testing of new features, and an open channel for users to suggest improvements
	Integration with policy and regulatory frameworks	Embed functionalities that help users understand and comply with relevant agricultural policies and regulations. The portal should provide updates on regulatory changes and offer tools to assess the impact of different soil management practices on compliance

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Table 23. The national coordinators of EJP SOIL and experts who responded to the questionnaire on DSTs.

Country	National coordinators of EJP SOIL and experts
Norway	Atilla Haugen, André Skoog Bondevik, Ylva Freed, Jan Eivind Kvam Andersen, Arne Kepp, Jon Mjærum, Maud Grøtta
Estonia	Alar Astover
UK	Dr Suzanne Higgins
Austria	Rebecca Hood-Nowotny
Belgium	HUYGHEBAERT
Denmark	Lars J. Munkholm
Belgium	Greet Ruysschaert, Paul Pardon, Tom De Swaef, Karoline D'Haene, Adriaan Vanderhasselt
France	Pierre Benoit
Hungary	Zsófia Bakacsi
Ireland	David Wall
Italy	Maria Fantappiè, Giovanni L'Abate, Lorenzo d'Avino
Lithuania	Žydrė Kadžiulienė
Slovakia	Jaroslava Sobocká
Portugal	Maria da Conceição Gonçalves and Nádia Castanheira
Sweden	Sofia Delin
Switzerland	Klaus Jarosch
Türkiye	Sevinc Madenoglu
Finland	Elina Nurmi, Johanna Leppälä, Tapio Salo, Risto Uusitalo
Netherlands	Anna Besse-Lototskaya

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Annex 1. Stocktake and evaluation

Table A1.1 Questions in the questionnaire for national coordinator of EJP SOIL.

Topic	Question
Respondents and a definition of DST	1. Name
	2. Country and institution
	3. Would you agree with this definition for DSTs: "DSTs are digital tools that farmers, advisors and/or policymakers can use to monitor and/or make decisions addressing soil organic matter, water retention or nutrient efficiency. Tools can be software, apps, web portals or on other digital supports. The tool would typically require some data about the soil, crop, field history and weather and then use an evidence-based algorithm to calculate an output. The output could be an analysis of the effect of current or improved soil, water, and nutrient management practices at different scales (e.g., field, farm, regional, national)"?
Use and Users of DSTs	4. What type of decisions can be facilitated by using DST: A. Farm B. Advisory C. Regional D. Policy E. Other level
	5. What is/are the most used DSTs in your country on soil water availability and retention?
	6. What is/are the most used DSTs in your country on soil organic carbon?
	7. What is/are most used DST in your country on soil nutrient use efficiency?
	8. Who are the major users of the main DSTs in your country (same DSTs as indicated in question 5, 6 and 7): A. Farmers B. Researchers C. Agronomist/consultants D. Private companies/non-governmental organizations E. Monitoring policy makers?
Assessment of DSTs	9. How would YOU rate from 1 to 5 the DST you indicated in questions 5, 6 and 7 in terms of: A. Adoption by end-user B. Is the use of the tool optional C. Data input D. User friendly interface E. Perceived reliability of the DST F. Cost of the DST G. The tool has been developed with participatory research/co-innovation H. Suitable to reach national goals I. Suitable to reach regional goals J. Suitable to reach farmers goals
Improvement of DSTs	10. How could the specific DSTs you indicated in question 5,6 and 7 as main DSTs be improved?
	11. Which type of tools are now not available but are needed and/or planned to be developed for: A. Soil organic matter B. Nutrient use efficiency C. Water retention
Factors related to the use of DSTs	12. What are the factors determining the use of DSTs in your country: A. farmer education is a critical factor in determining the use of DSTs by farmers B. members of farmers 'associations and cooperatives tend to use DSTs more than individual farmers C. Crop farmers tend to use DSTs more than livestock farmers D. DSTs are used by living labs E. digital illiteracy is among the main factors hampering the use of DSTs F. E. organic and biodynamic farmers tend to use DSTs more than conventional farmers
Additional aspects on the use and improvement of DSTs	13. In your opinion, what additional aspects – that we did not mention -should be considered concerning the use and the improvement of DST related to: A. Soil water retention B. Soil organic carbon C. Nutrient use efficiency?

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Table A1.2. Questions in the questionnaire for stakeholders.

Topic	Questions
Responder details	1.1. What is your age: A. 18-25 B. 26-35 C. 36-45 D. 46-55 E. 56-65 F. >65 A.
	1.2. What gender do you identify as A. Male B. Female C. Other
	1.3. What is the highest degree or level of education you have completed A. Junior high school B. Senior high school C. University degree D. PhD or higher
	1.4. Are you a A. Farmer B. Researcher C. Consultant/Agronomist D. Employee of a private company working in agriculture or food production E. Employee of a farmer's cooperative F. Other
	1.5. If you are a farmer how many hectares do you manage A. <10 B. 5-10 C. 10-20 D. 20-50 E. 50-100 F. 100-150 G. >200
	1.6. If you are a farmer, how much time are you busy with farming A. Full-time B. Part-time C. Only weekends
	1.7. If you are a farmer, do you own or rent your land A. I own all or the most of the land that I farm B. I rent all or most of the land that I farm
	1.8. What type of crops do you usually grow A. Cereals B. Maize C. Legumes D. Vegetables E. Fruits F. Olives for olive oil G. Oilseed crops H. Grapes for wine I. Forage ley J. Pasture K. Root crops (e.g. potatoes, sugar beet) L. Other
	1.9. Do you raise livestock? A. Yes B. No
	1.10. Do you consider yourself a A. Livestock farmer B. Crop farmer
	1.11. How do you manage your farm? A. Conventional agriculture B. Agro ecological approach – not certified C. Organic certified D. Biodynamic E. Other (please specify)
Farming challenges	2. What do you think are the most important soil related challenges of the local agriculture? A. Soil erosion

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	B. Low soil organic matter or soil organic matter depletion C. Low nutrient use efficiency (fertilizers are applied but crops have low response) D. Soil water management E. Soil compaction F. Others (please specify)
Farming and DSTs	3. Are you familiar with decision support tools (DST) or systems? A. Yes, I use them regularly B. Yes, I have used them in the past C. Yes, I know what they are but I have never used one D. No, never heard before
	4. Do you agree with the following statements? A. I do not trust DSTs results B. I do not think DSTs are useful C. DSTs are usually too complex D. I do not have devices to use DSTs E. DSTs require too many data that I cannot provide F. Working with DSTs is time consuming and not so helpful
	5. If you are familiar with DSTs, how would you define what a DST is?
	6. Are there other features of a DST that we did not mention, and you believe are important?
	7. If you use DSTs, how would you rank from 1 to 5 the most important features of a DST (where 1 is the most important, 2 the second most important etc.)? A. Do not require too many data from my hand B. User-friendly interface C. Clear visualization of results D. Trust/confidence in the results (based on scientific publications or on-farm calibration) E. Easy to access both in terms of costs and hardware requirement F. The design of the DST has been carried out in collaboration with end-users G. DST provide outcomes which are easy applicable and in real time (when I need info to manage the crop and not too late)
	8. How do you make decisions concerning nutrient management? Please, list here what tools, data sources, platforms, sensors, remote sensing, etc. are used concerning nutrient management and nutrient use efficiency. (For example, soil nutrient status, fertilizer recommendation, predicting nutrient release from mineralization, predicting crop residues from harvesting, estimating crop production, exploring the effect of cover crop on soil nutrient status etc.)
	9. How do you make decisions concerning water management? Please list here what tools, data sources, platforms, etc. are used concerning water management. (For example: How you get information about rootzone soil moisture, water depletion, maximum allowable depletion, field capacity, irrigation needs, infiltration capacity etc.)
	10. How do you make decisions concerning management that affect soil organic matter? Please, list here what tools, data sources, platforms, sensors, remote sensing, etc. are used concerning soil organic matter management. (For example, initial soil organic matter level, exploring practices to improve soil organic matter, recommendation of organic fertilizers and soil amendments, exploring practices related to crop residue management, exploring the effect of cover cropping on soil organic matter, exploring the effect of different crop rotations on soil organic matter etc.)
Use	11. Please provide some information about up to three tools that you use for: A. Nutrient management B. Water management C. Organic matter management
Assessment	12. Please rate the DST you just mentioned in terms of A. Data input B. User friendly interface C. Reliability of the results D. Cost of the DST E. The tool has been developed in collaboration with end-users (e.g. farmers) F. Helpful to reach my goals
Other aspects	13. Are there other aspects concerning DST that you want to share?

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Table A1.3. Questionnaire to national coordinators of EJP SOIL. Question 2: Country and institution?

Country	Institution
Austria	The University of Natural Resources and Life Sciences (BOKU)
Belgium (Flanders and Walloon)	Flanders Research Institute for Agriculture, Fisheries and Food (ILVO), The Walloon Agricultural Research Center (CRA-W)
Denmark	Aarhus University (AU)
Estonia	Estonian University of Life Sciences (EMU)
Finland	Natural Resources Institute Finland (LUKE)
France	National Research Institute for Agriculture, Food and Environment (INRAE)
Hungary	Institute for Soil Sciences (ATK TAKI)
Ireland	Agriculture and Food Development Authority (TEAGASC)
Italy	Council for Agricultural Research and Economics (CREA)
Lithuania	Lithuanian Research Centre for Agriculture and Forestry (LAMMC)
Netherlands	Wageningen University and Research (WUR)
Norway	Biodrone, Agdir Drift, Eurofins, Yara, Jordplan, The Norwegian Agricultural Extension Office (NLR)
Portugal	The National Institute of Agricultural and Veterinary Research, IP (INIAV)
Slovakia	The National Agricultural and Food Centre (NPPC)
Sweden	Swedish University of Agricultural Sciences (SLU)
Switzerland	Agroscope (AGS)
Türkiye	General Directorate of Agricultural Research and Policies, Ministry of Agriculture and Forestry (TAGEM)
United Kingdom	Agri Food & Biosciences Institute (AFBI)

Table A1.4. Questionnaire to national coordinators of EJP SOIL. Question 4: What type of decisions can be facilitated by using DST?

No.	***Country***	***Farm level***	***Advisory level***	***Regional level***	***Policy level***	***Others***
1	Austria	X				
2	Belgium, Flanders	X	X	X	X	Field level
3	Belgium, Walloon	X	X	X	X	
4	Denmark	X	X			
5	Estonia	-	-	-	-	-
6	Finland	X	X		X	
7	France	X	X	X	X	
8	Hungary	X	X	X	X	
9	Ireland	X	X	X	X	
10	Italy	-	-	-	-	-
11	Lithuania	X	x			
12	Norway	X	X	X	X	
13	Portugal	X	X	X		
14	Slovakia	X	X	X	X	
15	Sweden	X	X			
16	Switzerland	X	X			
17	Türkiye	X	X	X	X	National
18	United Kingdom	X	X		X	

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Table A1.5. Questionnaire to national coordinators of EJP SOIL. Further details given to Question 4: What type of decisions can be facilitated by using DST?

Farm level	Advisory level	Regional level	Policy level
DST are primarily useful for farmers to help them better manage their soils, with the aim of improving yields and the economic profitability of the farm.	Secondly, DST help advisers. They enable them to validate, objectify and make more reliable and trustable their advice to farmers in technical, economic and environmental terms.	DST can help to gather and synthesise information at regional level so that agricultural policies can be developed in line with society's expectations.	Based on the results of the DST, policy makers can develop agricultural policies in line with society's expectations
Nutrient use/balance, soil compaction risks, field mapping	Nutrient use/balance, soil compaction risks, field mapping	Nutrient inputs, Water Recharge, Soil Organic Matter	Regulation and environmental support
Nutrient inputs, Soil Organic Matter	Nutrient inputs, Water Recharge, Soil Organic Matter	Economic, Soil Organic Matter, Water Management	Nutrient inputs, Water Recharge, Soil Organic Matter
Nutrient inputs, Soil Organic Matter, Water Management, Farm management	Nutrient management, Soil Organic Matter, Water Management	Nutrient inputs, Water Recharge, Soil Organic Matter	Economic, Soil Organic Matter, Water Management
Nutrient inputs, Soil Organic Matter	Nutrient inputs, Water Recharge, Soil Organic Matter	water conveyance efficiency, water application efficiency	Nutrient inputs, Water Recharge, Soil Organic Matter
Irrigation scheduling. Estimation of soil properties (organic matter, nitrogen, phosphorus, potassium, and pH H_2O)	Irrigation scheduling	Harmonized Reg. & Int. System	Soil Portal
Calculator for nutrients, Fertilization schedule	Soil Portal	Harmonized Reg. & Int. System	Compliance with nitrate vulnerable zones
Nutrient inputs, fertiliser limits	Nutrient inputs, Nutrient use efficiency		
Nutrient management, SOM preservation and build-up, reduction of soil erosion	Nutrient management, SOM preservation and build-up, reduction of soil erosion		

Table A1.6 Questionnaire to national coordinators of EJP SOIL. Who are the major users of the main DSTs in your county (same DSTs as indicated in question 5, 6 and 7)?

Country	DST	Farmers	Researchers	Agronomist/ Consultants/ Advisors	Private companies/ NGO's	Monitoring policy makers
Austria	terrazo	X		X	X	
	Austrian Carbon calculator		X			
	ÖDüPlan Plus	X	X	X	X	
	eo4water		X	X	X	X
Belgium (Flanders)	Demetertool	X	X	X		
	C-slim	X		X		
	CARAT	X	X	X		X
	WatchitGrow	X	X	X		
	Waterradar	X	X	X		X
	SWAP-WOFOST		X			X
	NEMO					X
Belgium (Walloon)	REQUAFERTI			X		
	FaST	X		X		
	BELCAM	X	X	X		
	DECIDE		X	X		X
	Cool Farm Tool			X	X	
	Geofolia	X		X		
	CAP'2ER		X	X		X
Denmark	Vandingsregnskab Online	X		X		
	ESGreenTool Climate	X		X		
	Crop Manager	X				
	MarkOnlie			X		
Estonia	Humus balance calculator	X	X	X	X	X

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	NPK balance calculator	X	X	X	X	X
Finland	Soil scout sensors	X	X	X		
	Nutrient balance calculations	X	X	X		X
	Phosphorus planning tool	X	X	X		
	Nitrogen balance calculator	X	X	X		
	ProAgria WISU	X		X		
	PeltotukiPro	X		X		
	Agrineuvos	X		X		
	Nutrient balance calculator		X	X	X	X
	Eurofins Soil NIR	X		X		
	Biomassa-atlas		X	X	X	X
	Field observatory org	X	X			
	Viljelykiertolaskuri	X		X		
France	AMG / Simeos-AMG	X	X	X	X	
	ABC Terre			X		X
	Syst'N		X	X	X	
	Azofert			X	X	
	MAELIA		X	X	X	X
Hungary	PROPLANTA	X	X	X	X	
Ireland	Carbon Navigator	X	X	X	X	X
	NMP On-line	X	X	X	X	X
	Pasturebase Irl & Grass10	X	X	X		
	AgNAV	X	X	X		X
Italy	vite.net			X		
	granoduro.net			X		
	Elaisian			X		
Lithuania	Digital N-fertilization with sensors	X		X		
	Nitrogen fertilization mapping.	X			X	
Norway	Agdir Farm	X	X	X	X	
	Pix4dFields	X		X		
	Biodrone	X		X		
	Jordplan	X		X	X	
	CropPlan	X				
	Agrilogg	X				
	Klimakalkulatoren	X	X	X		X
	Calculating water balance	X	X	X	X	
Portugal	IrrigaSys	X	X	X		
	VirtuaCrop	X	X	X		
	Irristrat	X	X	X		
	OneSoil	X	X			
	MOGRA	X	X	X		
	Calendario de Rega	X	X	X		
	Avisos Rega Projeto PARE	X	X	X		
	Fertil	X	X	X		
	WiseCrop	X	X	X		
	Calculator for nutrients	X		X	X	
	Harmonized Reg. & Inf. System	X		X	X	
	Partial Soil Monitoring		X		X	X
	Fertilization schedule	X		X		
	Animal Storage Capacity	X		X		
Sweden	Raindancer	X				
	Soil Moisture Sensor	X				
	PT Soil Station service	X				
	Hur mår min jord? (How is my soil doing?)	X	X	X		
	CropSat	X	X	X	X	
	Yara N-sensor	X				
	Winter oilseed rape nitrogen estimator	X		X		
	Gödselkalkylen	X		X		

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	Vera			X		
	Växtnäringsbalans på nätet (nutrient balance, web based)	X				
	Yara Växtnäringsberäkning (Yara palnt nutrient calculator)	X			X	
	Enkel fosforbalans	X				
Switzerland	Humusbilanzrechner	X	X	X		
Türkiye	TAGEM suET	X	X	X	X	X
	TAGEM Soil Fertilizer Information System (under construction)	X	X	X	X	X
UK	PLANET	X		X		
	MANNER	X		X		
	Gatekeeper - Farmplan	X				
	Farm Crap App Pro	X		X		

Table A1.7. Questionnaire to national coordinators of EJP SOIL: The rating of individual DSTs.

DST	Adoption by end-user	Is the use of the tool optional?	Data input	User friendly interface	Perceived reliability of the DST	Cost of the DST	The tool has been developed with participatory research/co-innovation	Suitable to reach national goals	Suitable to reach regional goals	Suitable to reach farmers goals
	1= little or no use 5= widely	1= Yes 2= No	1= few data needed 5=many data needed	1= too complex for users 5= very user friendly	1= low reliability; 5= very high reliability	1= Free of charge 5=Very expensive	1= no users involvement in the design; 5=user-centred design	1= not suitable 5= very suitable	1= not suitable 5= very suitable	1= not suitable 5= very suitable
Terazo	2	1	3	2	3	1	5	5	5	5
ÖDüPlan Plus	3	1	3			2	4	4	4	5
Austrian Carbon calculator	1	1								
Demetertool	1	1	3	4	3	1		1	2	3
C-slim		1	3	4	3	1		1	2	3
CARAT	1	1	3	3	3	1	4	1	1	4
WatchitGrow	3	1	2	3	3	1	4	2	2	4
Watarradar	3	1	1	4	4	1	4	2	2	3
SwAP-WOFOST	2	1	5	1	2	1	1	2	2	2
NEMO	4	1	4		4	1	5	5	5	1
REQUAFERTI	5	1	3	5	5	1	5		5	5
FaST		1	3	5		1	4	5	5	5
BELCAM	3	1	1	4	4	1	4			5
Geofolia	1	1		3		4				5
DECIDE	4	1	4	3	3	1	5		3	5
Cool Farm Tool	4	1	4		3					5
CAP'2ER	4	1	4	3	3	5				5
Vandingsregnskab Online	3	1	2	4	5	2		5	5	5
ESGreenTool Climate	2	1	2	4	5	3		3	3	4
Crop Manager	3	1	2	3	5	2		5	5	5
MarkOnline	5	1	5	5	5	3		5	5	5
Humus balance calculator	1	1	3	2	2	1	2	1	1	2
NPK balance calculator	1	1	3	3	4	1	2	2	2	4
Fertilizer requirement map	2	1	2	3	3	1	2	2	2	3
Soil scout sensors	2	1	1	3	4	3	4	3	3	4
Nutrient balance calculations	2	1	4	3	3	2	3	4	3	4
Phosphorus planning tool	3	1	2	4	4	1	4	5	5	5
Nitrogen balance calculator	2	1	3	2	3	1	3	4	4	4

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ProAgria WISU	4	1	4	4	4	3	5	5	5	5
PeltotukiPro	4	1	4	4	4	3	5	5	5	5
Agrineuvos	4	1	4	4	4	3	5	5	5	5
Nutrient balance calculator	3	1	1	3	4	1	4	5	5	2
Biomassa-atlas	3	1	1	3	4	1	4	4	4	2
Soil scout		1	1	4	4	5	3	1	1	3
Field observatory		1	1	4	4	1	4	2	2	3
Viljelykiertolaskuri		1	4	4	3	1	4	2	2	5
AMG (Simeos-AMG)	4	1	2	5	4	3	4	4	4	4
SYST'N	3	1	3	4	3	1	4	3	3	4
ABC Terre		1	2	3	4	4	3	4	4	2
Azofert	4	1	2	4	4	3	2	4	4	4
MAELIA	4	1	4	2	4	1	3	4	4	4
PROPLANTA	3	1	4	2	5	3	1	1	1	5
Carbon Navigator	4	1	3	3	4	2	3	4	4	3
NMP On-line	5	1	3	3	5	2	3	5	5	4
Pasturebase Irl & Grass10	3	1	2	5	4	1	4	3	3	5
AgNAV	2	1	2	3	4	2	2	5	5	4
Digital N-fertilization with sensors	3			3				4		4
Apply nitrogen fertilizer in various proportions	3			3				4		4
Nitrogen fertilization mapping	3			3				4		4
Klimakalkulator	2	1	5	3	4	3	4	5	2	3
Beregning av vannbalansen	3	1	2	5	4	1	2	2	2	5
Jordplan	3	1	3	4	5	2	5	3	3	3
CropPlan	1	1	3	3	4	5	5	2	2	4
Agrilogg*	3	1	1	3	4	3	5	1	1	2
Eurofins Soil Carbon Check	2	1	2	4	5	2	3	5	5	5
Agdir Farm	2	1	3	4	3	2	3	5	5	5
Biodrone	1	1	3	4	4	4	4	3	3	3
Pix4dFields	2	1	3	5	4	2	4	5	3	3
IrrigaSys	3	1	1	5	4	1	5	5	5	5
VirtuaCrop	5	1	3	5	3	2	5	1	2	5
Irristrat	5	1	3	3	3	4	1	3	3	3
Avisos Rega Projeto PARE	1	1	5	3	4	1	1	1	1	3
MOGRA	1	1	3	3	4	2	3	2	4	4
Calendario de Rega	4	1	2	5	5	2	5	3	5	5
Avisos Rega Projeto PARE	5	1	2	5	4	1	3	3	5	5
Calculator for nutrients	5	1	1	3	4	1	1	5	5	5
Partial Soil Monitoring	2	1	1	5	3	1	1	3	3	3
Fertilization schedule	5	1	1	5	3	1	2	5	5	5
Animal Storage Capacity	5	5	5	5	3	1	2	5	5	5
Raindancer		1								5
Soil Moisture Sensor		1								5
PT Soil Station service		1								5
Hur mår min jord? (How is my soil doing?)	3	1	2	4	4	1	4	4	4	4
CropSat	4	1	1	4	3	1	3	4	4	4
Atfarm	3	1	2	5	4	2	2	3	3	4
Yara N-sensor	3	1	2	3	4	5	2	4	4	5
Svensk raps Winter oilseed rape nitrogen estimator	4	1	1	5	4	1	3	5	5	5
GREPPA Winter oilseed rape nitrogen estimator	2	1	1	4	4	1	2	3	3	4
Gödselkalkylen	4	1	1	4	4	1	4	5	5	5
Vera (Nutrient balance)	5	1	4	4	3	1	3	5	5	4
GREPPA Växtnäringsbalans på nätet (nutrient balance, web based)	5	1	4	4	4	1	2	5	5	4
Yara Växtnäringsberäkning (Yara plant nutrient calculator)	4	1	3	5	4	1	2	3	3	5
Yara Checkit	4	1	1	4	5	1	2	3	3	5
Enkel fosforbalans (simple P balance, organic farms)	3	1	4	4	4	1	3	5	5	5

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Humusbilanzrechner	3	1	2	3	2	1	3	2	2	2
TAGEM suET	5	1	2	4	5	1	5	5	5	5
TAGEM Soil Fertilizer and Water Resources Central Research Institute national Soil InformationSystem (under construction)	2	1	2	3	5	1	1	5	5	5
PLANET	5	1	4	5	5	1	5	5	5	5
MANNER	5	1	4	5	5	1	5	5	5	5
Gatekeeper - Farmplan	3	1	5	2	3	3	3	3	2	3
Farm Crap App Pro	3	2	4	5	4	1	5	1	5	4

Table A1.8. Questionnaire to national coordinators of EJP SOIL. Question 9: How would YOU rate from 1 to 5 the DST you indicated in questions 5, 6 and 7 in terms of…? Correlation matrix (Pearson) for the responses to sub-question A-J (Table 6). Statistically significant correlations (p<0.01, n=64) marked with orange asterisk (*).

	A	B	C	D	E	F	G	H	I	J
A		0.18	-0.02	0.41*	0.20	-0.12	0.13	0.43*	0.52*	0.40*
B			0.27	0.2	-0.13	-0.11	-0.07	0.07	0.16	0.12
C				-0.23	-0.12	0.17	0.01	-0.03	-0.10	-0.03
D					0.28	-0.18	0.31	0.25	0.40*	0.50*
E						0.12	0.25	0.29	0.35*	0.42*
F							0.15	-0.04	-0.14	-0.05
G								0.11	0.19	0.09
H									0.82*	0.38*
I										0.52*

Table A1.9. Questionnaire to national coordinators of EJP SOIL. Question 10: How could the specific DSTs you indicated in question 5,6 and 7 as main DSTs be improved?

Soil organic carbon		
Country	***DST***	***Need improvement***
Austria	Austrian Carbon calculator	Needs updating based on new scientific information and needs a web or app design
Belgium Flanders	CARAT	Include other types of agroforestry (eg hedges), reduce the need for data-input (eg by automating, linking with other data sources, …), improve SOC simulation (at present potentially underestimation). There are also plans in the nearby future to make predictions for crop yield and in the longer future to make a module for nutrient and water availability.
Belgium Walloon	DECIDE	Have modules for advising on P and K fertilisation. Have a module for calculating changes in organic carbon stocks in grassland.
	Cool Farm Tool	Improvement of the module for calculating changes in organic carbon stocks in grassland
	CAP'2ER	Improvement of the module for calculating changes in organic carbon stocks in crops and grassland
Denmark	ESGreenTool Climate	Exact farm data inputs instead of general norms/improved C model
Estonia	Humus balance calculator	Replace with some modified simulation model like Roth-C etc
Finland	Soil analysis	traditional basic analysis, lots of improvements done already, e.g. automatic input to agricultural softwares
	NIR analysis	interpretation of results
	Viljelykiertolaskuri	More examples of use, visualization
	Greenhouse gas inventory	Scaling to subnational level
France	AMG/Simeos-AMG	adaptation to perennial crops (grape vine and miscanthus already done) and low input cropping systems
	ABC Terre	adaptation to perennial crops and low input cropping systems
Ireland	Carbon Navigator	incorporation of new measures/practices into the DST that will mitigate GHG's or sequester Carbon
	Ag NAV	New farm scale information capture to underpin C farming and GHG benchmarking
Norway	Jordplan, Skifteplan	It's an open loop. Farmers do planning based on a theoretical framework that has huge gaps (e.g.. no adjustment for soil acidity), and virtually no one collects structured data at the end of the season.
Portugal	VirtuaCrop	Requires more field data with digital photography to improve the tool performance

Slovakia	Soil Portal	DST is compeletely under reconstruction
Switzerland	Humusbilanzrechner	Better integration of current scientific knowlege on SOC dynamics in soil.
Türkiye	TAGEM Soil Fertilizer and Water Resources Central Research Institute national Soil Information System (under construction)	The infrastructure works of the system should be fully completed and it should be made available to the users as soon as possible.
	The National SOC Map	The map needs to be updated at certain intervals and its resolution to be increased in terms of the better determination and monitoring SOC.
	The National SOCseq Map	The map needs to be updated at certain intervals and its resolution to be increased in terms of the better determination and monitoring SOC.
Soil nutrient use efficiency		
Country	***DST***	***Need improvement***
Austria	terrazo	On-going improvement
	ÖDüPlan Plus	There is a new update coming out
Belgium Flanders	NEMO	In the current model not all pathways of phosphorus losses are modelled.
	KNS	An update of nitrogen uptake and efficiency for new varieties is regulatory needed. The data also has to be reviewed taking into account the more extreme weather conditions due to climate change.
Belgium Walloon	REQUAFERTI	Have a nitrogen fertilisation advice module for grassland. Have P, K and Mg fertilisation advice modules
	FaST	Have a nitrogen fertilisation advice module for grassland. Have P, K and Mg fertilisation advice modules
	Geofolia	-
Denmark	MarkOnline	Adaptation to new regulation
	Crop Manager	Improvements on estimations/data input etc
Estonia	NPK balance calculator	Online user-interface integrated with electronic field-book softwares (work in progress)
	Fertilizer requirement map	Updating to real fertilizer products (currently gives only element based values)
	Lime requirement map	Updating to real lime products (currently gives only CaCO3 values)
Finland	Nutrient balance calculations	interpretation of results, time scales over the years
	Nitrogen balance calculator	More testing for different field conditions.
	ProAgria WISU	Support farmers for using nutrient and carbon balance options.
	PeltotukiPro	Support farmers for using nutrient balance options.
	Agrineuvos	Support farmers for using nutrient and carbon balance options.
	Nutrient balance calculator	Input data updated regularly.
	Biomassa-atlas	Input data updated regularly.
France	Syst'N	adaptation to low input cropping systems ; other assessments
	Azofert	adaptation to include new types of organic inputs and wastes, new crops
	MAELIA	user friendly interface
Hungary	PROPLANTA	user interface
Ireland	NMP On-line	Improved soil information within the DST system i.e. plot scale soils information included as a default layer
	Pasturebase Irl & Grass10	Imporved temporal advice on N fertiliser applications on each plot/field
Norway	Biodrone	Functions, integrations, design
	Jordplan, Skifteplan, CropPlan	-
	Surfôrtolken	Unsure wheether the limit values are suited to evaluate organic feed
	Klimakalkulatoren	Large improvements are needed. There are still many aspects not taken into consideration. There is a need to enter more data on your own instead of retrieving it. Because data are to be gathered from different sources, not all farms will be able to use Klimakalkulatren. The result has little value for the farmer, but use of the calculator can give rise to valuable conversations between farmers and advisors that can lead to better farm practice.

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	Næringsstoffbalanse	Development of and better availability of the excel file. This could become a good tool, but it must be developed to better user friendliness and availability. It could perhaps be combined with fertilization planning programs to enable feedback about the effect of used fertilizer. Should however also be available as a standalone tool.
	Gårdskart/Kilden NIBIO	Better coverage of the country when it comes to soil data.
Portugal	One Soil	Owned by private company (the team lacked deep knowledge on the tool to evaluate)
	Fertil	Owned by private company (the team lacked deep knowledge on the tool to evaluate)
	WiseCrop	Owned by private company (the team lacked deep knowledge on the tool to evaluate)
Slovakia	Calculator for nutrients	Good DST no idea about improvement
	Harmonized Reg.& Inf. System	DST is under partial reconstruction
	Fertilization schedule	Good DST
	Animal Storage Capacity	Good DST
Türkiye	Fertilizer Tracking System (GTS)	NA
	Türkiye National Boron Map	There is no specific need on its improvement
UK	Gatekeeper - Farmplan	High level of input detail is required, which can be off-putting for some users. Quite complex to understand. Does not provide recommendations for nutrients. Is a planning tool rather than a calculator.
Soil water availability and retention		
Country	***DST***	***Need improvement***
Austria	eo4water	This was based on a project, constant funding or base funding would be good to build the tool AT wide.
Belgium Flanders	SWAP-WOFOST	parameterisation and validation for different crops is needed
Denmark	Vandingsregnskab Online	no information
Finland	Soil scout sensors	connection to weather stations
	Eurofins Soil NIR	More testing for Finnish soil types.
	Soil Scout	Automated interpretation of data
	Field observatory org	Automated interpretation of data
Norway	Agdir	-
Portugal	IrrigaSys	Better use of remote sensing data for taylor-made recommendations of irrigation schedules
	Irristrat	Requires more field data to calibrate the probes
	SAGRA-NET	Better use of information agrometeorological data for taylor-made recommendations of irrigation schedules
	MOGRA	Better use of hydric balance technical for recommendations of irrigation schedules
	Calendario de Rega	Better use of irrigation records, irrigation needs, actual water consumption
	Avisos Rega Projeto PARE	Better service in regional irrigation notices based on irrigation needs and standardized methodologies
Slovakia	Hydrological report	More information on soil, not only temperature but retention capacity and othe properties
	Interdrought	Good DST could be integrated
Türkiye	TAGEM suET	The system needs to be moved to the mobile platform for easier access and use by the farmers.
Integrated tools		
Country	***DST***	***Need improvement***
Norway	Skifteplan (Soil organic carbon and soil nutrient use efficiency)	Does not work for organic farming or low yields. Should be more user friendly. Should have had functions for optimizing fertilization. Surfôrtolken could perhaps be integrated with Skifteplan? Mineral balances should be total, not just one by one. Development and rejuvenation of Skifteplan is long due.
UK	PLANET (Soil organic carbon and soil nutrient use efficiency)	-
	MANNER (Soil organic carbon and soil nutrient use efficiency)	Less information is required to be entered by the farmer, but as a result the report produced is not as comprehensive.
	The Fram Crap App Pro (Soil organic carbon and soil nutrient use efficiency)	-

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	MuddyBoots (Soil organic carbon and soil nutrient use efficiency)	This system is centred around food safety and quality throughout the chain, as opposed to on farm records and decision making.
Italy	vite.net (The three parameters)	Useful information should be automatically calculated from different online databases/satellite sensors. Manually insertertion of analytical data should be allowed.
	granoduro.net (The three parameters)	Useful information should be automatically calculated from different online databases/satellite sensors. Manually insertertion of analytical data should be allowed.
	Elaisian (The three parameters)	Useful information should be automatically calculated from different online databases/satellite sensors. Manually insertertion of analytical data should be allowed.
Türkiye	Farmer Registration System (ÇKS) (The three parameters)	NA
Not clear		
Country	***DST***	***Need improvement***
Finland	Carbon check	very new, not known yet, maybe interpretation of results
Norway	Pix4dFields	Integrations with other sensor systems or import data from other systems
	Agrilogg	-
No answers		
Lithuania	-	-
Netherlands	-	-
Sweden	-	-

Table A1.10. Questionnaire to national coordinators of EJP SOIL. Question 11: Which type of tools are now not available but are needed and/or planned to be developed?

Tools for Soil organic matter	**Countries**
A tool which allows calculation of possible C credits would be good	Austria
App (algorithme)	Belgium_Walloon
Carbon check and NIR analysis are expected to be widen in use, regional tools for calculationg field carbon balances, C balance webportal	Finland
Indicators and thresholds for SOM/SOC and other soil health indicators	Ireland
Klimrek climate scan. This is an LCA-based whole farm climate decision support tool. Plan is to connect a soil carbon sequestration module to also account for SOC losses or SOC sequestration. https://klimrekproject.be/	Belgium_Flanders
Koolstoftool - decision support tool as part of the soil passport (see below). First version ready and should be launched over the coming months (https://pureportal.ilvo.be/nl/publications/report-on-design-and-lessons-learned-for-the-geospatial-informati).	Belgium_Flanders
Sensors	Norway
Simple app	Sweden
SOC monitoring, reporting and evaluation system (online)	Türkiye
Software	Norway
Sofware/indicators	France
Virtuacrop is a cell phone application (still a prototype) app and machine learnng model	Portugal
Webportal	Slovakia
Webportal/software/app	Hungary
Within the AGRIDIGIT VITICOLTURA project (https://www.crea.gov.it/-/agridigit) my team is going to provide such a tool.	Italy
No answer	Denmark, Estonia, Lithuania, Netherlands, Switzerland, UK
Tools for Nutrient use efficiency / nutrient management	
Models in Austria need to take into account losses from N2O, and show the problem of overfertilization from an environmental view point.	Austria
App (algorithme)	Belgium_Walloon
Biodrone	Norway
Currently a DST is developped so that all B3W farm advisors calculate the N fertilisation rate at planting and sowing based on the same, most recent research results.	Belgium_Flanders
Ecofert (Advise on fertilisation of leek)	Belgium_Flanders
Monitoring, reporting and evaluation system (online)	Türkiye
Nutrient accounting that shows nitrogen efficiency/phosphorus efficiency/potassium efficiency. Would be good to integrate this in fertilization planning software.	Norway
Biodrone (web based)	
Software and sensors	

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Nutrient surplus (kg/ha) calculator at field scale	Ireland
On-line nutrient status measurement-kits from the crops	Finland
Software	Slovakia
Software and sensors	Norway
VirtuaCrop is a cell phone application (still a prototype)App and machine learning model. App and machine learnng model	Portugal
Within the AGRIDIGIT VITICOLTURA project (https://www.crea.gov.it/-/agridigit) my team is going to provide such a tool.	Italy
No answer	Denmark, Estonia, France, Hungary, Netherlands, Sweden, UK, Lithuania, Switzerland
Tools for Water availability and retention	
Assessment tool indicating when it is safe to traffick soils with machinery /grazing animals in spring	Ireland
Klimrek climate scan. Plan is to develop a water module to assess water consumption, water need and water saving measures at field parcel level.	Belgium_Flanders
WatchitGrow - crop management tool for irrigation scheduling	Belgium_Flanders
Prognose-models for moisture status in soils, pedotransfer function tool for calculating pF curve	Finland
Simple app	Sweden
Software	Slovakia
Software and sensors	Norway
Soil moisture monitoring system (online)	Türkiye
WatchitGrow - crop management tool for irrigation scheduling	Belgium_Flanders
webportal and application	Portugal
webportal/software/app	Hungary
Within the AGRIDIGIT VITICOLTURA project (https://www.crea.gov.it/-/agridigit) my team is going to provide such a tool.	Italy
No answer	Austria, Belgium_Walloon, Denmark, Estonia, France, Netherlands, UK, Lithuania, Switzerland
Integrated tools (which include all of those three aspects)	
App	Hungary
DST tool (field & farm scale) that integrates multiple sustainability goals (related to soil functions) - Primary Production, Water quality, Climate Change & Ammonia, Nutrient cycling & Biodiversity Goals	Ireland
For end-users single-gate wep-portal is needed instead of single tools/models. It must be wider than solely these 3 mentioned "topics".	Estonia
Not reported	Slovakia
Software, sensors, satelite, drones, robotics	Norway
Soil passport: webapp linked with LPIS - under development; should be launched in one of the coming months. While the soil passport gives the farmers the opportunity to have a good overview of available parcel, crop and soil data of their field parcels, the Koolstoftool (see above) is a decision support tool where they can get an idea of the evolution in SOC when they continue the crop rotation of the past years and where they can simulate the impact of alternative crop rotations. The data available in the soil passport (crop history, soil texture, initial C) are automatically connected to the Koolstoftool and the model behind this. The idea is to connect more decision support tools in the future. For the moment connections with the labs are made so that available soil analyses of field parcels become visible in the soil passport and so that %C can serve as input for carbon modelling in the Koolstoftool	Belgium_Flanders
Within the AGRIDIGIT VITICOLTURA project (https://www.crea.gov.it/-/agridigit) my team is going to provide such a tool.	Italy
No answer	Belgium_Walloon, Denmark, Finland, France, Netherlands, Portugal, Sweden, Türkiye, UK, Lithuania, Switzerland

Table A1.11. Questionnaire to national coordinators of EJP SOIL: Questions 13-15: In your opinion, what additional aspects – that we did not mention -should be considered concerning the use and the improvement of DST related to soil water retention (13), soil organic carbon (14), and nutrient use efficiency (15)?

Country	Answer
Soil water retention	
Finland	Irrigation possibilities or device are not always possible to have. Irrigation is currently profitable for only part of plant production. Thus farmers who would benefit from irrigation scheduling are not that many. Due the climate change the profitability of irrigation might change and interest for water retention evaluation can increase.

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France	We should integrate in DST the effects of (i) vegetal cover (eg. Cover crops) on soil infiltrability, (ii) tillage on water flow in soils (eg. Physical limits to roots growth and exploration)
Ireland	effect of management practice on resilience to climate change (adaptation to more frequent droughts and flooding)
Norway	Drainage. They need to document where the drainage pipes are so that they can perform maintenance over time instead of digging new trenches every 30 years.
Portugal	Concerning the use of DST could be addressed what factors the user consider relevant to choose a DST. Also, if their perceptions of the reliability of a DST are different when promoted by farmers' associations or private companies. To improve DST related to soil water retention should be included soil characterization, and the development of pedotransfer functions to estimate field capacity and wilting point.
Slovakia	Soil water retention is very significant characteristics to be use for many practical reasons. There is recognized several databases which could be processed by new software or available on website. Also soil-water sustainable management could be taken into consideration. A lack of this DST.
Sweden	Most tools are about irrigation, which is useful. But there are no tools to guide the farmer on how to optimise soil moisture with other measures. At the same farm both flooding and drought could be a problem at different times of the year and farmers need guidance on how to be resilient to both these problems. To be able to irrigate, there also need to be a water storage available that the farmer is allowed to use.
Türkiye	In our cases, more attention should be given for DSTs by all stakeholders including, farmers, researchers, policy makers etc.
Italy	Robust and detailed soil database play a crucial point allowing most probable analytical data to be customized by farmers or Agronomists
Austria	True stakeholder co creation and co-consultation when developing tools is essential
Soil organic carbon	
Finland	The time scale to increase soil carbon is long, at least 5 yrs takes to see the effects. With DST it is basically possible to calculate the changes in carbon balances, but we should also include laboratory determination of organic matter (or soil carbon) in our field test package. So far the soil analysis are using the visual evaluation and not laboratory determinations that would not be too expensive. Thus, we would get a precise field-based estimate of the soil organic matter status.
France	Relationships between SOM and soil quality/health (physical, chemical and biological)
Ireland	Indicating the benefits (incl. soil function provision) to the end user/farmer of improvement of SOM/SOC on their land
Norway	Monitoring over time, make use of historic data, relate farm practices to results on a crop (part of a field) level
Portugal	Soil Sampling Density, Model Validation, Temporal Dynamics, Data Integration. The same aspects mentioned in Question 13 could be addressed (relevant factors that influence the choice of a DST and the perception by end users). To improve DST related to soil organic carbon it is important to consider soil depth.
Slovakia	Soil organic carbon is a leading indicator supporting life on the planet. Its quality and quantity is linked with good soil conditions and microbiome amount expressed by favourable soil structure. C-bonds in soil are complex and to find a right way for DSF development requires a research innovations. A lack of this DST.
Sweden	To predict soil C can be tricky and there is a risk that new tools could overestimate the effect of some measures and disregard the effect of others.
Türkiye	In our cases, more attention should be given for DSTs by all stakeholders including, farmers, researchers, policy makers etc.
Italy	Robust and detailed soil database play a crucial point allowing most probable analytical data to be customized by farmers or Agronomists
Austria	The benefits need to be big for the farmers to lots of data
Nutrient use efficiency	
Belgium_Walloon	At algorithm level, take into account the potential for mineralisation (C and N)
Finland	The yearly changes in crop yields can be big and affect a lot to results. We have currently a few research-based tools that could be integrated with the more widely used farm management DSTs. When farmers need to use fertiliser planning programs, they could with little extra work and knowledge also use the NP planning programs.
Ireland	Synergies and trade-offs between improved nutrient status for primary production and the other objectives (Water quality, carbon sequestration, biodiversity etc)
Norway	Same as above. In addition: who owns the tool?
Portugal	Soil Sampling Density, Model Validation, Temporal Dynamics, Data Integration. The same aspects mentioned in Question 13 and 14 could be addressed (relevant factors that influence the choice of a DST and the perception by end users).
Slovakia	Nutrients in soil are a well researched topic and basically their contribution to crop production is settled. Therefore, even in our conditions, it is possible to create and apply DST while ensuring sufficient data monitoring. It is a good helper for farmers practicing sustainable management.
Sweden	Most existing DSTs for nutrient use efficiency for farmers only consider the efficiency in the field and not as a whole where also the origin of source and what that means for the planet is considered. For national or regional scale (or global) scale that could be something to add.
Türkiye	In our cases, more attention should be given for DSTs by all stakeholders including, farmers, researchers, policy makers etc.
Italy	Robust and detailed soil database play a crucial point allowing most probable analytical data to be customized by farmers or Agronomists
Austria	I think GHG should be in the nutrient efficiency to show impact of over fertilization

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Table A1.12. Questionnaire to stakeholders. Questions 1: Responder details.

	Finland	Netherlands	Italy	Latvia	Sweden	Türkiye
Total number of responders, n	2	7	5	14	13	84
What is your age?						
18-25	0 %	0 %	0 %	0 %	0 %	7 %
26-35	0 %	14 %	40 %	21 %	0 %	26 %
36-45	0 %	29 %	0 %	14 %	8 %	24 %
46-55	0 %	29 %	0 %	43 %	54 %	17 %
56-65	100 %	14 %	60 %	7 %	38 %	17 %
65-	0 %	14 %	0 %	14 %	0 %	9 %
n	2	7	5	14	13	82
What gender do you identify as?						
Male	50 %	43 %	40 %	57 %	50 %	82 %
Female	50 %	57 %	60 %	43 %	50 %	18 %
Other	0 %	0 %	0 %	0 %	0 %	0 %
n	2	7	5	14	12	84
What is the highest degree or level of education you have completed?						
Junior high school	0 %	0 %	0 %	0 %	0 %	21 %
Senior high school	0 %	29 %	0 %	21 %	8 %	23 %
University degree	100 %	57 %	100 %	64 %	85 %	49 %
PhD or higher	0 %	14 %	0 %	14 %	8 %	7 %
n	2	7	5	14	0	84
Are you a....						
Farmer	0 %	0 %	20 %	79 %	0 %	56 %
Researcher	0 %	29 %	0 %	29 %	46 %	11 %
Consultant/Agronomist	0 %	29 %	60 %	7 %	0 %	25 %
Employee of a private company working in agriculture or food production	0 %	0 %	0 %	7 %	0 %	5 %
Employee of a farmers cooperative	0 %	43 %	0 %	0 %	0 %	1 %
Others	100 %	29 %	60 %	7 %	8 %	15 %
n	2	7	5	14	13	84
If you are a farmer how many hectare do you manage?						
<10	0 %	0 %	100 %	9 %	0 %	15 %
5-10	0 %	0 %	0 %	0 %	0 %	9 %
10-20	0 %	100 %	0 %	0 %	0 %	11 %
20-50	0 %	0 %	0 %	18 %	0 %	21 %
50-100	0 %	0 %	0 %	9 %	0 %	19 %
100-150	0 %	0 %	0 %	36 %	13 %	9 %
>200	0 %	0 %	0 %	27 %	88 %	15 %
n	0	1	1	11	8	53
If you are a farmer, how much time are you busy with farming?						
Full-time	0 %	0 %	0 %	55 %	88 %	65 %
Part-time	0 %	100 %	100 %	27 %	13 %	27 %
Only weekends	0 %	0 %	0 %	18 %	0 %	12 %
n	0	1	1	11	8	52
7. If you are a farmer, do you own or rent your land?						
I own all or the most of the land that I farm.	0 %	100 %	0 %	82 %	50 %	63 %
I rent all or most of the land that I farm.	0 %	0 %	100 %	18 %	50 %	37 %
n	0	1	1	11	8	54
What type of crops do you usually grow? (You can select more than one group of crops)						
Cereals	0				100 %	29%
Maize	0				0 %	38%
Legumes	0				75 %	3%
Vegetables	0				13 %	28%
Fruits	0				0 %	47%
Olives for olive oil	0		100%		0 %	47%
Oilseed crops	0				100 %	21%
Grapes for wine	0				0 %	16%
Forage ley	0				50 %	19%
Pasture	0				50 %	0%
Root crops (e.g. potatoes, sugar beet)	0				25 %	5%
Other	0				13 %	17%

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n	0		1		8	58
Do you raise livestock?						
yes	0 %	50 %	0 %	82 %	63 %	28 %
no	0 %	50 %	100 %	18 %	38 %	72 %
n	0	2	1	11	8	64
Do you consider yourself a						
Livestock farmer	0 %	0 %	0 %	36 %	43 %	14 %
Crop farmer	0 %	100 %	100 %	64 %	57 %	86 %
n						49
How do you manage your farm?						
Conventional agriculture	0 %	100 %	0 %	64 %	75 %	52 %
Agro ecological approach – not certified	0 %	0 %	0 %	9 %	0 %	21 %
Organic certified	100 %	100 %	100 %	27 %	25 %	23 %
Biodynamic	0 %	0 %	0 %	0 %	0 %	2 %
Other (please specify)	0 %	0 %	0 %	9 %	0 %	20 %
n	1	1	1	11	8	56

Table A1.13. Questionnaire to stakeholders. Question 3: Are you familiar with decision support tools (DST) or systems?

Are you familiar with decision support tools (DST) or systems?	Finland	Netherlands	Italy	Latvia	Sweden	Türkiye
Yes, I use them regularly	0 %	57 %	25 %	8 %	36 %	7 %
Yes, I have used them in the past	0 %	0 %	25 %	15 %	36 %	4 %
Yes, I know what they are but I have never used one	0 %	0 %	50 %	54 %	9 %	28 %
No, never heard before	100 %	43 %	0 %	23 %	18 %	60 %
n	1	7	4	13	11	67

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Table A1.14. Questionnaire to stakeholders. Question 4. Do you agree with the following statements?

I do not trust DSTs results	Finland	Netherlands	Italy	Latvia	Sweden	Türkiye
strongly agree	0 %	0 %	0 %	0 %	0 %	14 %
somewhat agree	0 %	0 %	50 %	8 %	50 %	11 %
neither agree or disagree	0 %	29 %	25 %	8 %	33 %	5 %
somewhat disagree	100 %	14 %	25 %	42 %	17 %	14 %
strongly disagree	0 %	43 %	0 %	8 %	0 %	20 %
don'tknow	0 %	14 %	0 %	33 %	0 %	36 %
n	1	7	4	12	6	44
I do not think DSTs are useful						
strongly agree	0 %	0 %	0 %	0 %	0 %	7 %
somewhat agree	0 %	14 %	0 %	8 %	33 %	11 %
neither agree or disagree	0 %	14 %	25 %	17 %	50 %	7 %
somewhat disagree	100 %	0 %	50 %	25 %	17 %	11 %
strongly disagree	0 %	57 %	25 %	17 %	0 %	32 %
don'tknow	0 %	14 %	0 %	33 %	0 %	32 %
n	1	7	4	12	6	44
DSTs are usually too complex						
strongly agree	0 %	0 %	25 %	8 %	0 %	0 %
somewhat agree	0 %	29 %	25 %	42 %	33 %	24 %
neither agree or disagree	0 %	57 %	0 %	8 %	17 %	17 %
somewhat disagree	100 %	0 %	25 %	8 %	33 %	12 %
strongly disagree	0 %	0 %	25 %	0 %	17 %	5 %
don'tknow	0 %	14 %	0 %	33 %	0 %	43 %
n	1	7	4	12	6	42
I do not have devices to use DSTs						
strongly agree	0 %	0 %	0 %	8 %	0 %	33 %
somewhat agree	0 %	0 %	0 %	0 %	0 %	11 %
neither agree or disagree	0 %	43 %	0 %	8 %	33 %	7 %
somewhat disagree	100 %	14 %	0 %	8 %	33 %	7 %
strongly disagree	0 %	0 %	100 %	33 %	33 %	11 %
don'tknow	0 %	43 %	0 %	42 %	0 %	31 %
n	1	7	4	12	6	45
DSTs require too many data that I cannot provide						
strongly agree	0 %	0 %	0 %	0 %	0 %	7 %
somewhat agree	0 %	14 %	0 %	25 %	17 %	19 %
neither agree or disagree	100 %	43 %	75 %	8 %	0 %	7 %
somewhat disagree	0 %	29 %	0 %	8 %	67 %	12 %
strongly disagree	0 %	0 %	25 %	17 %	17 %	9 %
don'tknow	0 %	14 %	0 %	42 %	0 %	47 %
n	1	7	4	12	6	43
Working with DSTs is time consuming and not so helpful						
strongly agree	0 %	0 %	0 %	0 %	0 %	5 %
somewhat agree	0 %	29 %	25 %	27 %	33 %	13 %
neither agree or disagree	100 %	29 %	25 %	0 %	17 %	8 %
somewhat disagree	0 %	0 %	0 %	9 %	50 %	8 %
strongly disagree	0 %	29 %	50 %	18 %	0 %	20 %
don'tknow	0 %	14 %	0 %	45 %	0 %	48 %
n	1	7	4	11	6	40

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Table A1.15. Questionnaire to stakeholders. Question 7. If you use DSTs, how would you rank from 1 to 5 the most important features of a DST (where 1 is the most important, 2 the second most important etc.)?

	Finland	Netherlands	Italy	Latvia	Sweden	Türkiye
1. Do not require too many data from my hand						
1	0 %	100 %	100 %	0 %	0 %	25 %
2	0 %	0 %	0 %	0 %	50 %	17 %
3	0 %	0 %	0 %	67 %	25 %	25 %
4	0 %	0 %	0 %	33 %	0 %	8 %
5	0 %	0 %	0 %	0 %	25 %	25 %
n	0	1	1	3	4	12
2. User-friendly interface						
1	0 %	0 %	0 %	0 %	0 %	0 %
2	0 %	33 %	0 %	50 %	0 %	29 %
3	0 %	33 %	0 %	0 %	25 %	29 %
4	0 %	33 %	0 %	0 %	50 %	29 %
5	0 %	0 %	0 %	50 %	25 %	14 %
n	0	3	0	2	4	7
3. Clear visualization of results						
1	0 %	0 %	0 %	0 %	0 %	0 %
2	0 %	33 %	0 %	0 %	0 %	0 %
3	0 %	67 %	0 %	0 %	20 %	29 %
4	0 %	0 %	0 %	0 %	60 %	57 %
5	0 %	0 %	0 %	100 %	20 %	14 %
n	0	3	0	2	5	7
4. Trust/confidence in the results (based on scientific publications or on-farm calibration)						
1	0 %	0 %	0 %	33 %	50 %	38 %
2	0 %	33 %	0 %	0 %	17 %	25 %
3	0 %	0 %	0 %	33 %	0 %	25 %
4	0 %	33 %	0 %	33 %	17 %	13 %
5	0 %	33 %	0 %	0 %	17 %	0 %
n	0	3	0	3	6	8
5. Easy to access both in terms of costs and hardware requirement						
1	0 %	0 %	0 %	17 %	20 %	25 %
2	0 %	33 %	0 %	17 %	20 %	13 %
3	0 %	0 %	100 %	17 %	40 %	25 %
4	0 %	33 %	0 %	33 %	0 %	13 %
5	0 %	33 %	0 %	17 %	20 %	25 %
n	0	3	1	6	5	8
6. The design of the DST has been carried out in collaboration with end-users						
1	0 %	0 %	0 %	0 %	0 %	0 %
2	0 %	0 %	0 %	50 %	0 %	29 %
3	0 %	0 %	0 %	50 %	0 %	43 %
4	0 %	0 %	0 %	0 %	0 %	29 %
5	0 %	100 %	0 %	0 %	100 %	0 %
n	0	1	0	2	1	7
7. DST provide outcomes which are easy applicable and in real time (when I need info to manage the crop and not too late)						
1	0 %	100 %	0 %	20 %	25 %	10 %
2	0 %	0 %	0 %	0 %	50 %	10 %
3	0 %	0 %	0 %	0 %	25 %	10 %
4	0 %	0 %	100 %	40 %	0 %	30 %
5	0 %	0 %	0 %	40 %	0 %	40 %
n	0	3	1	5	4	10

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Annex 2. Regional workshops

Table A2.1. Script used at the regional workshops.

Session	Agenda
Plenary session	Each workshop started with a plenary session with an introduction of the EJP SOIL and PRAC2LIV project and a presentation some selected findings and examples from the European and national stocktake of available DSTs. In the first part of the workshop, participants were asked individually what they thought was main soil-related challenge, what was their objective with using a DST and if they had any other DSTs to add to the list.
Group discussion	In the second part of the workshop, the participants were divided in smaller groups to facilitate the discussions on specific topics. They discussed in smaller groups about barriers to DST adoption, and potential solutions to break them. They were also asked to discuss what features they miss in DSTs that they currently use and for what decisions the tools are still missing but needed and to make a ranking of the most important features of a tool. Some statements (listed below) were submitted to participants for opening a discussion about their agreement/disagreement and why. The elements discussed with stakeholders during small group session were as follows: 1. The most important features of a DST are: • It doesn't require much information from me • It has a user-friendly interface • The decision support delivers results that are easy to apply in real time • The results are reliable and based on science and calibration on farms in the area • Easily accessible both in terms of cost and hardware requirements • It has clear visualization of results • The design is developed in collaboration with users 2. Do participants agree or disagree with: • All tools should have an app for a smartphone • In addition to plant production and soil quality, tools should also provide information on environmental impact • Tools must be flexible and consider actual weather conditions 3. What are the missing features in the available DSTs? What missing information is needed to make the right decision?
Summary	After the group discussions, the main results were presented to all participants, in order to draw the main conclusions of the workshop. During the workshops, interviews were conducted with selected participants, including farmers, advisors, and others. These interviews have been recorded and presented in the form of short videos summarizing highlights of each workshop.

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Table A2.2. Main soil related challenges as indicated by the workshop participants representing different professions in the different countries.

	Farmers	Advisors	DST providers	Researchers	Policy makers and farmer union representatives	Sum
Sweden						
Soil compaction	3	1		1		5
Soil fertility			1			1
Climate adaption			1			1
Nitrogen efficiency			1			1
Soil organic matter	2					2
Water availability	2					2
Acidification						0
Soil erosion						0
Latvia						
Soil compaction			1			1
Soil fertility	1		1	1		3
Climate adaption						0
Nitrogen efficiency						0
Soil organic matter	1	1		4	3	9
Water availability						0
Acidification			2	1	1	4
Soil erosion		1		1		2
Italy						
Soil compaction	1					1
Soil fertility	1	2	1	2		6
Climate adaption	1			1		2
Nitrogen efficiency						0
Soil organic matter	1	3		2		6
Water availability	1	1	1	2		5
Acidification						0
Soil erosion						0
Türkiye						
Soil compaction	1			1		2
Soil fertility	2	1		2		5
Climate adaption				1		1
Nitrogen efficiency						0
Soil organic matter	3	2		3		8
Water availability						0
Acidification						0
Soil erosion	1			1		2
Soil water management	5	4	1	4		14

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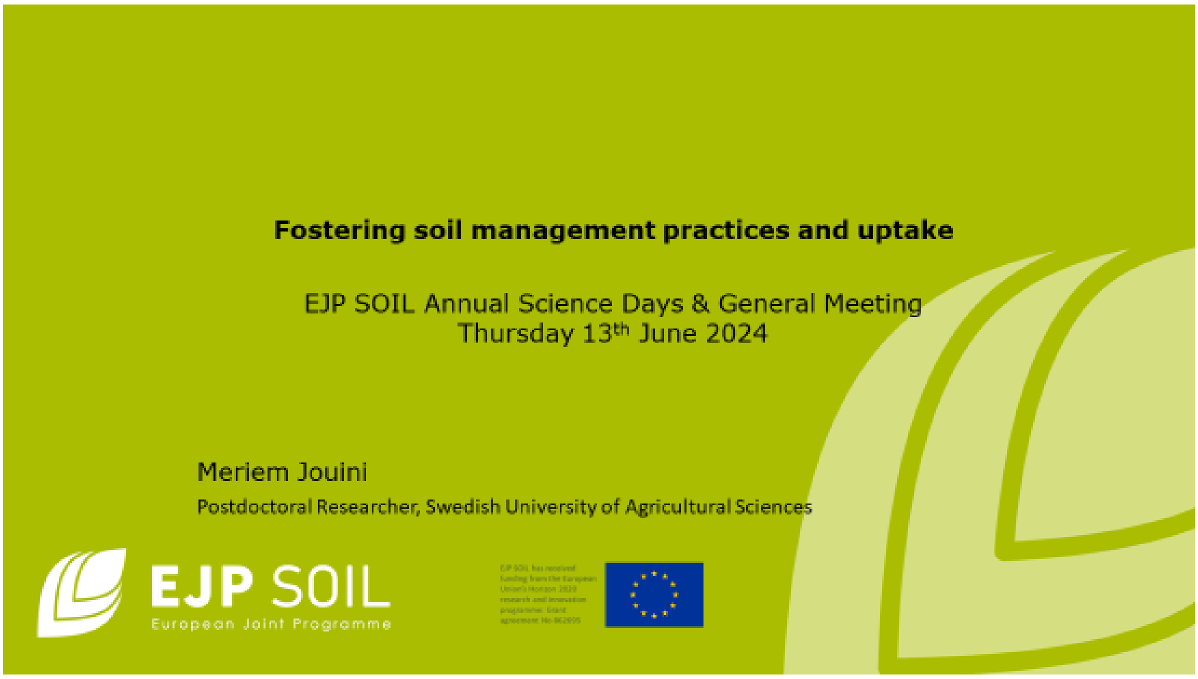
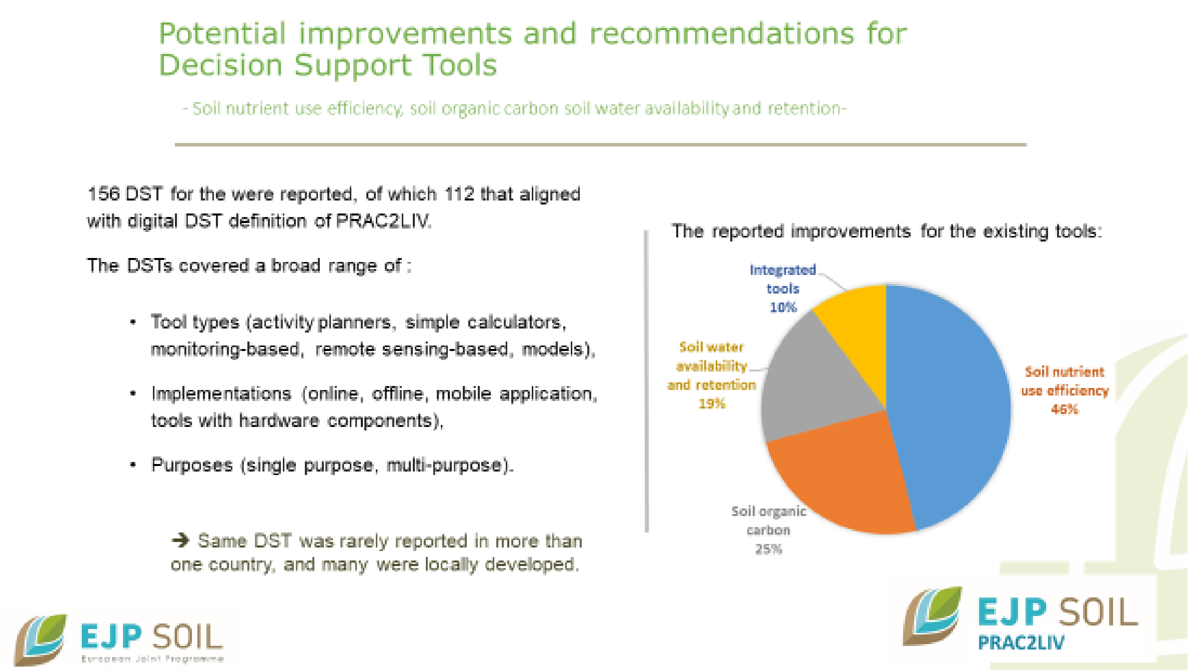
Annex 3. Contribution to policy workshop (ASD, 2024)





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- The importance of considering different spatial scales in DSTs, from the field and farm scales to the regional and national scales, but most development needs were considered at farm level and field level, and scenario calculations.
- The adoption by end-users depends on the suitability for reaching **end-user goals.**

Nutrient use efficiency

DSTs account for soil nutrient status, fertilization balance, over fertilization.

Soil organic matter

DSTs that account for soil health indicators, thresholds for SOM/SOC, carbon credits, regional carbon balances, calculation of farm carbon footprint.
Managing soil organic matter involves more long-term decisions.

Water retention

DSTs account for soil moisture **status**, water requirements and irrigation **need**, provide **forecast** on soil moisture conditions. The **catchment scale** should be considered. The types of new tools : software, mobile applications, web-based tools, sensors and monitoring tools, and remote sensing and forecast tools.

Ned to manage both drought and flood, sometimes in the same season.

Single entry web portal

Single entry web portal instead of multiple individual tools.
Tool that integrates multiple sustainable goals related to soil functions, such as primary production, water quality, climate change, nutrient cycling, and biodiversity.

EJP SOIL European Joint Programme

EJP SOIL PRAC2LIV

To what extent are the tools applicable at different scales?

	Farmers' goals	*Regional goals*
Soil organic matter	•Reduce inputs and increase the economic profitability of farms •Recommendations for crop rotations and soil management •Carbon budget calculation •To make **informed management decisions**. •Sustainable soil management monitoring •Sustaining/improving soil fertility and moisture retention •Increasing and maintaining the productivity of farmer's land, income and protect soil against climate change	•LULUCF targets •Climate policies •Retention of soil carbon, Soil C balance •Regional SOC targets •**Informed management decisions** •Sustaining / improving soil Carbon •To **monitor**, maintain and increase SOC, especially in agricultural lands
Nutrient use efficiency	•Fertilizer use efficiency and increase the economic profitability of farms •Increased soil fertility due to improved nutrient distribution within the farm •Better yield • Reduce costs and sustainable production. •To make informed management decisions	•Reduce GHG emission and reduced nitrate leaching •Nitrates Directive •Environmental policies •Water quality maintenance / improvement and GHG mitigation •**Informed management decisions** •To achieve nutrient balance and better nutrient management in soil.
Water retention	•Reduced use of irrigation water •Irrigation scheduling, yield estimations •Cost-effective interventions •Irrigation efficiency •Optimization of soil moisture •Increasing and maintaining the productivity of farmer's land.	•Estimate water demand for irrigation •Drought **preparedness** •Minimizing the risk of nutrient runoff •Water saving •Achieve proper irrigation management and early detection of drought.

EJP SOIL European Joint Programme

EJP SOIL PRAC2LIV

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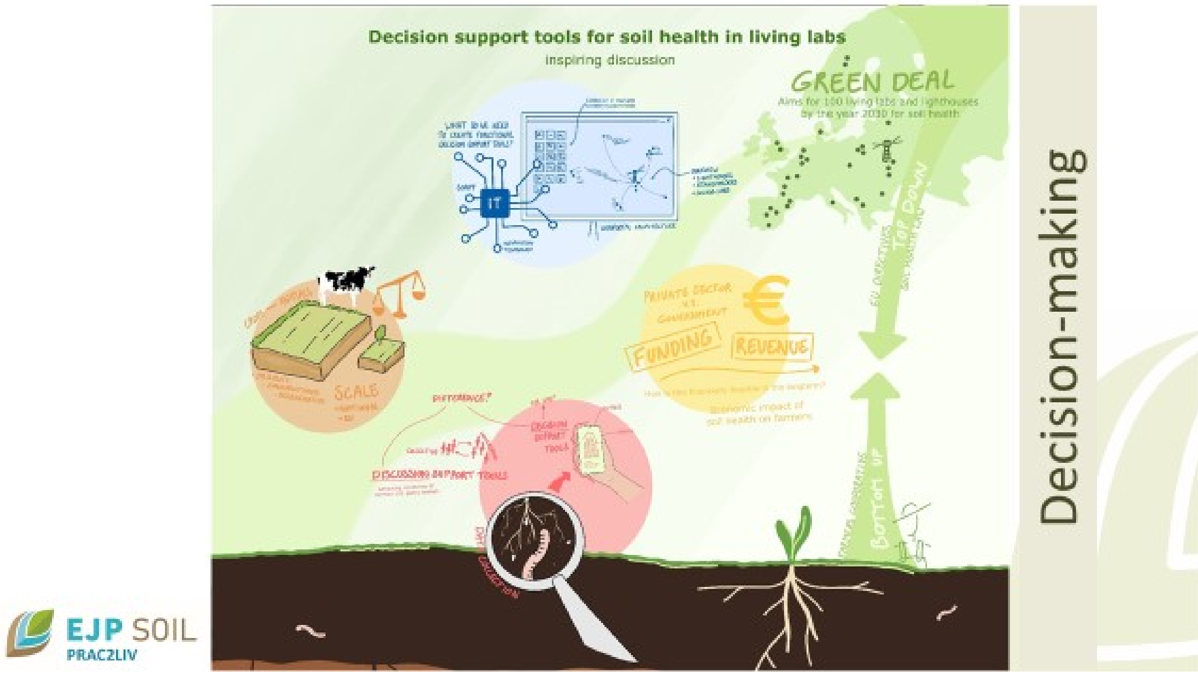

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